Landscape Futures Analysis

NCCARF
National Climate Change Adaptation Research Facility

Australian Government
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Adapted future landscapes
– from aspiration to implementation

Final Report
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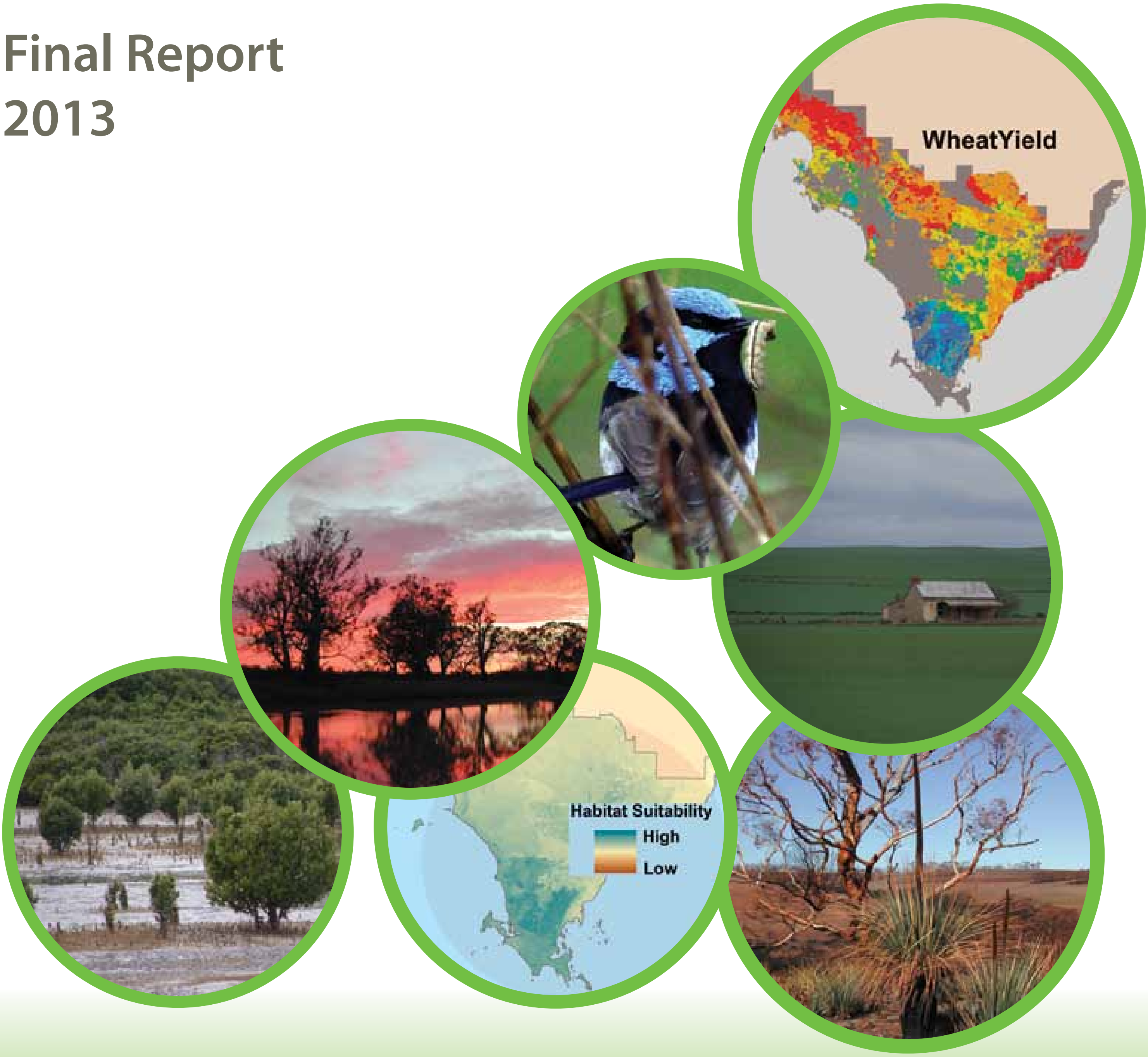

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The role of NCCARF is to lead the research community in a national interdisciplinary effort to generate the information needed by decision-makers in government, business and in vulnerable sectors and communities to manage the risk of climate change impacts.

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Disclaimer

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Abstract

This project worked with the Eyre Peninsula and South Australian Murray-Darling Basin Natural Resource Management (NRM) regions to develop a process of science based "optioneering" that explored future land use options that could be embedded in NRM Board planning and community engagement. The project sought to integrate a stakeholder engagement process called envisioning with the development of a web based planning interface called the Landscape Futures Analysis Tool. The envisioning process helped to identify the values that people influencing NRM use in making decisions about engagement, plans and actions, while the LFAT enabled easy assessment of the possible implications for land use and water resources arising from climate change, commodity prices and carbon pricing.

A series of facilitated workshops was used to explore the application of envisioning. It was apparent that all levels of the planning system, from state public servants to farmers, want the planning process "experienced" in the same way. Core principles relevant to future use of the envisioning process that were identified during the project include: that envisioning can operate as a bridge between science and decision making; that it can integrate the contribution from multiple stakeholders with diverse perspectives; and that we must be able to adapt the process to local variations in the social, political, agricultural and natural landscape.

The Landscape Futures Analysis Tool (http://www.lfat.org.au) is underpinned by analyses that were mostly developed from existing models that were added to and refined for this project, partly on the basis of local experience. Climate change scenarios were based on relevant recent climate (S0), and a mild (S1), moderate (S2) and severe (S3) increase in temperature with accompanying decrease in annual rainfall. All data and projections were developed using regional spatial data stored and subsequently displayed as Geographic Information System (GIS) map layers.

The analysis finds that it will be possible to adapt to a changing climate if changes in land use are made. It also highlights that policy incentives are likely to be needed to guide and encourage changed practice. Use of the LFAT helped to demonstrate to end users that:

- agricultural opportunities in the region rest on the adoption of different management regimes or changes in land use on soil types identified as being negatively impacted by climate change;
- in both study regions, conservation priorities became concentrated in more southern latitudes and higher altitudes as warming and drying increased.
- a large gradient exists in carbon sequestration potential from the drier to wetter areas with economically viable carbon plantings indicated only in the wetter areas.

It is evident from evaluation of the project with the two partner NRM regions that the analysis and LFAT have been beneficial in raising awareness of the possible changes that can occur in the region and that many land use options can be considered in developing new NRM plans. Accompanying this is a greater appreciation of the need for capacity development through training. Science informed, climate-ready planning requires quality tools like LFAT, together with the predisposition of regional planners through willingness, capacity and commitment.

Executive Summary

Changing climate, markets and social requirements demand that we modify how land is used for food production and conservation in Australia. Helping regional resource managers to plan for, and implement changes in, land use will enable landholders and communities to adapt as circumstances change.

This project worked with the Eyre Peninsula (EP) and SA Murray Darling Basin (SA MDB) Natural Resource Management (NRM) regions to develop a process of science based "optioneering" that could become embedded in NRM Board planning and community engagement. The project sought to integrate a stakeholder engagement process called envisioning with the development of a web based planning interface called the Landscape Futures Analysis Tool.

The project began with a review of the previous regional NRM planning process to assist with understanding the role and purpose of the NRM plan in managing the natural resources of the two regions. Significant differences were evident but both had concerns about the community ownership of the Strategic Plan (one of four volumes of the broader NRM Plan) and that suggested that its ongoing use was limited. This limited ownership was the motivation for experimenting with envisioning as a new method to make explicit those values that NRM Board members, planners and the community use in making decisions about NRM priorities, plans and actions.

Envisioning

A series of facilitated workshops was used to explore the application of envisioning. It was apparent that all levels of the planning system, from state public servants to farmers, want the planning process "experienced" in the same way. That is, in a way that incorporates values such as transparency, participation, respect, honouring different kinds of knowledge (local, indigenous and scientific) and autonomy to respond to their complex bio-socio-economic environments.

Core principles relevant to future use of the envisioning process that were identified during the project include:

- Envisioning operates as a bridge between science and decision making that can integrate more than just "the science" – it can bring together and integrate the contribution from multiple stakeholders with diverse perspectives.
- One size doesn't fit all – we must be able to adapt the process to local variations in the social, political, agricultural and natural landscape.
- The process must reconnect the notions of planning and implementation. Planning must be seen as part of an integrated process, directed to action on the ground, rather than an end in itself, ticking the regulatory box.
- The role that time plays must be understood and respected. Adaptive work can be uncomfortable and lack of time can be used as a method of avoiding the adaptive work required.

Key findings that emerged in the course of the envisioning work that are relevant to NRM planning for climate change in general include:

- Willingness to change – Much energy was expended trying to find a 'hook' to motivate the NRM boards to engage with this process. This highlights the need to assess willingness to change, or dissatisfaction with the status quo, before doing anything else.
- Regional locus of control – Local planners' perceived locus of control vis-à-vis the state planning bureaucracy – the dynamics of local versus central power – will be an important source of variation between regions.
- Who represents the regional system? – Attention must be given to the relationship between the NRM Board and their local community. Some local communities will feel well represented by the NRM Board, some will feel mistrustful, some will feel no connection at all. This is another source of regional variation that the process needs to accommodate.

- Capacity Building, Complexity and the Role of Envisioning – Envisioning has the capacity to identify common ground among diverse stakeholders and to build relationships. This is important in terms of group dynamics and developing a willingness to collaborate.
- Influencing the Systems of Planning and Implementation – It is apparent that all levels of the planning 'system', from state public servants to farmers, want the planning process experienced in the same way. Nevertheless, it is clear that many participants do not experience planning in this way. The process of planning and implementation built on and informed by co-created vision is designed so that it can deliver the experience of these core values to all participants.

Modelling and the use of LFAT

The Landscape Futures Analysis Tool (http://www.lfat.org.au) is underpinned by analyses that were mostly developed from existing models that were added to and refined for this project. Part of the refinement was to adjust model inputs based on local experience and to update inputs such as recent commodity prices and variable costs. The aim was to use appropriate regional data to enable estimates of responses to scenarios of climate change, commodity prices and carbon price.

Climate change scenarios were based on relevant recent climate (S0), and a mild (S1), moderate (S2) and severe (S3) increase in temperature with accompanying decrease in annual rainfall. All data and projections were developed using regional spatial data stored and subsequently displayed as Geographic Information System (GIS) map layers. Based on feedback from the engagement process the primary management modules built into the LFAT were as follows:

- **Agricultural productivity –** Estimates were mainly determined with outputs from the APSIM wheat crop growth, water use and yield model. The modelling results suggest that the opportunities and options available for climate change adaptation will vary across the Eyre Peninsula and within the low, medium and high rainfall regions. Opportunities within the region rest on the adoption of different management regimes or changes in land use on soil types identified as being negatively impacted by climate change.
- **Biodiversity –** Native species distribution scenarios were developed using plant species distribution models to show responses to a warming and drying climate. Those species most adversely affected were identified and with potential dispersal assigned, an index of adaptive capacity was developed. In both the EP and SA MDB conservation priorities became concentrated in more southern latitudes and higher altitudes as warming and drying increased. The methodology presented in the project provides a quantitative and repeatable means to prioritise conservation and restoration under climate change.
- **Carbon sequestration –** Forest productivity (biomass yield) was estimated using the woody plant model 3PG2, for a homogenous hardwood plantation (Eucalyptus cladocalyx), a generic oil mallee species and a multi-species environmental plantation. When applied spatially in each of the regions, together with an expected carbon price, the distribution of likely economic returns from carbon sequestration plantings could be displayed. This then enabled comparison with projected returns from agriculture and provided an indication of possible trade-offs between current agriculture and re-vegetation. The results showed a large gradient from the drier to wetter areas with economically viable plantings indicated only in the wetter areas.

With the derived responses of agricultural productivity, plant species distribution and carbon sequestration to climate change captured in GIS layers, the LFAT interface enables users to interrogate this information, which is crucial to sound planning. Through this project, we have developed a geographic information system (GIS) and modelling framework that brings critical information about a region together. It enables projections to be made about what land use might best occur where, providing options that will help adaptation. Analysis suggests it will be possible to adapt to a changing climate if changes in land use are made. It also highlights that policy incentives are likely to be needed to guide and encourage changed practice.

It is evident from evaluation of the project with the two partner NRM regions that the analysis and LFAT have been beneficial in raising awareness of the possible changes that can occur in the region and that many options can be considered in developing new plans. Accompanying this is a greater appreciation of the need for capacity development through training. Science informed, climate-ready planning requires quality tools like LFAT, together with the predisposition of regional planners through willingness, capacity and commitment.

Further development of the LFAT could include:

- Expansion to other regions in Australia, starting with agricultural cropping regions in South Australia such as in the Northern and Yorke, Adelaide Mt Lofty Ranges and South East NRM Regions;
- Including measures of agricultural productivity beyond wheat yields, such as was done for the South Australian MDB region;
- considering invasive species composition based on the potential for new species to enter from other regions under future climate rather than just current species distribution under future climate; and
- linking modelled and actual distribution of local/ indicator species using regularly updated field monitoring data.

Objectives of the research

1

For operational and communication purposes the goal was defined as:

"Develop a process of science based 'optioneering' that can become embedded in NRM Board planning and community engagement."

The research was planned to capitalise on the projections made by earlier research, in Landscape Futures Analysis, which illustrated that regional adaptation to climate, market and social changes is possible by changing what is done where on the land (Bryan et al. 2011).

Local and regional productivity goals, conservation goals and social aspirations can be achieved by farming to land capability, changing land use to capitalise on the emerging carbon market, and identifying practices that result in a landscape mosaic of production and conservation uses, collectively providing multiple ecosystems services. It is possible to make estimates of the costs and foregone returns for such transformations.

In this context the principle objectives were:

1. Identify and test an implementation process that sees individuals, localities and regions take the outputs of modelled future scenarios, together with a considered assessment of the risks of change, and embed them into their planning processes.
2. In collaboration with the Eyre Peninsula and SA Murray Darling Basin Natural Resources Management Boards develop and use an engagement and planning process that is informed by local experience and documented resilience planning from other Australian NRM regions.
3. Develop software that interfaces between the Landscape Futures Analysis datasets and the effect of different policy options on land use and the resultant economic, environmental and social indicators and ecosystem services.
4. Provide a guidebook for planning with Landscape Futures Analysis (LFA) that can be adapted for other regions.

2 Research activities and methods

2.1 Context

Within the Australian Government's Clean Energy Future Plan there is a program to support the 56 regional natural resource management (NRM) organisations to revise existing regional NRM plans with the aim of making the plans "climate ready". Part of being 'climate ready' is identifying where in the landscape biodiversity plantings and carbon abatement activities should be undertaken, and utilising climate change impact information and scenarios to guide land use planning.

South Australian researchers have already developed tools and substantial databases of information to assist NRM Boards with developing plans for future land use change. 'Climate ready' planning needs a process that brings together the aspirations of regional people for their landscape with a well-founded evidence base, developed from the best available data and decision support tools.

2.2 Work plan operational objectives

To achieve the project goals, two objectives had to be met:

1. Working primarily at an NRM Board level, develop a planning process that can support development of a "climate ready 2014 – 2019 regional plan" which has legacy (on-going) value; and
2. Engage the community in a manner that facilitates shared ownership of the vision and plan, so that decisions at every level can be made in alignment, recognising that there are constraints – resource, political and administrative boundaries - within which feasible options can be proposed, discussed and tested.

Given the limited time for the project, effort was focussed on objective 1 and providing a working example of how the tools, learning and capacity developed in 1 can be implemented in 2.

2.3 Method

The team worked with staff from the Eyre Peninsula and South Australian Murray-Darling Basin Natural Resource Management Boards to develop and trial a process for developing climate ready NRM plans. This project coincided with the start of a new round of planning for the development of a second regional strategic plan.

The intention was to bring together:

- an understanding of change processes that can help develop a shared and co-created vision of a regional community's desired landscape, and
- tools and data already available for planning for future land use change.

Given the short time-frame of the project, the process was trialled primarily within the NRM planning group with limited interaction at a subregional level.

Analysis identified the options for possible future land uses that were consistent with the shared vision, and gave the region the best chance of adapting to climate change and other emerging 'drivers'.

It was expected that the process would generate new ways of considering the regional NRM investment priorities and their implementation, in the context of the shared regional vision. This process complements informed decision making at regional, local and enterprise levels. The intention was to enhance the capacity of the NRM Board staff to engage at these levels in a way that integrates the science into the decision making process. The process provides stakeholders with a comprehensive assessment of land and water use options; and the economic, environmental and social consequences that may result.

Freshwater biodiversity was an additional consideration in the planning process for both regions. In the SA MDB NRM region it is a major priority because activity focuses on the Murray River corridor. In the EP NRM Region concerns are with small, localised surface water catchments and, more importantly, with the effects of land use and management on the groundwater recharge areas that serve Port Lincoln's major water supply.

This project was managed within an action research framework, providing regular opportunity for participants and researchers to reflect on and document the lessons from the processes and outcomes.

2.4 Project phases

The project began in January 2011 and finished in March 2013. The majority of engagement with NRM Boards and stakeholders occurred from February to December 2012.

2.4.1 Phase 1 – Consult, Envision, Design: February to April 2012

Phase 1 consisted of four main actions completed in the first quarter of 2012.

1. Develop an overview paper for communication purposes with key stakeholders.
2. Document current climate change adaptation planning processes by consulting with NRM Board staff and reviewing the literature. This considered:
   - current responsibilities and involvement in climate change adaptation planning
   - previous regional plan processes with respect to the science input to the plan
   - assessment of what has worked well and where there are opportunities for improvement in relation to the science input and its traction (or lack of)
   - document current plan requirements; document the 'state' of the NRM Board positioning (where they see themselves and their role in the planning process).
3. Envisioning to determine:
   - what the Australian Government, State Government, Local Government, NRM Board and staff, scientists, stakeholders 'see' as the role of the NRM in engaging in communities to become Climate Change Ready
   - at regional NRM Board level, what the Board, the staff, scientists and key stakeholders envision as the role of NRMs in engaging the community to become Climate Change Ready
   - using indicators extracted from the previous point, design a process for effective community engagement in terms of the way science can be successfully integrated, with its outcomes in terms of people's experiences and the NRM staff's required capacity.
4. Design and propose a process and 'data interface' specifications
   - design ongoing engagement
   - define the role of interface tool(s) in data collation and analysis toward facilitating communication
   - draw on past successes in designing the tool
   - develop specifications of such interface tool(s) and the capacity processes to support their use
   - empower Design and Development team(s) (D&D team).

The main outputs were reports that:

- Document the current way climate change adaption planning is undertaken in the NRM regions.
- Describe a modified planning process that includes local experience, stakeholder envisioning, identifying indicators of success that reflect the shared vision and components of resilience-based planning from other regions and LFA projections.

2.4.2 Phase 2 – Collate data and build the tool: February to August 2012

Phase 2 consisted of two main actions to be completed by the end of the 3rd quarter of 2012:

1. Audit of data and tools
   - interview NRM Boards to determine what data and tools the regions currently use
   - add land condition layers to LFA data layers
   - determine minimum data required for the analyses
2. Software development – build summary and visualisation tool(s), α-test with D&D team, define needs for visualisation capability and real time 'what-if' as part of the plan development and subsequent prioritisation process.

The main outputs were reports that:

- Describe user-oriented interface software that will enable land-users, planners and NRM policy strategists to explore different landscape futures by manipulating parameters such as market prices, regulatory institutions, technology adoption and policy intervention. This will allow both visual and numerical representation of the impacts and trade-offs involved in the selection of different land use mixes.

- Report on the NRM board's engagement processes and document capacity-building activity undertaken to enhance this.

2.4.3 Phase 3 – Implement the tool: July to November 2012

Phase 3 was to be completed by December 2012, including piloting the community engagement process and the use of the tool(s), plus building NRM Board staff capacity to independently facilitate the process and operate the tools.

The main outcomes and outputs were:

- Reports that describe the outcomes, synergies, opportunities and barriers to the attainment of one or multiple futures of climate change adaptation for each region. These will be highlighted as case studies into the effectiveness of the engagement, planning and LFA process since each region has a mix of both complementary and conflicting regional objectives.
- Two regional workshops in each region to use the tool.
- Staff capability to engage the regional community in a science informed process of envisioning their desired future and identifying their preferred range of options.
- Indicators of success in bringing the vision into reality, in addition to ongoing engagement options to track progress.

2.4.4 Phase 4 – Promote and publish: February 2012 to April 2013

Phase 4 involves promoting and publishing the results of this project. In addition to written material this was achieved through briefings of key stakeholders (e.g. Australian Government and State Departments) and through conducting a workshop to better establish state-wide climate change adaption planning processes.

The main outcomes and outputs were:

- Briefings with key stakeholders during and after the project.
- Workshop report to identify state-wide climate change adaption planning processes.

Results and outputs

3

3.1 Phase 1 – Consult, Envision, Design

3.1.1 Overview paper for communication purposes with key stakeholders

An important part of this project was the early and ongoing engagement with the two regional NRM stakeholders. This process was initiated with a brief and very general description of the project and its intentions in December 2011 (Attachment 1), which was followed by a brief explanatory paper (Attachment 2). The overview was important as an introductory paper for both the research team and the stakeholders in the two regions, developing a greater understanding of the project intentions and the context in which the research was to be done.

3.1.2 Current climate change adaptation planning processes

The reviews of the planning process that the two regions had undertaken to develop their first strategic plans and subsequent operational plans are Attachments 3 and 4. The following general observations were drawn from the interactive process:

- the two regions had differing experiences with the NRM plan development process
- the main articulated weaknesses related to principles of integration, accountability and capability
- there were differences in perceived inclusiveness between the regions – SAMDB perceived Board and community inclusiveness as strong while EP participants perceived inclusiveness as weak, particularly in the later stages of the plan development
- different levels of capability were evident between the regions and both plans were adjudged as "not being well informed by the best available science"
- both regions were concerned at the lengthy time taken to develop the NRM plans and their relevance
- both regions identified that the plans were inadequate at providing direction when opportunistic funding from Federal and State Agencies became available and, as an alternative, it was suggested that it may be best to have a series of guiding strategies (not actions) for investment which could be tailored to new and emerging funding options
- both regions questioned the merit of the regional NRM plan – few people read it, few use it to guide decisions, there is little local community ownership of it and the evidence is that the plan did not primarily drive the NRM Board's business – hence the worth of nearly four years of financial and intellectual investment to develop the plan was questioned
- as part of the point above there was a sense of general apathy towards the plan development process by those involved in it. i.e. people did not seem to care post-plan development.

The research team drew the inference that there is a need for clarity with respect to who the plan is being developed for and its ongoing function. Part of the issue seems to revolve around the lack of genuine ownership and hence belief that the Regional NRM Plan is well conceived, well informed and adaptable, and truly reflects the aspirations of the stakeholders. This finding was consistent with the impressions that were used to design this research proposal and why the proposal included the assessment of a different engagement approach using an 'envisioning' process. The outputs from this process are described in the next section.

3.1.3 Envisioning to determine how stakeholders want to experience the planning process and the landscape

Methodology for the 'Envisioning Process'

Action research (AR) enables an emergent design for an emergent process in circumstances where we were unsure of the amount of time that may be available for participants to engage with us, and where we would evaluate progress as we travelled the path. As much as we might like to develop a project management plan in advance and 'roll it out', experience of other research teams suggested that this was unlikely to reflect reality, which would be messier and less efficient due to developing relationships, incompatible language (different disciplinary backgrounds) and learning as the research team progressed (Martin et al., 2010)

Action Research includes a vast number of methods. Ison and Russell (2000) draw upon a distinction from Checkland (2000) between a 'systematic' and 'systemic' approach which they argue aids the epistemological awareness of the researcher. The distinction is between systemic, being "thinking in terms of wholes" (Ison, 2008, p148) and systematic, "linear, step-by-step thinking …"(ibid.) This distinction could be construed as 'either/or' but Ison (2008) highlights the benefits of considering it a useful duality, allowing research capable of employing both forms of thinking – with awareness of the researcher being "the observer who gives rise to the distinctions that are made and the responsibility we each have in this regard" (Ison, 2008, p148).

The distinction between systemic and systematic brings a constructionist perspective in contrast to the positivist perspective to the research. This distinction is perhaps uncommon in the physical sciences. It is exactly this constructionist perspective to which Kuhn (1962) referred in his work on 'scientific revolutions', when he discussed proponents of different paradigms "practising in different worlds" (cited in Umpleby and Dent 1999, p95). In this manner, systemic thinking acknowledges the inherent 'uncertainty' of our individual human experiences, and the importance of different perspectives (Umpleby & Dent, 1999).

Checkland & Howell (1998) provide a useful cycle for action research, which is closely associated with creating a foundation for quality qualitative research.

This cycle requires the declaration of a framework of ideas (F), a methodology (M) and an area of application (A) with articulated research themes.

With regard to this research:

The framework of ideas (F) is described above in the form of the research objectives:

1. gain an understanding of change processes that can help develop a shared and co-created vision of a regional community's desired landscape with
2. tools and data already available for planning for future land use change that
3. lead to land managers adapting their land management practices to respond to the threats and opportunities of climate change.

The methodology (M) is employing cycles of action research by implementing the 'envisioning process' and exploring the linkage to the LFAT

The area of concern (A) is that of NRM strategic planning and community engagement to promote 'climate ready' (adaptive change) at farm, local and regional levels in a manner that incorporates the best available scientific knowledge.

The methods employed

AR at its most basic is an iterative cycle of action and reflection. Methods we employed within this basic cycle included planning and delivering a series of workshops, seeking written and verbal feedback from participants after workshops, observing participants' interactions during workshops, recording outputs from workshops, recording our own reflections after workshops, engaging in our own reflections as a research team after each engagement with NRM boards and their communities, and returning to our own reflections over time to reveal our own mental models and engage in our own double-loop learning.

The process unfolded

A series of workshops were convened involving as many people and representing as diverse a range of interests possible associated with the NRM regional planning process. The intention was to have an interaction that involved the hierarchy of influencers from Federal and State agencies through to the regional NRM Boards and the Board planning staff.

The central question being explored was how to work with people in a way that connects visions of their desired futures (and the values embedded within those visions) with decisions informed by the science, so that a more sustainable future emerges. Our processes were developed with the recognition that if change is to be transformational, then our processes need to be cognisant of the mental models and assumptions that are at the heart of both the conventional and proposed processes.

During the project we explored how each community really wanted to experience the NRM strategic planning process itself. Some of the information collated during this stage was incorporated in the brief for the LFAT development; most informs us about ways the LFAT may be used with communities.

We then trialled the initial stages of the envisioning process focussing on the landscape, as the SA MDB want to experience it. We facilitated the development of indicators that would be observed when their vision is being brought into reality and explored the creation of a bridge between those indicators and decision making informed by the LFAT. The final phase of integrating the envisioning process into the regular regional planning cycle, to develop an action and reflection loop ('action learning'), was not undertaken with this group because of the constraints of the research funding timetable.

Following a workshop in Adelaide on 27 April 2012, it was apparent that a greater level of explanation was needed to help people involved in the process gain a better understanding of the link between the envisioning and engagement process and the ongoing planning process. Information that is to be used in regional planning very quickly becomes complex and confusing once the full scope of regional variation is realised. Add to this the increased complexity that is generated by considering future climate and commodity price scenarios and it is understandable that the important link between aspiration and inclusion in the plan becomes weak. A brief explanation was developed of the project intentions and the role of envisioning in helping provide people-informed directions that the plan should take (Attachment 5). The explanation was subsequently distributed to workshops that followed in the two regions.

The workshop in the SA MDB was at Karoonda on 17 May 2012. The process of envisioning was enthusiastically engaged with by the 40 people present. The summary of the output is at Attachment 6. It was apparent that some people were bemused that the workshop was asked to address the question of "how do you want to experience the NRM planning process in your region?". This is a quite different question to one that they may have anticipated along the lines of "what is your vision for the region?". The important element of this approach is that it seeks to identify the values that people inevitably use in making decisions but which are rarely made explicit. As an example, the following values were identified as critical to be exhibited in any new NRM planning process:

- relevant and transparent communication (2 way)
- everyone is invited
- consider what motivates action
- simplicity
- valuing knowledge from all sources
- trustworthy.

With this experience, another workshop was held in Port Lincoln, Eyre Peninsula, on 31 May 2012. While similar values were identified, there was additional work on defining 'indicators of progress' (Attachment 7). These are couched in terms of "what would you observe if your vision was being lived now?" that would provide evidence that the important values associated with the planning process were being acknowledged.

While good progress seemed apparent at the time of this workshop, we were to learn later that some participants felt that the envisioning process was too time-consuming. It was also evident that some participants were uncomfortable with a focus on identifying values – this was outside the usual methods of engagement that focus almost entirely on bio-physical content and only implicitly on personal values, feelings and relationships. (Both the comments with regard to time and the degree of discomfort may be interpreted as indicators that the participants were engaging in real 'adaptive change' and seeking ways to 'avoid the work' as can be expected when adaptive work is undertaken (Heifetz & Linsky, 2002)).

Additional details of the legislative context of NRM planning, the results of the consultation on the previous planning process and additional interpretation of the envisioning workshops are given in the Milestone 2 report (Attachment 8).

Apart from experimenting with a different engagement approach, the purpose of the workshops and discussions with regional NRM staff was to refine design specifications for the information display and analysis tool that regions could use to inform their planning. The results of this design process are described in the next section.

3.1.4 Design and propose a process and 'data interface' specifications

The experimental envisioning process as described above was primarily about an improved engagement process and through this to gain a better understanding of the form and type of information that would be most helpful in regional NRM planning. This process was not specifically about the content of the 'tool'; rather it was about developing a greater sense of ownership of any plan. For clarity, the project activity could be conceived to have two components – the 'processes' and the 'tool content'.

The process characteristics were identified from the Karoonda workshop (Attachment 6). The project therefore needed to deliver a process that recognised the strengths and weaknesses of past NRM planning approaches and build an improved understanding of how people want to 'experience' climate change informed planning.

With respect to the content of the Landscape Futures Analysis Tool (LFAT), discussions with the regional NRM planning staff resulted in a very preliminary design specification (Attachment 9). At this stage in the engagement, interest centred around carbon sequestration plantings and potential effects as well as some interest in projections of climate change effects on biodiversity.

As part of the ongoing engagement and as an introduction to the LFAT logic of, and need for, the Tool, the steps involved in generating the content and analyses of the Tool and a representation of the interaction process was developed. This (Attachment 10) was shown at workshops with the planning personal in both regions. The LFA was described as a five-step process:

- Gather and collate primary data sets for the region
- Use primary datasets to derive and display regional variability and opportunities for actions
- Use models to estimate spatial distributions
- Develop implications of climate change scenarios
- Provide integration outputs of production, conservation and economics.

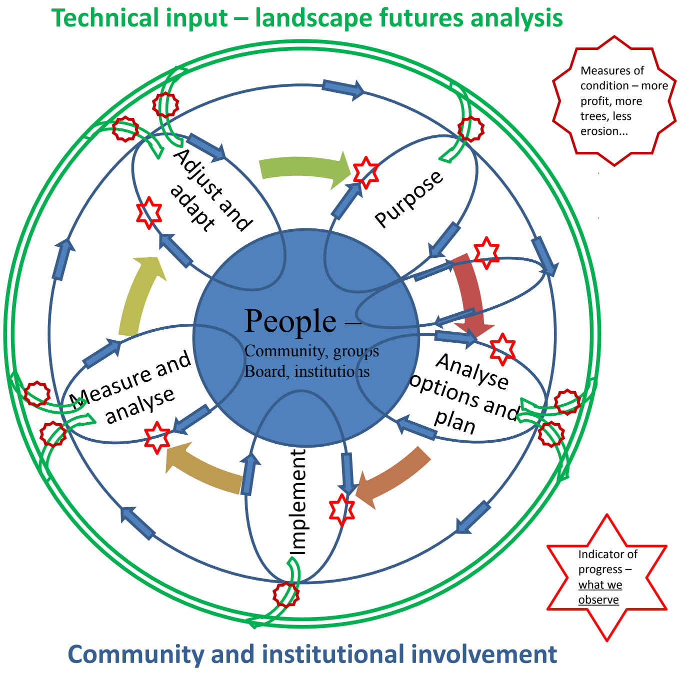
To assist understanding of the engagement and tool development processes a conceptual figure was used (Figure 1) for illustrative purposes.

With this introduction and with further discussion of the way in which the planning process could use regional projections in response to climate change, carbon price and commodity price, a Tool specification and trial plan was developed (Attachment 11). This revised plan was informed by the interactions up to that time including the understanding of the successful approaches that had been used during the first regional plan. Three stages were identified:

1. Discuss what you want the landscape to look like, how you want to experience it and what information can help to plan for future land use.
2. Use geographic information to work out what land use options could go where, to maximise landscape scale agriculture and biodiversity outcomes.
3. Ask how effective the land use planning exercise was and what capacity needs to be built to deliver a similar process.

This plan guided the subsequent interactions and from these an evolving set of specifications for the LFAT was developed.

Figure 1: Conceptual, interactive arrangement of the role that Landscape Futures Analysis can have in the NRM planning process.



As indicated in Attachment 11, our initial proposal on output from the LFAT was in the form of regional maps that could be used in a workshop setting. However, before this could be realised, more exact specification of the LFAT was needed to empower the interface design and information development team (D&D team). A comprehensive description (Attachment 12) was developed and this identified specific NRM issues that the regions were increasingly saying were important. The three key NRM planning issues were:

1. Conserving biodiversity—managing remnants and restoring corridors
2. Managing weeds—targeted monitoring of future invasion risk hotspots
3. Storing carbon—finding the best places for carbon plantations.

These three demonstration issues also illustrate different approaches to the application of landscape futures analysis. Conserving biodiversity uses an economic cost-benefit type approach to inform policy such as targeted incentive schemes under climate change. Managing weeds uses a risk analysis framework to identify areas at high risk of both agricultural and ecological weed invasion under climate change for targeting monitoring and management efforts. Storing carbon uses a landscape planning type approach to identify areas that are suitable (and unsuitable) for carbon plantations subject to satisfying several specific criteria. Each of the three issues was implemented as a separate interface in the LFAT. The Tool is extensible, as interfaces can be added to address other specific NRM planning issues as necessary.

With this Tool specification in place after much interaction with the regional planning staff the next interactions revolved around demonstrations of the prototype Tool and noting the suggestions that they made. Notes from the demonstration workshops with Eyre Peninsula and SA MDB are at Attachments 13 and 14 respectively.

From these meetings it became obvious that a fourth major NRM planning issue was a high priority – agricultural productivity and its distribution both in space and time. This issue was then added to the existing issues to make four **planning modules** that could be displayed and overlain using the LFAT.

More specific recommendations and refinements to the Tool were identified (Attachment 15) and these have been incorporated in the β test version.

Regional information for water management

Water is a critical natural resource in the two NRM regions and its availability is almost always limiting. Three 'sources' are identified; rainfall, surface water (rivers, creeks, lakes) and groundwater. The distribution of rainfall, both spatial and temporal is embedded within all of the climate data and hence is a major driver of the models and estimates of native vegetation and agricultural growth and productivity.

To provide more explicit information to regional planners and managers additional water related data was added to LFAT as indicated below. It is expected that this information will act as baseline data to stimulate LFAT users to identify additional and derived water related data layers.

Groundwater recharge potential

Groundwater recharge is important in sustaining the availability of water for many agricultural or domestic uses (DWLBC, 2007). This is often of critical importance in semi-arid to arid regions where other water sources are not readily available. However, excessive recharge can have harmful side-effects such as salinisation of the root zone due to the rising water table and aquifer contamination (DWLBC, 2007).

Groundwater recharge potential data was sourced from the Soil Landscapes Analysis data published by the Department of Water, Land and Biodiversity Conservation (DWLBC, 2007). Recharge potential was calculated as a function of soil water holding capacity, substrate porosity and rainfall. Areas were classified as having a low, moderate or high recharge potential.

Wetlands (from Directory of Important Wetlands of Australia)

Data layers related to wetlands were sourced from the Directory of Important Wetlands in Australia (Environment Australia, 2001). These are areas of marsh, peatland or water, which can be natural or artificial in origin. The wetlands can be permanent or perennial; comprised of static or flowing; and fresh or salt water.

A set of criteria were used to determine if identified wetlands were classified as nationally important wetlands based on their environmental, ecological, hydrological, historical or cultural significance (Environment Australia, 2001). Data developed in conjunction with the Directory of Important Wetlands of Australia was clipped to each of the study areas and converted into raster format for analysis within the carbon sequestration module.

Rain interception by trees

Interception of rainfall by trees reduces the amount of rainfall reaching the ground surface resulting in diminished soil moisture and a reduction of aquifer recharge from rainfall (Chen et al, 2008). Increasing the amount of forest cover can have a dramatic impact on hydrological processes in certain areas.

Rainfall interception was modelled in $3PG_2$ as a function of leaf water-retention up to a maximum thickness of retained water and evaporation at the wet-surface rate during a rainfall event (Almeida et al., 2007). Input variables were required for rainfall intensity and the maximum thickness of water on leaves.

A description of the primary data sets, the derived and modelled data along with the scenario specification and its use follows.

3.2 Phase 2 – Collate data and build the tool

3.2.1 Audit of data and tools

Much of the regional data was collated during a preceding project (see Meyer et al., 2012a, 2012b). Reports from the preceding project that detail the data layers collected for each region are at Attachments 16 and 17.

As an illustration, the minimum data sets for a regional description include:

- natural (topography, rivers, lakes) and built (towns, roads, utilities) features
- cadastral information
- land use types over time
- geology, soils and groundwater data
- native vegetation areas / reserves and remnant endemic vegetation
- climate data (for as long as records are available)
- demographic and economic data.

While regions had access to much of this information through connections with the responsible State agency (initially DWLBC and most recently DEWNR) the use was variable and influenced by resident staff capability. It was apparent from NRM Board staff that while Geographic Information System (GIS) capability was variably available either directly or by contracted arrangements during the development of the first regional plan, this capability had diminished during the past 2-3 years. There was explicit recognition that this capability needed to be improved and new positions are to be filled in late 2012 and early 2013.

There is a growing list of tools and information sources that are becoming available to regional NRM staff for monitoring and assessment of resource condition in their regions. An example is the availability of soil erosion vulnerability assessment using historical and current remotely sensed data. As part of this project a report (Attachment 10.18) was developed based on the research by Clarke et al. (2011). This assessment is very cost effective and should become part of a standard array of monitoring tools. Additionally, the spatial coverage and data handling is entirely compatible with the GIS layers used in Landscape Futures Analysis. As regions regain or develop GIS capability as standard operating practice, soil erosion vulnerability assessment will be a valuable monitoring tool.

3.2.2 Software development – basic structure

The diagrammatic representation of the Landscape Futures Analysis process is given in Figure 2. The baseline data is that described in 3.2.1 while the models used and the arrangement of data, analyses and interface characteristics of the LFAT are described in the following sections.

3.2.3 Software development – model parameterisation and testing

This section describes the three major modelling exercises: wheat crop growth water use and yield, native plant species distribution, and carbon accumulation associated with trees and woody vegetation. Each of these models was verified against current data where possible and then used to estimate changes in yield or distribution in response to possible climate scenarios.

Regional agricultural productivity through wheat productivity modelling using APSIM

The substantial development of the regional agricultural productivity modelling had been done during two previous, major projects.

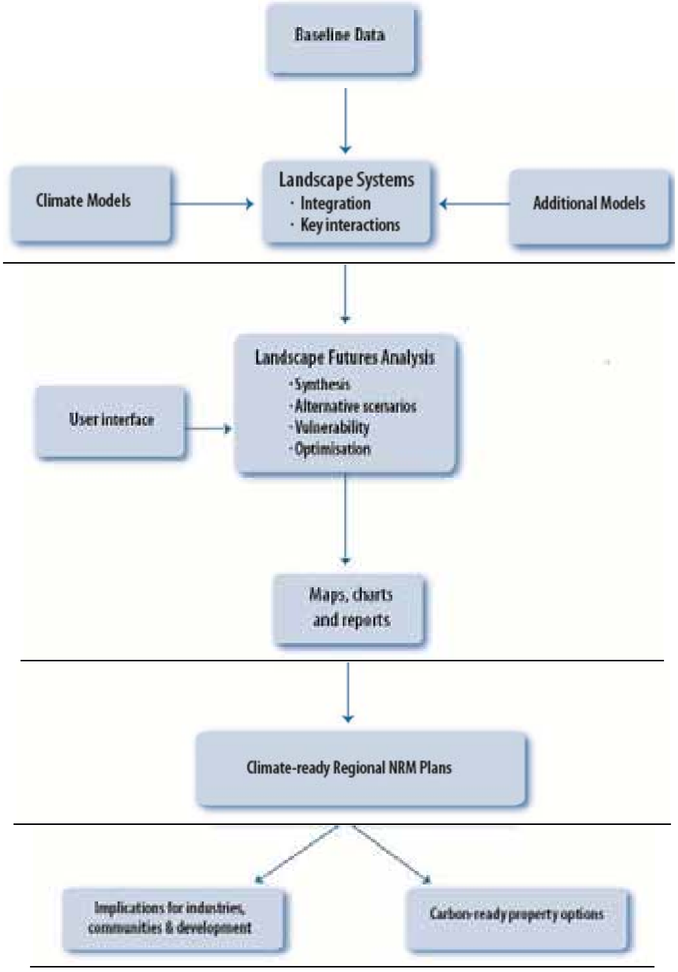
- For the SA MDB, much of the modelling and associated 'ground truthing' was compiled during the Lower Murray Landscape Futures Project and reported in Bryan et al. (2007a, 2007b, 2007c).
- For the Eyre Peninsula NRM Region, productivity distribution was estimated through the Agricultural Production Systems Simulator (APSIM) crop model (Keating et al., 2003) and reported in Meyer et al. (2012a, 2012b).

The previous studies used crop models to simulate the climate-soil interactions at the regional scale. Asseng et al. (2001a) applied the APSIM crop modelling system to five soil types across two transects which incorporated 25 locations along a low to high rainfall gradient. For the Lower Murray study region, Wang et al. (2009) used 16 climate stations and 14 soil profile types deemed representative of the broad soil classes.

The same crop model has been used to estimate the effects of climate change on crop yields (Reyenga et al., 1999; Asseng et al., 2004; Luo et al., 2005b; Tubiello et al., 2007). The effects are site specific and dependent on the current climate analogue, the size of reduction in rainfall and the degree of increase in temperature and carbon dioxide level. For example, Wang et al. (2009) assessed the interactive effects of CO_2 concentration and temperature on wheat yields. They suggested that the doubling of CO_2 to 700ppm would increase yield by 28-43% but increases in temperature of 3°C would decrease yields by 25-60%. However, this effect was not consistent across a regional setting and its magnitude varied spatially due to climatic gradients.

The estimation of agricultural productivity in the SA MDB NRM region included estimates of wheat, lupins

Figure 2: Representation of the Landscape Futures Analysis process where the 'User interface' is that associated with the LFA Tool.



and pasture, all using common climate and soil inputs for the region through the APSIM crop modelling system. As indicated above, these had mostly been carried out for the Lower Murray Landscape Futures Project. For the current project, the climate data sets were reviewed and the soil data was reassigned using the most recent classification of South Australian soils estimated yields compared with the most recent farm survey information.

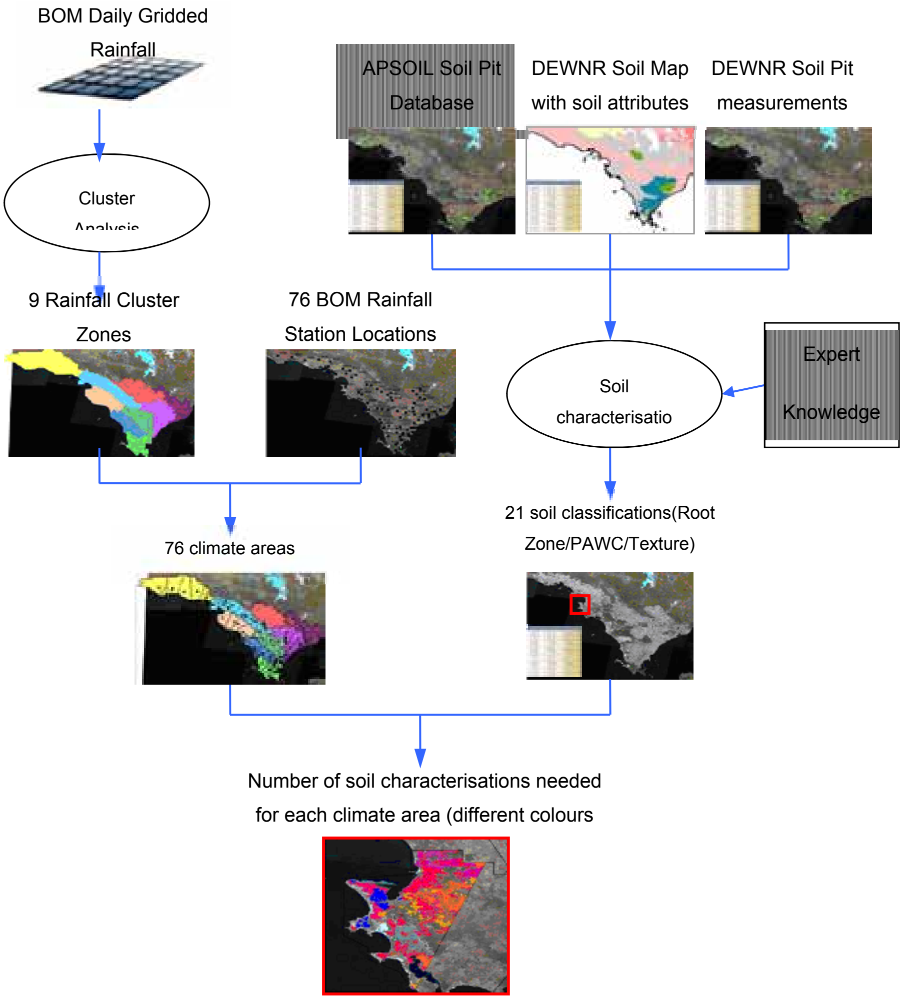
For the Eyre Peninsula (EP) region, more review and refinement of the APSIM wheat crop modelling was undertaken and for information this modelling development is described more fully below. The intention was to generate estimates of wheat yield that were considered by EP wheat growers and their advisers to be accurately descriptive of the temporal and spatial variability in harvested yields. The endorsement that the modelled estimates were acceptably accurate provided a credibility basis from which projected yields with changed climate conditions could be generated with reasonable confidence. The following sections provide a general description of the model development with highlights indicating the additions and refinements of the model inputs associated directly with this project.

Mapping the spatial distribution of simulated input variables

A schematic representation of the process used to classify the different rainfall subregions and then the associated soil type descriptions is shown in Figure 3.

As described previously (Meyer et al. 2012b), cluster analysis was undertaken on the interpolated surfaces of

Figure 3: Schematic illustration of the methodology used to derive the specific soil classifications associated with particular rainfall stations for the Eyre Peninsula.



monthly rainfall across the Eyre Peninsula (EP) between April and October from data provided by the Australian Bureau of Meteorology (BOM). This analysis identified nine rainfall regions with distinct rainfall variations. These regions were assigned a low, medium or high rainfall zone ranking based on their long term average rainfall values. Rainfall station data from the SILO patch point dataset where rainfall records were greater than 50 years was extracted. A total of 76 stations were selected and input to a geographic information system (GIS). These 76 climate areas define the spatial variation of climate information that was used as climate input into the crop simulation modelling.

Three spatial datasets were used to define the spatial variation in soil characterisations.

The South Australian State Land and Soil Information Framework (SASLSIF) generated from the South Australian State Land and Soil mapping program (Department of Environment, Water and Natural resources (DEWNR)) provides soils datasets in a spatially distributed format. Within the framework, two fundamental soil attributes for simulation modelling are available; plant available water holding capacity and soil texture within the top 10cm of the soil profile. These attributes provide broad classifications of potential magnitudes for both variables.

The third attribute needed in the simulation modelling is rooting depth. This range of values was derived from other mapped variables and the corresponding literature available with the mapping (Hall et al., 2009). Similarly, four rooting depths were assigned and then validated from soil observations from the DEWNR soil pit information. Additionally, during the current project, expert knowledge from local growers, agricultural consultants and regional advisers was used to readjust the original mapped plant available water holding capacity values to fit in with the new rooting depth estimates as well as to validate the resultant spatial distributions.

This methodology generated 21 mapped soil characterisations representing the potential combination of rooting depth, plant available water holding capacity and soil texture variables derived from the soil mapping data on the EP. These mapped characterisations acted as a summary template from which the input variables used in the crop simulation model can be matched.

Both spatial datasets were brought into the GIS and joined spatially to identify the variation in soils within each climate area. This process identified the number of simulations runs needed and the variation of soil characterisation in each of the 76 climate zones.

Simulation modelling of the mapped input variables

With adjustments made to the rainfall subregions and particularly the soil classifications (and associated parameters) the APSIM crop model was re-run to simulate wheat yields with current and climate changed conditions.

The APSIM 7.3 crop model was parameterised for this study. From the previous section we identified 76 climate areas with a selection of 21 possible soil characterisations. To model the impacts of climate change on these areas we followed the method developed by Reyenga et al. (1999). This method involved taking the historical climate analogue and modifying the daily historic climate data by adding a fixed temperature and carbon dioxide offset and applying a percentage reduction to the historic rainfall. Ludwig and Asseng (2006) state that using this method is useful because it shows what the effect is of reduced rainfall using the same inter-annual variation of the historic climate.

To follow this method, climatic data from the SILO Patched Point Dataset was extracted for the 76 regions based on the time period between 1900 and 2010. This past analogue represented the current climate scenario (S0). Climate data from the S0 scenario was then adjusted to represent the climate projections for three climate change scenarios (S1, S2 and S3) highlighted in Table 1.

Table 1: Nominal temperature, rainfall and carbon dioxide conditions associated with current (S0), mild (S1), moderate (S2) and severe (S3) climate change scenarios.

Scenario	Temperature change (%)	Rainfall change (°C)	Carbon dioxide concentration
S0	-	-	390
S1	+1	-5%	480
S2	+2	-15%	550
S3	+4	-25%	750

The rationale for choosing the combination of atmospheric carbon dioxide (CO_2), temperature and rainfall changes was developed from the original review of climate change projections for South Australia by Suppiah et al. (2006). Hayman et al. (2011) used the Suppiah projections and illustrated the temperature and rainfall projections made by the range of climate models as probability distributions for the SA MDB region.

The range of projections is strongly influenced by the choice of projected greenhouse gas emissions.

With this background, it was decided that four climate scenarios (Table 1) would be used as input for the models. These represent:

- climate up to the year 2000 (S0)
- a mild increase in temperature (S1) that approximates conditions expected at about 2030
- a moderate increase in temperature (S2) at approximately 2070 with medium emissions between now and then
- a severe setting (S3) that could be expected even at 2070 if emissions accelerate at the very high end of the emission range.

Within these scenarios, the daily weather data is represented, including global radiation, rainfall, maximum and minimum temperatures. This data is needed to run the simulation model for each of the four climate scenarios. From the previous section we highlighted 21 mapped soil characterisation representing combinations of rooting depth, plant available water holding capacity and soil texture values. We explored the APSIM soil characterisation database and matched the 21 mapped soil characterisations to soil characterisations measured on the EP with equivalent rooting depth, plant available water holding capacity and soil texture values.

These measured characteristics incorporated soil surface characteristics including soil albedo, water entry and retention capacity, evaporative potential and surface residue cover. In addition hydraulic properties of the soil profile – water contents at saturation, drained upper limit, and 15 bar suction water content and a drainage coefficient were defined for each soil layer.

An APSIM set-up was established which used a simplified dryland wheat-fallow farming system model. The wheat variety chosen for all simulations was Janz, a mid- to late-maturing variety. The Janz variety is very well documented and parameterised within APSIM and has a long history of use in well tested and validated experiments. Also, a mid season variety such as Janz was preferred in order to account for the uncertainty associated with a wide sowing window and a rainfall accumulation trigger for planting (1 May to 1 July – see Appendix 1). The uncertainty in the date of sowing is exacerbated due to the influence of the climate change scenarios which are expected to push the date of sowing further back in the year as it takes longer for sufficient soil moisture to accumulate The crop was deemed to be sown every year (continuous wheat monoculture) followed by a summer fallow period from harvest until the next sowing date. The cropping and management parameters of the model are available in Appendix 1.

Rainfall variation across the Eyre Peninsula has an effect on the amount of nitrogen mineralised in the soil (nutrient availability) as does the amount applied by the grower for crop management. The model incorporates two sources of fertilisation which represent a fixed amount of nitrate mineralisation and ammonium at the start of a simulation and an applied amount at sowing. The model also provides the ability to apply a top dressing amount at particular crop growth stages which is common practice in medium and higher rainfall zones.

To incorporate this spatial variability, a list of nutrient availability values was created to represent the values expected across the variation in rooting depth and soil textures in the three rainfall zones (see Appendix 1). These values were derived from published literature (Adcock, 2005), unpublished trial soil measurements and expert opinion. Fertilisation rates were also varied by rainfall zone and these application rates were derived from gross margin handbooks and expert knowledge.

Simulations were run for the current scenario (S0) and future climate change scenarios (S1-S4) across each of the 76 climate areas to produce wheat yields (kg/ha) for the 21 soil characterisation across 110 years. Wheat yields were then averaged over the time period to produce a long term average wheat yield for each soil characterisation within each climate area and for each climate scenario.

Validation of the results from the S0 scenario was achieved through the use of expert opinion from growers near the soil characterisations sites and EP based agricultural consultants. This involved feedback from:

- Around 50 landholders, including both a random selection of those attending workshops and targeted landholders representing different rainfall districts and different soil types.
- Agronomic consultants with clients across the western, eastern and central Eyre Peninsula districts.
- Research and agricultural extension staff from the Minnipa Research Centre.
- Port Lincoln Rural Solutions SA staff.

This feedback was supported by seasonal comparisons of actual yield data obtained from trials on the chosen soil characterisations across Eyre Peninsula and a sub-regional comparison of yield provided by the Australian Bureau of Statistics and the Minnipa Agricultural Research Station.

It should be noted that there are different data bases for soil and climate associated with the different models (e.g. the APSIM and 3PG2 models) because of the model specific requirements. The major differences are not the type of data used, rather the level of aggregation of data. For example, the soils data used in 3PG2 is taken from the ASRIS data base at land form level. For APSIM, the ASRIS data forms the higher level information which is added to with more detailed data at a finer spatial scale and where available, at a profile scale. The APSIM model is set up to make use of the more detailed information, 3PG is not. These models have been shown to be fit-for-purpose.

Mapping the impacts of climate change on wheat yield at a regional level

A look-up table was created with a variable key that was common to both the mapped soil characterisations and the yield outputs from simulation modelling. The key consisted of the rainfall station number and soil characterisation name. The two datasets were linked and resultant maps of the spatial distribution of long term average wheat yield for each scenario are shown below.

Figure 4 illustrates the spatial variability of long term average simulated wheat yield for the Eyre Peninsula for the S0 scenario. Yield variability ranges 150-1,500 kg/ha in the upper part of the Eyre Peninsula (low rainfall zone) and increases to 1,500-2,500 kg/ha in the middle medium rainfall zone. The bottom part of the figure illustrates simulated wheat yield for the smaller area high rainfall zone with yields varying from 2,500-4,500 kg/ha.

Figure 5 shows the estimated yields using the S1 climate change scenario. Application of this scenario across the EP gives an indication of what the potential climate could be in the next 10-20 years, even if significant mitigation efforts are undertaken globally. Results showed that yields increased on most soil

Figure 4: Simulated long-term average wheat yields for the Eyre Peninsula based on 110 years of past climate information.

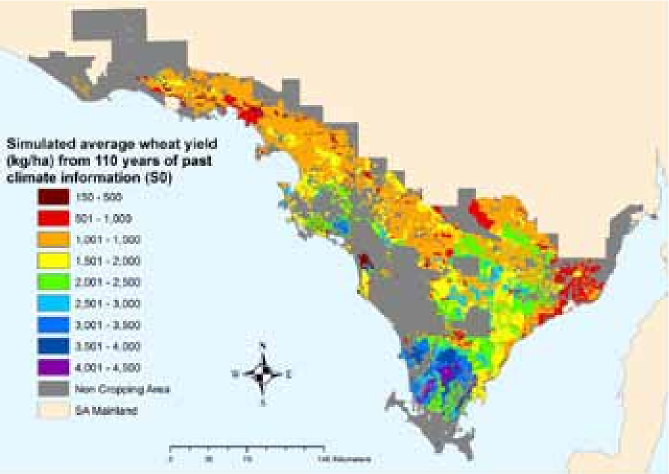
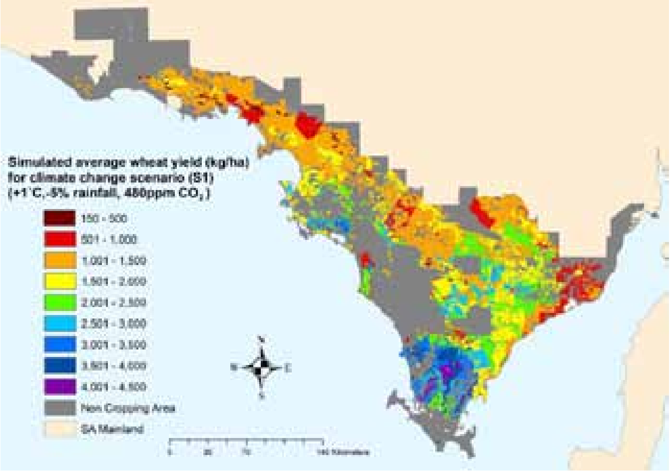


Figure 5: Simulated long-term average wheat yields for the climate change scenario (S1) for the Eyre Peninsula.



characterisations due to the increase in temperature and CO_2 level and limited reduction in rainfall across the identified low, medium and high rainfall zones.

Figure 6 shows the estimated yields using the S2 climate change scenario. Application of this projection across the EP could reflect a possible climate around 2050 or later, even if significant mitigation efforts are undertaken globally. The figure shows reductions in long term average yields for the low rainfall zone regions. Estimated yields increased moderately for coarser textured soils in the medium and high rainfall zones presumably because root zones are deeper and more stored water is accessible. There is considerable spatial variation in yield across all rainfall zones associated with the variations in soil characteristics.

Figure 7 shows the estimated yields using the S3 climate change scenario. Application of this scenario estimates large yield reductions in the low rainfall area particularly on the finer textured soils. In medium rainfall zones, slight increases in yield are estimated on coarser textured soils but yield reductions (10-30%) were simulated across the finer textured soil types. In higher rainfall areas, similar simulated yield trends are apparent with yield increases (0-20%) simulated on coarser soils and yield reductions (0-20%) estimated on finer soil types.

The simulation of wheat yields with the three climate scenarios acts as a regional indicator for possible effects of climate change in the region. The results show the large spatial variability in response that is due to the interactions between temperature increases, carbon dioxide increases and rainfall reductions on crop growth combined with soil type effects on plant available water and nutrient (principally nitrogen) availability.

Calculating agricultural economic returns for climate scenarios (S0-S3)

The following economic analysis was conducted on the model productivity of the study regions for all climate scenarios.

To calculate the economic revenue from agricultural production per hectare, the amount of agricultural production produced was multiplied by the price per tonne:

$$\mathbf{R = Q\ .\ (P.\ PM)}$$

Where:

R = Long-term average revenue from agricultural production per hectare

Q = Quantity of production in tonnes per hectare

P = Price received for agricultural production per tonne

PM = Agricultural price multiplier

Commodity prices for wheat, lupins and wool used in the LFAT modelling were based on 10 year averages from 2001 to 2011 using data sourced from the ABARE (ABARES 2012). The prices for wheat and lupins were set at \$254.72 per tonne and \$261.68 per tonne respectively. The wool price was set at \$5.62 per kilogram based

Figure 6: Simulated long-term average wheat yields for the climate change scenario (S2) for the Eyre Peninsula.

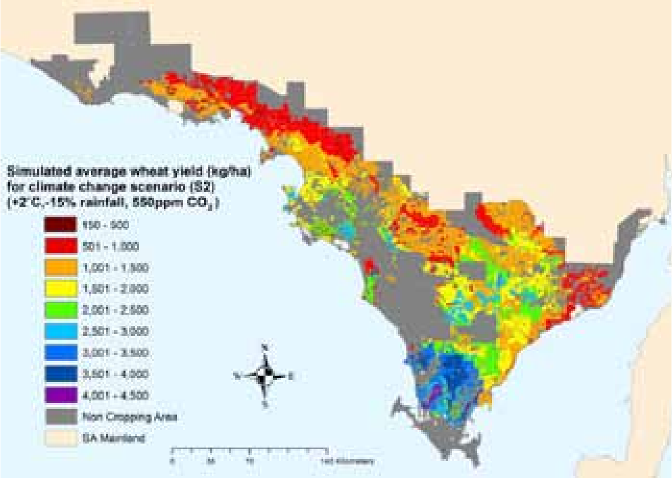
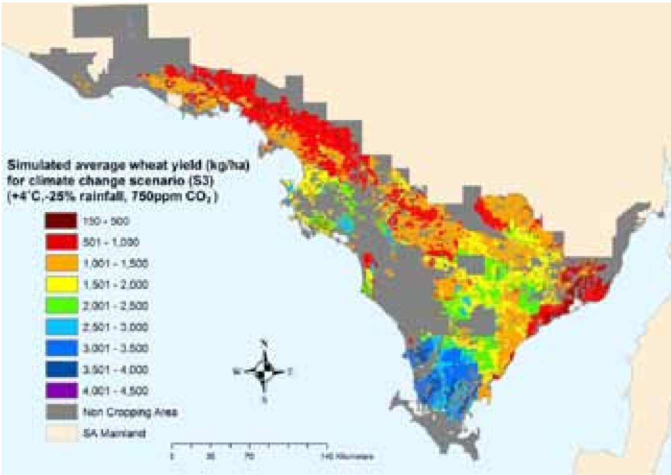


Figure 7: Simulated long-term average wheat yields for the climate change scenario (S3) for the Eyre Peninsula.



on the 10 year average greasy price. Prices for sheep meat was based on the average prices of mutton and lamb average over 10 years from 2001 to 2011 using data sourced from the Meat and Livestock Australia (MLA 2012). A weighted difference between the average mutton price of $58.30 per head and average lamb price of $88.91 per head was calculated, then a dry sheep equivalence to head conversion factor of 1.5 was used to convert the weighted difference head price of $68.50 per head into a dry sheep equivalence of $45.67. An agricultural price multiplier with rates of 0.5, 1, 1.5 or 2.0 was applied to take into account future variations in the price received for agricultural production. Application of the equation of economic revenue produced four maps of economic revenue for the EP and SAMDB regions.

To calculate profit at full equity (PFE) costs of production were included. The variable costs of production were taken from gross margin handbooks and these vary spatially according to rainfall zone (low, medium and high). For example, low fertiliser applications are used in low rainfall regions. Other financial estimates which make up the cost schedule were extracted from reports by the Australian Bureau of Statistics and the Australian Bureau of Agricultural and Resource Economics and Sciences. These costs were then verified by agricultural consultants in the regions.

$$\mathbf{PFE = R - (Cr\ .\ CM)}$$

Where:

R = Long-term average revenue from agricultural production per hectare

Cr = Cost of producing an agricultural output per hectare for each rainfall region

CM = Agricultural cost multiplier

Costs for wheat production across the EP and SAMDB study sites ranged from $198 per ha to $394 per ha. Costs were between $133 and $186 per ha for lupins and $3.1 and $70 per head (dry sheep equivalent) for grazing in the SAMDB. Similar to the economic revenue calculation, an agricultural cost multiplier with rates of 0.5, 1, 1.5 or 2.0 was applied to take into account future variations in the production costs. Application of the equation of PFE for wheat production produced 16 maps for the EP and SAMDB regions.

Comparison of economic returns from agricultural production and those from alternative land uses need to be compared over long time periods. To factor in this time period the Net Present Value (NPV) of agriculture-based financial returns is calculated. This calculation converts the PFE values in the future into present day valued using a defined discount rate of 7%.

$$\mathbf{NPV = PFE\ *\ (1 - (1 + disc)\ t\ )\ /\ disc}$$

Where:

disc = discount rate

PFE = the profit at full equity

t = the number of years – usually 64 in total.

These measures were used to assess the potential profitability of agricultural production across the study areas for each of the four climate scenarios.

Modelling species vulnerability under climate change

Climate change is likely to have significant effects on the distributions of many plant species which may shrink, expand and/or shift their geographic range (Santos et al., 2009; Schneider et al., 2007; Vos et al., 2008). Some species will become more vulnerable if natural migration is hindered by landscapes altered by humans (Manning et al., 2009). Hence, targeted conservation is required to facilitate adaptation and migration, especially for the most sensitive native species.

Vulnerability is commonly used within ecology and conservation planning to quantify the impacts of a variety of threats on species survival and extinction (e.g. Pressey & Taffs (2001), Visconti et al. (2010)). Here we are looking specifically at the threat posed by climate change. Climate change vulnerability is thought to consist of three distinct components. These include exposure to the threat or stress (in this case climate change), sensitivity to the stress, and the ability to adapt to the stress or adaptive capacity (Adger, 2006; Crossman et al., 2012; Schneider et al., 2007; Williams et al., 2008b). Many studies have examined these components separately. For example, plant species exposure to climate change has been quantified using species distribution modelling (SDMs). SDMs can model the current distribution of species and project how these distributions might change under future climate scenarios ((e.g. Pearson & Dawson, 2003; Thomas et al., 2004; Braunisch et al., 2008; Coetzee et al., 2009; Carvalho et al., 2010; Heikkinen et al., 2010; Crossman et al., 2011; Engler et al., 2011). Similarly, the sensitivity of species to climate change has been estimated by quantifying the likely impact of potential climate scenarios on projected species distributions. (Hijmans & Graham, 2006; Marmion et al., 2009; Kleinbauer et al., 2010). Species which are projected to experience shrinkage and or shifts in their geographic ranges are considered the most sensitive (Midgley et al., 2003).

The ability of species to disperse and migrate to new geographic locations is a key component of adaptive capacity within the context of climate change (Davis and Shaw, 2001; Carvalho et al., 2010). Particularly because new suitable locations may be dislocated geographically from current locations. Various spatial models have been developed to look at how species move through the landscape and try to quantify this ability to adapt by colonising new areas (e.g. Pearson & Dawson, 2005; Williams et al., 2005; Midgley et al., 2006; Phillips et al., 2008; Carroll et al., 2010; Carvalho et al., 2010; Crossman et al., 2011). Increasingly these different components of vulnerability are being integrated using SDMs (e.g. Carvalho et al., 2010; Thuiller et al., 2005; Crossman et al., 2012, Summers et al. 2012).

We combined these components to model the vulnerability of native and weed plant species in Eyre Peninsula and SA MDB NRM regions under the current climate and three climate change scenarios (S1, S2 and S3: see p. 23). Species distribution modelling was used to predict how individual species may move or shift geographically under climate change. This methodology was developed from previous work in the Adelaide and Mount Lofty NRM region and the Lower Murray which incorporates these three components of vulnerability (Summers et al. 2012; Crossman et al., 2012).

Data

Spatial layers of five independent environmental variables were used to predict habitat distribution in both the Eyre Peninsula and the Lower Murray:

- soil clay content
- soil pH
- temperature
- rainfall
- solar radiation.

Most of these analyses were performed on data collated from three NRM regions collectively called the Lower Murray. In addition to the SA MDB NRM Region the other regions were the Mallee and Wimmera CMA's in Victoria.

The reason for choosing these variables was twofold. First, these were viewed as primary drivers of plant growth and development (solar radiation, temperature and rainfall) and effects of soil properties (soil clay content that is highly correlated with water and nutrient holding capacity, and soil pH as a major controller of nutrient availability). Second, these variables were available for the study areas.

The two soil variables (clay content and pH) were extracted from the Australian Soil Resource Information System (ASRIS) (ASRIS, 2007) at a scale of 1:100 000. The three second Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) was used to model solar radiation using the Area Solar Radiation tool within the ArcGIS 9.3 toolbox (ESRI, 2009), and to model mean annual temperature and precipitation layers within the ESOCLIM module of ANUCLIM (Houlder et al, 1999). These layers were used as the historical or baseline climate (S0). Annual mean precipitation and annual mean rainfall under the three climate change scenarios (S1, S2 and S3) were created by adjusting the baseline climate layers by the relevant temperature increase and precipitation decrease.

Biological data was sourced from the South Australian Department of Environment and Natural Resources. In the Eyre Peninsula, this database consisted of 365,269 geo-located, point-based, presence-only records of 4,776 plant species over 6,897 unique sites. This database was refined by omitting water-dependent species, and species with fewer than 40 recorded observations. The refined database included 286 species with 52,692 records over 2,460 unique sites. In the Lower Murray this database held 247,839 geo-located, point-based, presence-only records with a total of 4,410 plant species over 57,564 unique sites. Like the Eyre Peninsula this was refined by omitting water-dependent species, and species with less than 40 recorded observations. The refined database included 584 species with 173,557 records over 27,810 unique sites.

Methods

Exposure: The exposure of plant species to climate change can be characterised as their predicted geographic range or distribution, and can be quantified using species distribution models (SDMs). These models quantify the relationship between independent variables and species occurrence based on known locations. They then predict species distributions using the independent variable layers. We selected three diverse models commonly used to predict species distributions, each using a different model: logistic regression (Márcia Barbosa et al., 2003; Schussman et al., 2006) using the ArcGIS geographic information system software, generalised additive models (GAM) (Elith et al., 2006; Guisan et al., 2002; Luoto et al., 2007) using the GRASP software package, and maximum entropy models using the Maxent package (MaxEnt) (Phillips et al., 2006).

We predicted species distributions (exposure) based on the five independent variables under each climate scenario (S0, S1, S2 and S3) using the three models.

Distributions were predicted under climate change by substituting the current climate layer with the future climate layers, and using the current distributions of species and their environmental correlates. For each species, we used the presence records and an equal number of absences randomly selected from the biological survey sites where the species was not recorded. To counter the potential bias from the generation of synthetic absence data, each of the three models was run 10 times for each species for each climate scenario.

For each run, unique calibration and validation datasets were created from the presence and absence species records through a random 70/30 split. The validation set was used to assess the predictive accuracy (using area under the curve (AUC) statistics) of individual models under the baseline climate (S0).

Finally, an ensemble model was developed which combined the outputs of the logistic regression, generalised additive, and maximum entropy models into a single prediction of species distribution for each species under each climate scenario. The predictive accuracy was calculated for each ensemble forecast for baseline climate S0 to enable a comparison of accuracy with the three individual models.

Species sensitivity: The sensitivity of plants to climate change can be calculated based on the likely impact of climate change on their predicted geographic ranges. Those species experiencing the greatest shrinkage and shift in geographic range under climate change are the most-sensitive.

We calculated the sensitivity of species to climate change as a scalar sensitivity weight, i.e. the ratio of the change in species distribution to the extent of species distribution under each climate change scenario for each species. Higher sensitivity weights are assigned to those species whose spatial distribution was projected to contract or shift, particularly if their geographic range is already limited. Species with an extensive distribution receive lower sensitivity weights, especially where distributions are projected to increase under climate change.

Adaptive capacity: Adaptive capacity can be quantified as species' ability to migrate to and colonise new habitat under climate change scenarios, as future geographic ranges may be spatially dislocated from current locations. This can be quantified using a dispersal kernel from current known species locations.

We calculated the dispersal potential for each species under each climate change scenario (S1, S2 and S3) to provide a measure of adaptive capacity. This was calculated using a negative exponential dispersal kernel based on the Euclidean distance to the nearest known location of each species. The negative exponential function creates a dispersal potential layer with values ranging between zero (cells that are far away) and one (cells that are close by). Thus, a higher potential dispersal score is assigned to areas closer to known species locations.

Calculating and evaluating spatial priorities for mitigating species vulnerability

In order to reduce species vulnerability to climate change, the components – exposure, sensitivity, and adaptive capacity, need to come together to inform spatial priorities for conservation actions. Spatial priorities for conservation may be most effectively identified through the principle of complementarity, such that each unique element of biodiversity has a minimum level of representation.

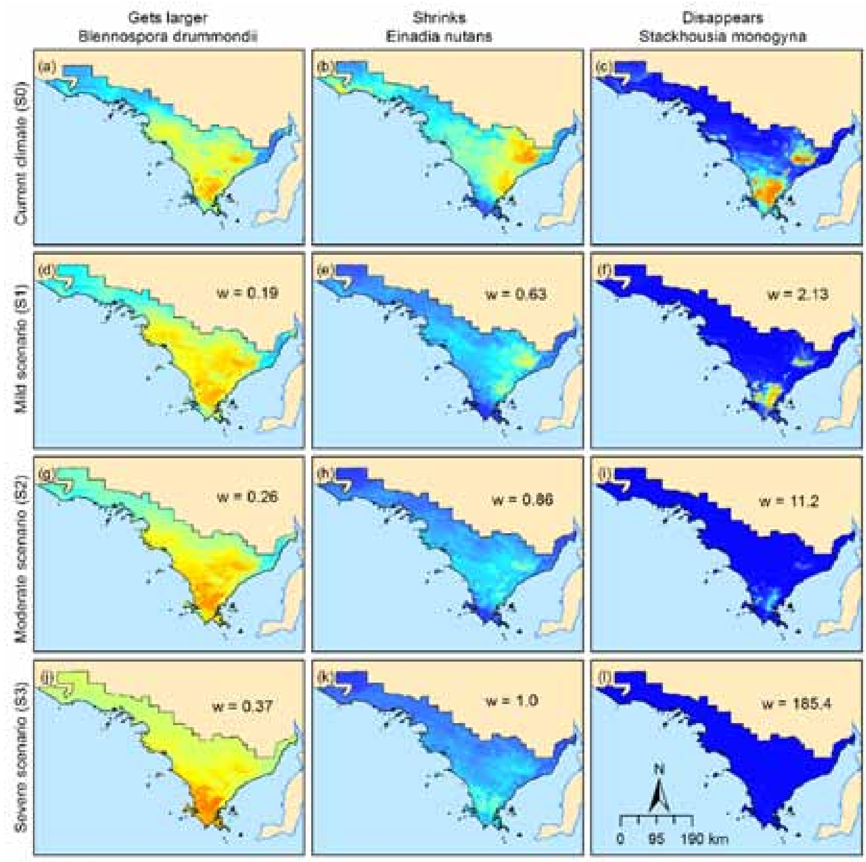


Figure 8: Examples of modelled species distributions in the Eyre Peninsula under climate change and resultant sensitivity weights.

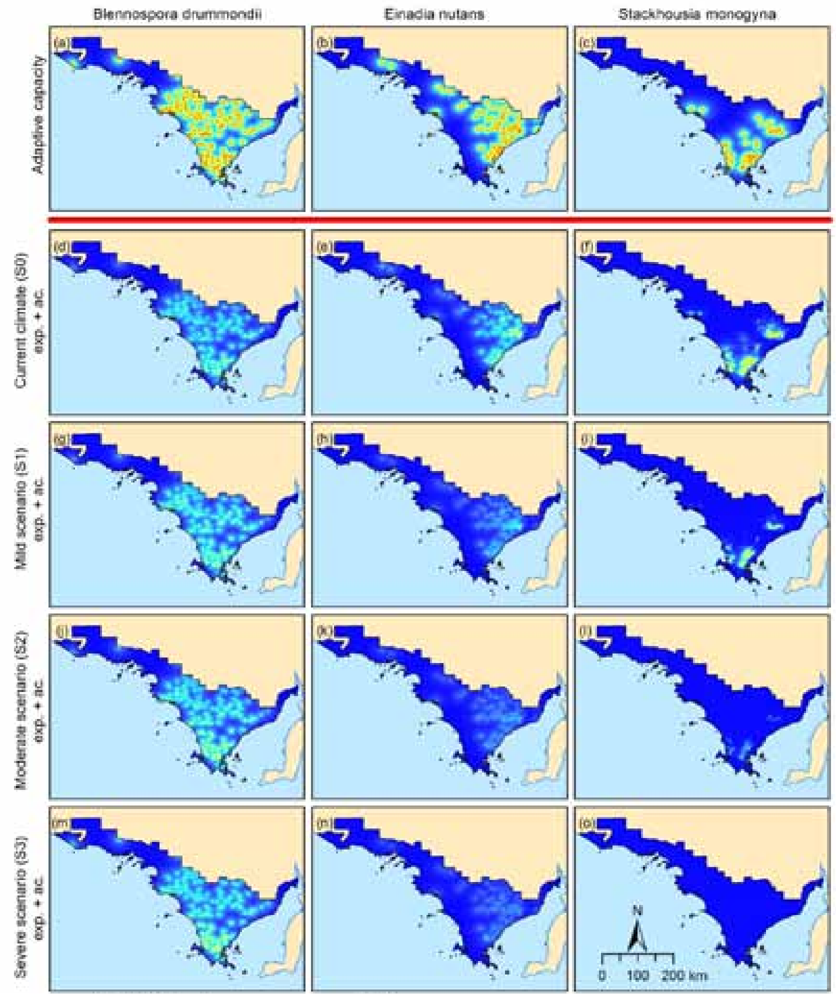
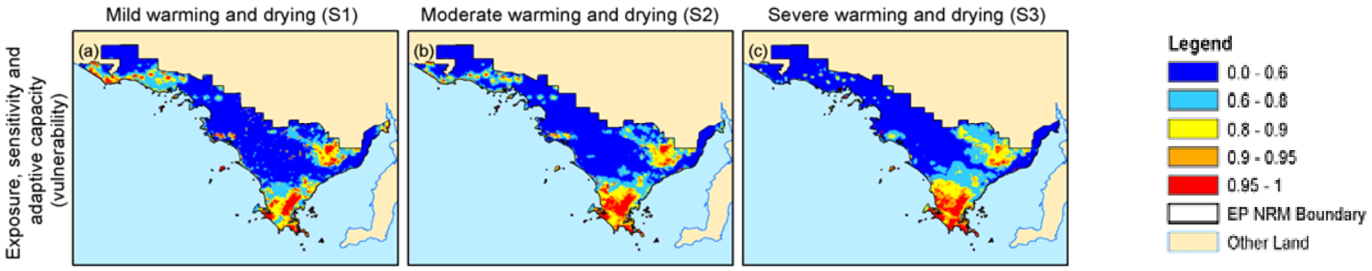


Figure 9: Examples of adaptive capacity, and adaptive capacity combined with exposure under current climate, and the mild, moderate, and severe climate change scenarios in the Eyre Peninsula.

Figure 10: Spatial conservation priorities for vulnerable species in the Eyre Peninsula.



We used the conservation planning software package Zonation (Moilanen & Kujala, 2008b) to identify priority areas for reducing species vulnerability under the three climate change scenarios S1, S2 and S3, and assessed the levels of species representation in these priority areas. Zonation uses a complementarity-based algorithm which iteratively removes cells from the analysis that incur the smallest marginal loss in conservation value (species representation) (Moilanen & Kujala, 2008a, 2008b). This software includes a range of methods for identifying and evaluating the selection of conservation areas. It also allows for the inclusion of supplementary information such as species weights, conservation costs, and the location of existing reserves.

In this study, we undertook core-area Zonation analyses to identify spatial conservation priorities under the three climate change scenarios. Core-area Zonation is designed to identify solutions that prioritise high-quality locations for all species while still accounting for priority weights attributed to them.

Eyre Peninsula results

Species vulnerability: exposure, sensitivity, and adaptive capacity: The ensemble model, combining each of the three individual models performed very well statistically with a mean Area Under the Curve of 0.832 (S.D. ± 0.089). Within this prediction a majority of the species were projected to have declining spatial distributions; 150 (52.3%), 160 (55.7%) and 152 (53.0%) under the mild, moderate and severe climate change scenarios respectively. The projected area of species distributions was calculated as the weighted sum of grid cell probabilities from the ensemble model. Under the current climate these ranged from 3830 km2 for *Xanthorrhoea semiplana* to 46,138 km2 for *Austrostipa nitida*.

The sensitivity weights assigned to each species during the species distribution modelling ranged between 0.04 and 12.1 for the mild scenario, 0.08 and 216.8 for the moderate scenario and 0.08 and 1056.0 for the severe scenario. Figure 8 illustrates species' range shifts and sensitivity weights. Examples of adaptive capacity, and adaptive capacity combined with exposure, under current climate, and the mild, moderate, and severe climate change scenarios are presented in Figure 9.

Spatial priorities for mitigating species vulnerability: Figure 10 shows spatial conservation priorities based on the vulnerability framework under the three climate change scenarios. Priority areas were largely identified in the west, east and south of the EP NRM region under the various climate change scenarios.

Large contiguous areas were identified in the east and south with more localised priority in the central and western parts of the study area (Figure 10a-c). The eastern priority areas coincide with an area of slightly higher elevation. Under the mild climate change scenario there were more priority areas identified in the west and centre of the study area. Under increasing warming and drying (moderate and severe climate scenarios) there were fewer priority areas in the west and a higher concentration in the south and east. This can be seen comparing the prioritisations under the mild (Figure 10a), moderate (Figure 10b) and severe (Figure 10c) climate change scenarios.

Lower Murray Results

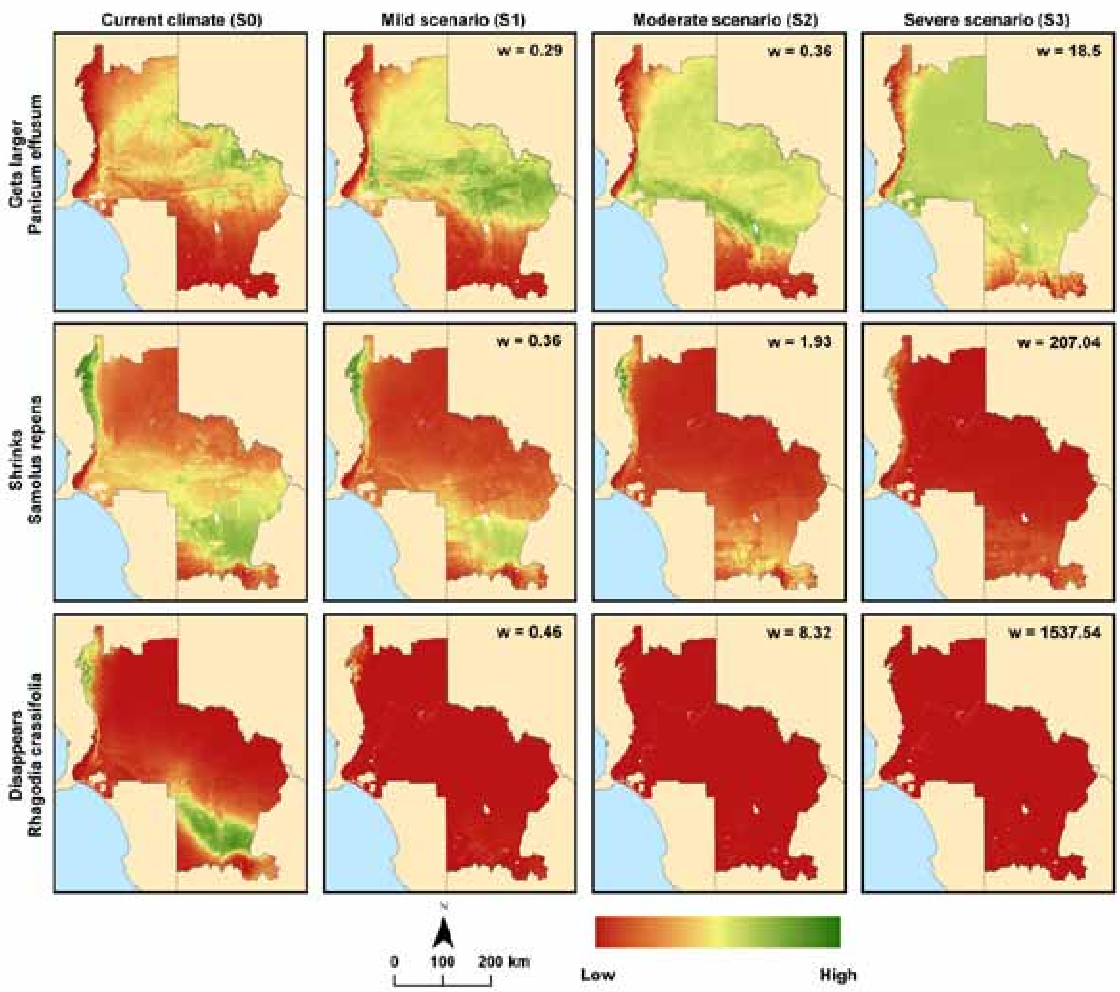
Species vulnerability: exposure, sensitivity, and adaptive capacity: The ensemble model also performed well in the Lower Murray region with a mean Area Under the Curve of 0.8498 (S.D. ± 0.0852). There were predicted declines in the distribution of 342 (58.6%), 347 (59.4%) and 352 (60.3%) species under the mild, moderate and severe climate scenarios respectively. As with the Eyre Peninsula, the area of projected species distributions under the current climate was calculated as the weighted sum of grid cell probabilities from the ensemble model. These ranged from 1,357 km^2 for *Pultenaea costata* to 62,475 km2 for *Ptilotus sp*.

The sensitivity weights for each species ranged between 0.06 and 19.0 for the mild scenario, 0.1 and 224.5 for the moderate scenario and 0.12 and 2994.7 for the severe scenario. Examples illustrating species' range shifts (exposure) and sensitivity weights are presented in Figure 11.

A dispersal kernel from known species locations, as determined by the biological survey database was used to quantify adaptive capacity. Examples of adaptive capacity, and adaptive capacity combined with exposure, under current climate, and the mild, moderate, and severe climate change scenarios are presented in Figure 12. These maps demonstrate the higher values (dispersal potential) closer to known locations.

Spatial priorities for mitigating species vulnerability: Spatial conservation priorities based on the vulnerability framework are under the three climate change scenarios are presented in Figure 13. Priorities were mostly in the western SAMDB, the southern Mallee and large parts of the Wimmera, across all scenarios (Figure 13 a-c).

Figure 11: Examples of modelled species distributions in the Lower Murray under climate change and resultant sensitivity weights.



Conservation priority areas are largely contiguous in the south and interspersed with localised priority areas. There are localised priority areas in the eastern SAMDB and northern Mallee Under the mild climate scenario (Figure 13a) and with increasing warming and drying (moderate and severe climate scenarios) these priority areas move south and into areas of higher altitude. This is evident in Figure 13b (moderate scenario) and Figure 13c (severe scenario) where there are no longer priority areas on the northern border of the Wimmera and there is a higher concentration along the western and southern boundary. Also, fewer priority areas are identified in the northern half of the SAMDB rather there are increasing concentrations along the eastern Flinders Ranges and the southern SAMDB.

Modelling biomass and carbon sequestration under climate change

Increased levels of greenhouse gases in the atmosphere from the clearing of forests for agricultural production over the short, medium and long-term are likely to contribute to the impacts of global climate change, resulting in the reduction and potential loss of vital ecosystem services (Albrecht and Kandji, 2003;

Figure 13: Spatial conservation priorities for vulnerable species in the Lower Murray.

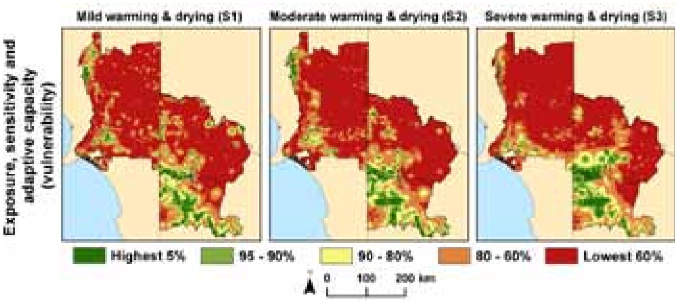
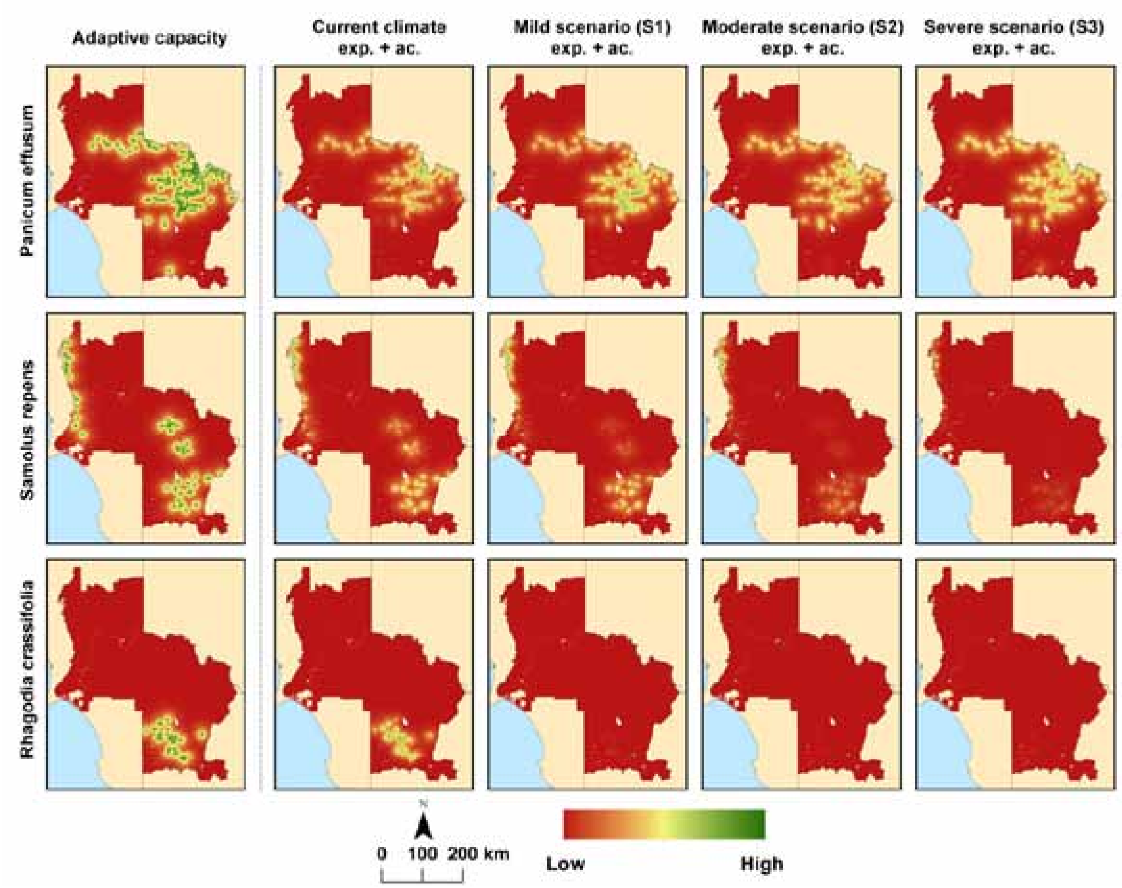


Figure 12: Examples of adaptive capacity, and adaptive capacity combined with exposure under current climate, and the mild, moderate, and severe climate change scenarios in the Lower Murray.



Rodriguez et al., 2006). As a consequence, there is a growing interest in the study of alternative land uses in agricultural regions including the production of biomass, and reafforestation for carbon sequestration.

Each of these strategies provides potential benefits including reduced greenhouse gas emissions and economic returns for farmers (Bryan et al., 2010a; Bryan et al., 2010b). Eucalypt biomass could supply the renewable electricity, activated carbon and eucalyptus oil industries, whereas the benefits of environmental plantations and hardwood plantations include the mitigation of dryland salinisation and soil erosion (Bryan et al., 2010a; Bryan et al., 2010b; Jackson et al., 2005). Environmental plantations also provide support for biodiversity (Foley et al., 2005; Jackson et al., 2005).

Process-based models use the biophysical parameters of tree species to simulate how characteristics including growth patterns, carbon storage and water cycles will be affected by external factors (Almeida et al., 2004b; Feikema et al., 2010). Models such as 3PG (**P**hysiological **P**rinciples to **P**redict **G**rowth) (Landsberg and Waring, 1997; Sands and Landsberg, 2002) have been used to determine forest productivity for a range of forest types, as well as assess site productivity and economic returns under different plantation management regimes and environmental conditions (Almeida et al., 2004a; Almeida et al., 2004b; Amichev et al., 2011; Battaglia and Sands, 1998; Bryan et al., 2010a; Bryan et al., 2007a; Coops and Waring, 2001; Coops et al., 1998; Coops et al., 2005; Landsberg et al., 2001; Landsberg et al., 2003; Nightingale et al., 2008).

3PG models forest growth patterns on a monthly time scale and has become the default process-based model for forest management due to its simplicity and the fact that it is freely available (Sands, 2004).

The CSIRO Land and Water division has recently developed a new version of 3PG, named 3PG2, which includes improvements to the water balance estimates by incorporating daily rainfall data, as well as including variables for an understorey, site salinity and ambient CO_2 (Almeida et al., 2007; Polglase et al., 2008).

We used 3PG2 to estimate forest productivity (biomass yield) for a homogenous hardwood plantation (E. cladocalyx), a generic oil mallee species and a multi-species environmental plantation, based on climate data modelled using the ESOCLIM module of ANUCLIM for each of the four climate scenarios (S0, S1, S2, S3).

With an estimate of biomass generated the total value of carbon over a nominal time could be generated and was displayed as the Net Present Value (NPV) of carbon. This was calculated as the carbon dioxide equivalent sequestered (tonnes CO_2^{-e}/ha) multiplied by the carbon price minus the costs of establishing and maintaining carbon plantations using a discount rate of 7% over 64 years. The 64-year time is a nominal period deemed to be sufficient to provide a long-term projection and consistent with agricultural planning horizons and the expected carbon sequestration life of trees if they are part of the production system. Similarly, the 7% discount rate is nominal and consistent with usual accounting practice for agricultural and natural resource accounting.

Modelling forest growth with 3PG2

3PG2 models forest growth patterns based on the absorption of photosynthetically active radiation (PAR) and constrained by environmental variables including temperature, vapour pressure deficit (VPD), frost, available soil water (ASW), stand age and site nutritional status. The spatial version of 3PG2 (Coops et al., 1998) can model productivity using raster data representing spatial variance in soil characteristics and climate for an area. The basic structure of 3PG2 simulation modelling is illustrated in Figure 14.

3PG2 requires a number of input data sets:

- monthly climate data including total solar radiation, total rainfall, average temperature, average vapour pressure deficit (VPD), rain days per month and frost days per month
- soil texture and soil depth
- individual species parameters.

Long-term average monthly climate data were sourced from ESOCLIM (Houlder et al., 1999). The specific layers used in this modelling were maximum temperature, minimum temperature, rainfall, rain days and solar radiation. The baseline climate scenario (S0) was based on the 2006 climate data remaining constant for a 64 year period (2006 to 2070). Data for the climate change scenarios [mild (S1), moderate (S2), and severe (S3)

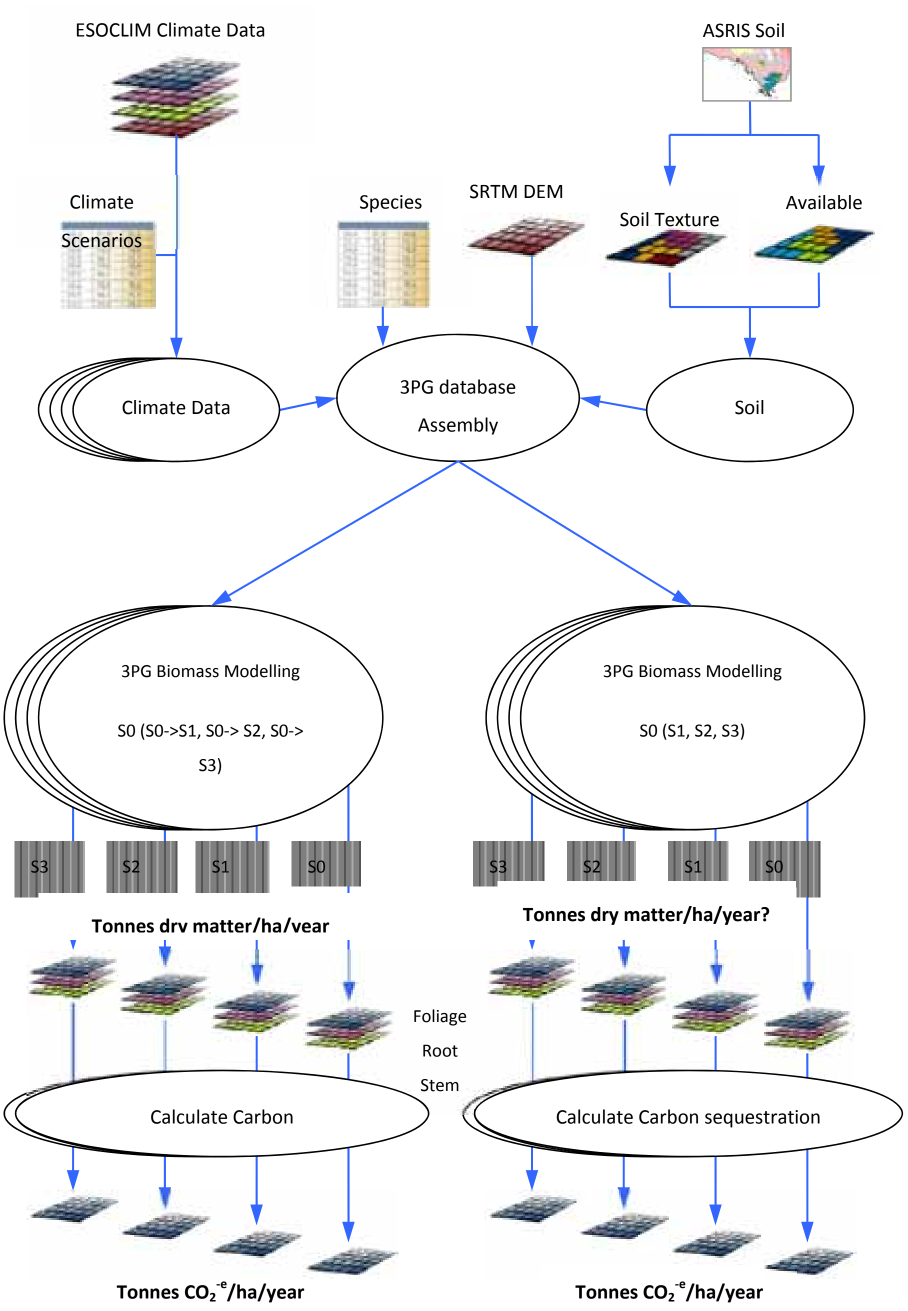


Figure 14: Structure of 3PG2 biomass and carbon sequestration simulation.

warming/drying] were created by altering the baseline temperature and rainfall records in annual increments from 2006 to 2070. Solar radiation for the initial year was kept constant for each year under the three climate change scenarios, and the amount of frost days was set to zero.

A raster layer describing the soil type was extracted from the Australian Soil Resource Information System (ASRIS) (ASRIS, 2007). This involved combining three different individual databases at three different scales. The finest scale soil information – ASRIS soil level 5 (≤1:100 000) – covered the largest area (4,603,900 ha) but in order to cover the whole study area, databases with broader spatial scales were also included. These included the ASRIS soil level 4 (~1:250 000) covering 111,500 ha of the study area and ASRIS soil level 3 (~1:1 000 000) covering 371,100 ha.

An example of the soil map produced for the Eyre Peninsula is shown in Figure 15. A soil depth raster layer was obtained from Polglase et al. (2008) who used a soil terrain analysis technique (MrVBF, Gallant and Dowling 2003) to estimate effective soil depth for soils that had a survey recorded depth of greater than 2 metres.

The original species parameters for 3PG were obtained from continued observations and measurements of forests and plantations (Landsberg et al., 2001). Almeida et al. (2007) recalibrated the original parameter files for use with 3PG2 in order to incorporate the enhanced growth and water balance components of the new model.

Hardwood plantations were modelled using a species parameter file for *E. cladocalyx*. *E. cladocalyx* is endemic to the Eyre Peninsula and Flinders Ranges regions and is among the most common species used in commercial plantations in southern Australia, with the potential to store large amounts of carbon through reafforestation over the long-term (Almeida et al., 2007; Polglase et al., 2008). Species parameter files were calibrated for *E. cladocalyx* (Almeida et al., 2007; Paul et al., 2007). Adjustments were also made to the maximum stem mass per tree at 1000 trees per hectare, and the maximum age in order to model the productivity of carbon plantations over the 65-year period from 2006 to 2070.

Environmental plantings offer additional benefits over single species plantations including support for biodiversity, resilience to climate change and lower ongoing management costs (Bryan et al., 2007a; Polglase et al., 2008; Polglase et al., 2011). There is also the potential that in some areas, environmental plantations may store more carbon than single species plantations over long periods of time (Polglase et al., 2008; Polglase et al., 2011).

The calibration of species parameters for the environmental plantings was based on a mixture of eucalypts, shrubs and acacias (Almeida et al., 2007; England et al., 2006; Polglase et al., 2008). Species parameters were recalibrated manually by adjusting parameters related to species sensitivity to environmental factors, age, and conductance. Due to limited calibration data availability for the Eyre Peninsula, environmental plantings parameters were calibrated using 36 measurements from low to moderate rainfall areas within the Eyre Peninsula and South Australian Murray-Darling Basin NRM regions. Environmental planting models were run over the same climate conditions and over the same period as *E. cladocalyx* (i.e. 2006 to 2070).

Drought-resistant mallee species have the potential to be useful in the production of bioenergy from biomass and eucalyptus oil when coppiced on short rotation under dry conditions (Bryan et al., 2010a; Wildy et al., 2004). Parameters for oil mallee were based on the average of *E. Loxophleba lissophloia, E. polybractea* and *E. kocchii* (Polglase et al., 2008), and used to represent the productivity of a typical oil mallee over a 6-year rotation.

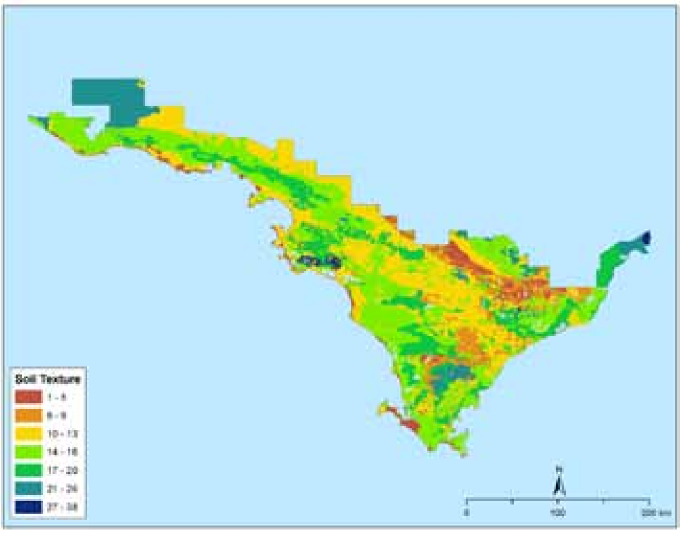


Figure 15: Soil texture in the Eyre Peninsula for 3PG2 modelling.

Oil mallee parameters used were calibrated by Polglase et al. (2008).

Site parameter files were used to define the study area and modelling scenario. The start age of each species was set to one year with assumed values set for initial stem mass, foliage mass and root mass, and the initial number of stems per hectare was set to 1,000 for each modelled species. For the purpose of this study, understorey and pasture components were not modelled because biomass is only simulated for the understorey (Polglase et al., 2008). As 3PG2 does not currently account for the effect of atmospheric CO_2, ambient CO_2 was set to a default value of 350 ppm for each species under each climate change scenario.

The selected outputs from 3PG2 were the total biomass of forest trees per hectare (tonnes dry matter/ha), allocated between foliage, root and stem. Gifford (2000) suggests that a figure of 50±2%C is a suitable figure to represent the percentage of carbon stored in the total biomass by weight. A multiplication factor (3.67) was then used to determine the total amount of CO_2 stored in the carbon (Standards Australia, 2002). Thus, 3PG2 estimates of biomass were converted to CO_2 using the formula:

$$E = \frac{(W_F + W_R + W_S) \times 3.67}{2}$$

Where:

E = Carbon sequestered (tonnes CO_2 –e/ha)

WF = Foliage biomass from 3PG2 (tonnes dry matter/ha)

WR = Root biomass from 3PG2 (tonnes dry matter/ha)

WS = Stem biomass from 3PG2 (tonnes dry matter/ha)

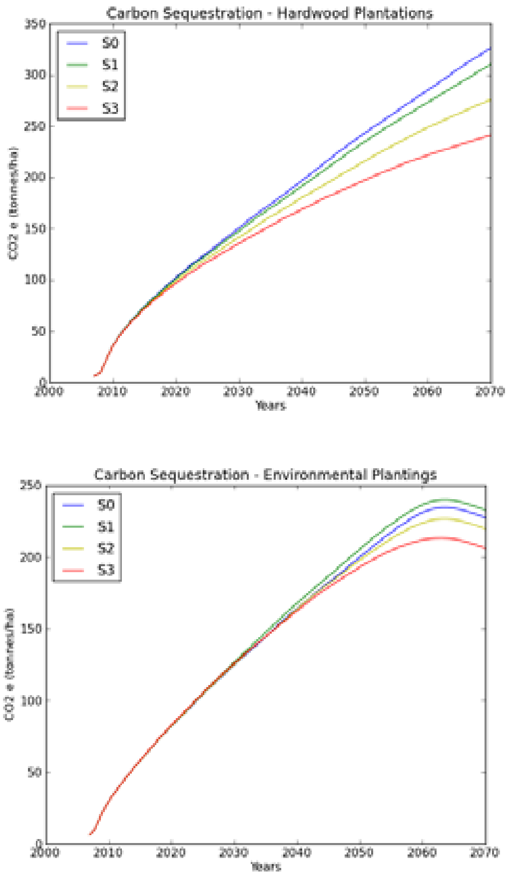
Carbon sequestration and forest growth in Eyre Peninsula

The total carbon sequestration for the modelled hardwood plantations in the Eyre Peninsula was around 326 tonnes/ha, averaging out to a carbon sequestration rate of about 5 tonnes CO_2^{-e}/ha/year over the 64-year simulation under the baseline climate scenario (Figure 16a). Across the study area sequestration rates varied significantly (Figure 17), ranging from 1.4 tonnes CO_2^{-e}/ha/year in the drier areas up to around 10 tonnes CO_2^{-e}/ha/year in higher rainfall regions.

Carbon sequestration rates of hardwood plantations decreased under warmer and drier conditions. The average annual sequestration rate over the 64-year simulation reduced by about 4.8% under climate change scenario S1, 15.3% under S2 and 26% under S3. Low productivity areas were affected significantly, with sequestration rates decreasing by up to 71% under severe climate change. The wetter, more-productive regions experienced a less-significant reduction in carbon sequestration, with sequestration rates decreasing by up to 2.4% under severe climate change (Figure 17).

Modelling of environmental plantings displayed an average sequestration rate of around 4.4 CO_2^{-e}/ha/year up to year 54, where the stand matures and the average carbon sequestration rate starts decreasing. In comparison to hardwood plantations, carbon sequestration estimates for environmental plantations

Figure 16: (a) Temporal dynamics and variation in carbon sequestration for hardwood plantations (top) and (b) environmental plantings (bottom) in the Eyre Peninsula under the baseline and climate change scenarios.



were lower, with a total sequestration of around 227 tonnes/ha under the baseline climate scenario. This averaged out to an annual carbon sequestration rate of approximately 3.5 tonnes CO_2^{-e}/ha/year over the 64 year simulation (Figure 16b). Spatially, sequestration rates varied significantly across the study area (Figure 17), ranging from 0.9 tonnes CO_2^{-e}/ha/year in the arid regions up to around 12.5 tonnes CO_2^{-e}/ha/year in the higher rainfall regions.

Average annual carbon sequestration rates of environmental plantings increased by 2.3% under climate change scenario S1, and then decreased by around 3.5% under S2 and 9.4% under S3. Overall, environmental plantings were more resilient to climate change scenarios than hardwood plantations. As with the hardwood plantations, low productivity areas experienced a significant decrease in carbon sequestration rates, with sequestration rates decreasing by up to 54.3% under severe climate change. More productive regions experienced an increase in carbon sequestration rates under each climate change scenario, with an increase in carbon sequestration rates of up to 2.4% under climate change scenario S3.

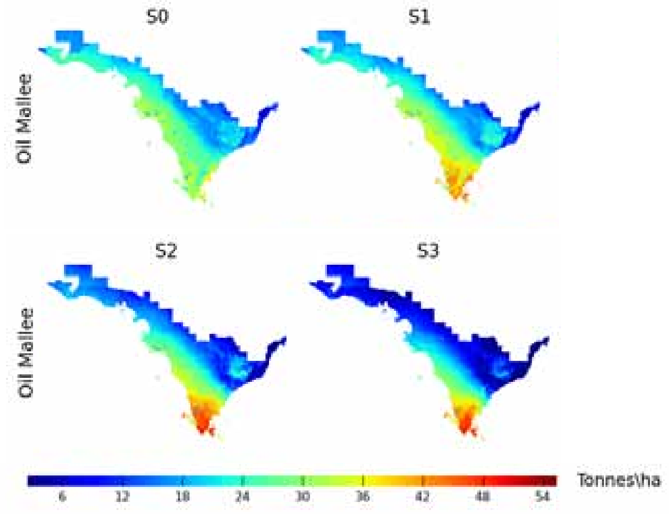
$3PG_2$ modelling of oil mallee for biomass production under the baseline climate displayed an average total dry weight of 22.6 tonnes per hectare, averaging out to an annual growth rate of around 3.8 tonnes per year over the first 6 years before harvest. Across the study area, growth rates ranged from less than a tonne per year (0.7 tonnes/ha/year) in lower rainfall areas, to 6.7 tonnes per year in higher rainfall areas (Figure 18).

Average growth rates for oil mallee increased under climate change scenario S1 by 4.7%, but decreased by 10.8% under S2 and 34.5% under S3. In lower rainfall areas, growth rates decreased by up to 41% under the severe climate change scenario. In contrast, growth rates increased in high rainfall areas, with increases of 18.6%, 29.6% and 37.8% observed for S1, S2 and S3 respectively.

Carbon sequestration and forest growth in the Lower Murray

Total carbon sequestration of hardwood plantations across the Lower Murray region ranged from 3.7 tonnes/

Figure 18: Productivity of oil mallee in the Eyre Peninsula after 64 years (t/ha).



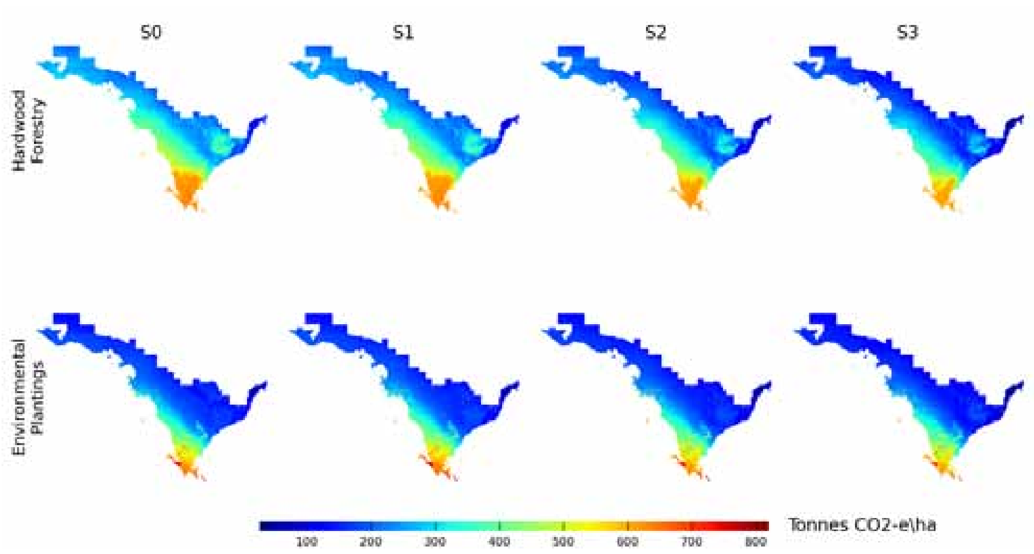


Figure 17: Estimated CO_2 sequestration potential of hardwood plantations and environmental plantings in the Eyre Peninsula after 64 years (t/ha).

ha to 689 tonnes per hectare (Figure 19), with an average total carbon sequestration of 318 tonnes per hectare. This translates to an average annual sequestration rate of around 5 tonnes CO_2-e/ha/year (Figure 20a).

Carbon sequestration rates of hardwood plantations decreased across the study area under each of the climate change scenarios, with the average sequestration rate decreasing by 8.3% under S1, 23% under S2 and 37.2% under S3. Sequestration rates remained stable in higher rainfall areas, with potential carbon sequestration decreasing by only 0.7% under severe climate change. Areas where sequestration rates were low under the baseline climate saw no change under each of the climate change scenarios.

Modelling of environmental plantings presented a total carbon sequestration amount of 290 tonnes/hectare on average across the study area, translating to an annual sequestration rate of 4.5 tonnes CO_2-e/ha/year (Figure 20b). Sequestration rates varied across the study area, with sequestration rates of up to around 10 tonnes CO_2-e/ha/year in more productive areas, to 0.1 tonnes CO_2-e/ha/year in the arid regions.

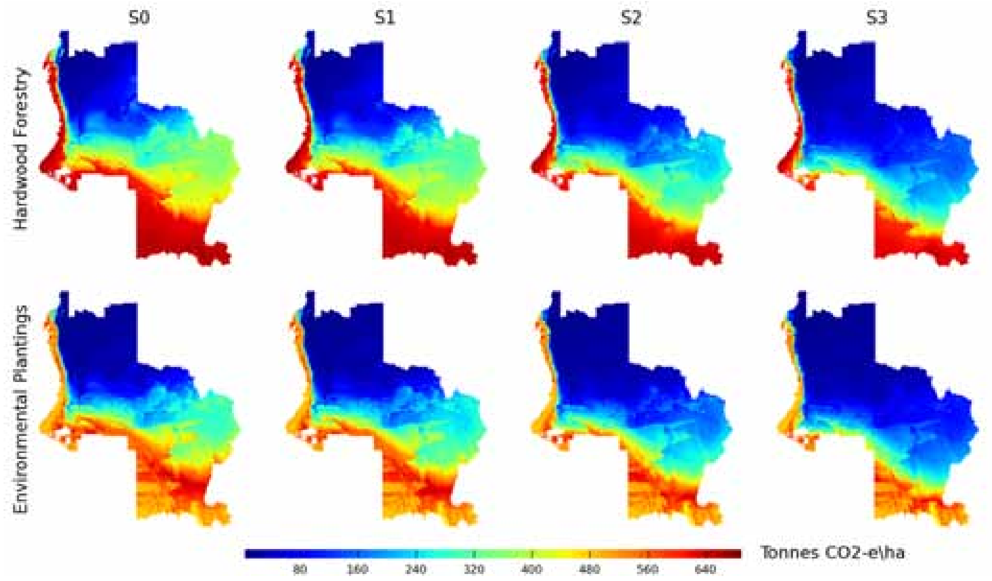
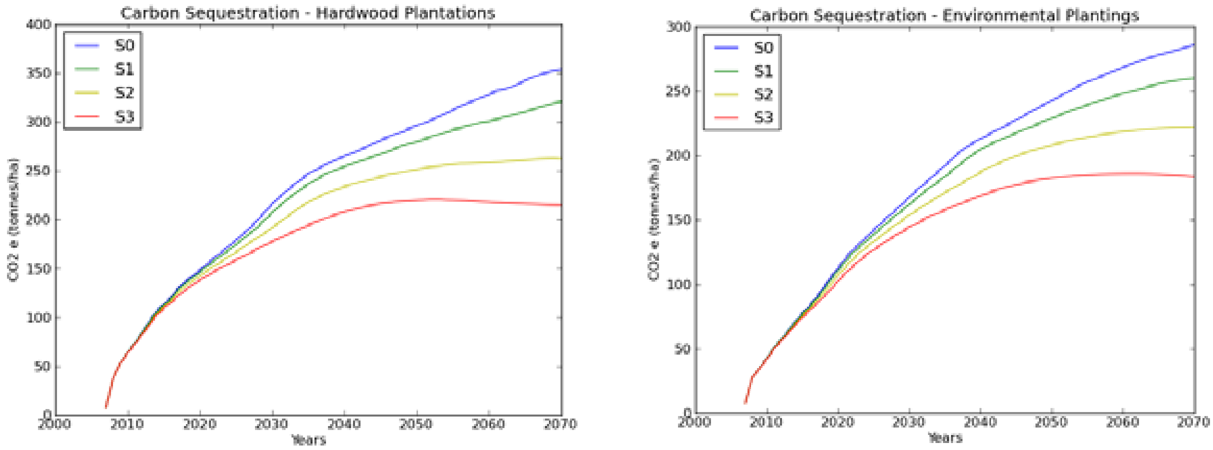


Figure 19: Estimated CO_2 sequestration potential of hardwood plantations and environmental plantings in the Lower Murray after 64 years (t/ha).

Figure 20: (a) Temporal dynamics and variation in carbon sequestration for hardwood plantations (top) and (b) environmental plantings (bottom) in the Lower Murray under the baseline and climate change scenarios.

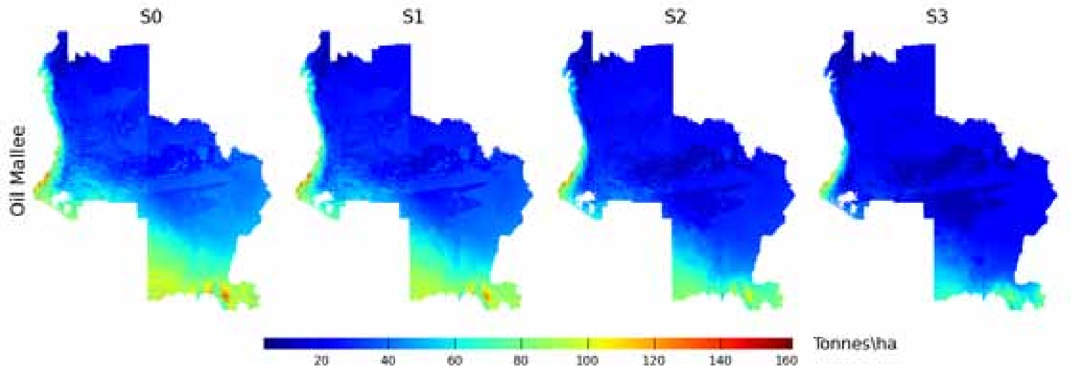


Average annual sequestration rates decreased by nearly 9% under climate change scenario S1, 23% under S2 and 37% under S3. Sequestration rates remained relatively stable in higher production areas with carbon sequestration decreasing by up to 2% under the impact of severe climate change. In arid areas there was no change in carbon sequestration rates.

3PG$_2$ modelling of oil mallee for biomass production displayed an average total dry weight of 43.7 tonnes per hectare, averaging to an annual growth rate of around 7.3 tonnes per year over the first six years before harvest. Across the study area, growth rates ranged from less than a tonne per year (0.4 tonnes/ha/year) in lower rainfall areas, up to around 26 tonnes per year in higher rainfall areas (Figure 21).

Average growth rates for oil mallee decreased by 13% under climate change scenario S1, 30.2% under S2 and 46% under S3. Growth rates in high production areas increased by up to 3.3% under S1 and 1.7% under S2, but decreased by as much as 6.7% under S3. There was no change observed in the minimum growth rates in low rainfall regions of the study area.

Figure 21: Productivity of oil mallee in the Lower Murray after 64 years (t/ha).



3.3 Phase 3 – Implement the tool

Here we outline a software tool which puts landscape futures information into the hands of natural resource managers and decision-makers for closer investigation and analysis. The Landscape Futures Analysis Tool (LFAT) has been developed for the two project partner NRM regions.

Both Eyre Peninsula (EP) and South Australian Murray-Darling Basin (SAMDB) regions are dominated by agricultural land use; both are subject to ongoing environmental degradation; and both will be affected by external drivers such as climate change, policy (e.g. carbon price), and commodity prices.

In the initial version, LFAT includes demonstration applications focussing on four key NRM planning issues (referred to as Planning Modules). It will enable natural resource managers and planners to explore potential options for managing these issues given future climate, policy, and economic uncertainties. The four NRM planning modules are:

- agricultural production—managing food and fibre production
- conserving biodiversity—managing remnants and restoring corridors
- managing weeds—targeted monitoring of future invasion risk hotspots
- storing carbon—finding the best places for carbon plantations.

Each of these four issues illustrates different approaches to the application of landscape futures analysis.

- **Agricultural production** uses a systems modelling approach which predicts levels of production under climate change scenarios and then applies economic models to explore outcomes from different cost and price scenarios.
- **Conserving biodiversity** uses an economic cost-benefit type approach to inform policy such as targeted incentive schemes under climate change.
- **Managing weeds** uses a risk analysis framework to identify areas at high risk of both agricultural and ecological weed invasion under climate change for targeting monitoring and management efforts.
- **Storing carbon** uses a landscape planning approach to identify areas that are suitable (and unsuitable) for carbon plantations subject to satisfying several specific criteria.

Each of the four issues is implemented as a separate Planning Module. LFAT is extensible, as interfaces can be added to address other specific NRM planning issues as necessary.

Regional NRM agencies typically have limited access to Geographic Information Systems and limited capacity for their effective use. Therefore, we proposed a web-based solution to communicate information on landscape futures that is described in detail below.

3.3.1 Scenarios

The software includes a range of scenarios (listed below) that allow for the exploration of different production and market conditions.

- There are four climate scenarios that will interact with other environmental variables included in the vegetation models that will affect the estimated productivity of the land.
- There are also four cost and price scenarios that will affect the economic viability of different production systems. These are provided as multipliers relative to 2012 commodity prices.
- There are four carbon price scenarios which are provided as absolute dollar numbers.

These different primary variables allow the user to explore the effect of market conditions as well as primary production. For example, high commodity prices and low production costs may maintain the economic viability of agricultural production despite declining yields associated with a warmer drier climate.

The scenarios provided in the software are listed below:

- Climate scenarios (as described previously, p. 28):
  - S0 Baseline: Historical climate
  - S1 Mild warming/drying: +1 degree, 5% reduction in rainfall and 480ppm CO2
  - S2 Moderate warming/drying: +2 degrees, 15% reduction in rainfall and 550ppm CO2
  - S3 Severe warming/drying: +4 degrees, 25% reduction in rainfall and 750ppm CO2

- Agricultural commodity price scenarios are considered: 0.5x, 1.0x, 1.5x, and 2.0x the Australian average prices for wheat, wool, and sheep meat for the period 2001-11.
- Four production cost scenarios are considered: 0.5x, 1.0x, 1.5x, and 2.0x the average costs for different production systems from gross margin handbooks and ABARES farm survey results within the period 2005 to 2010. (http://www.daff.gov.au/abares/publications_remote_content/publication_series/farm_survey_results)
- Four carbon price scenarios are considered: 15, 30, 45 and 60 \$/t CO_2-e.

This results in up to 256 possible combinations of climate, commodity price, production cost and carbon price.

3.3.2 NRM planning issues and interfaces

Below is an explanation of the four NRM planning module interfaces (agricultural production, conservation biology, managing weeds and storing carbon) and a description of how they can be used in natural resource planning. Each of these interfaces can be used independently to identify and analyse different policy and planning options. However, there is also significant interoperability between the modules as many of these planning issues are related. Thus, in identifying suitable areas for conservation, a user has the opportunity to consider, for example, the agricultural productivity of different areas, or the potential impact of different ecological weeds.

There is also much underlying data that is relevant across all applications. For example; satellite imagery or aerial photography, remnant vegetation patches, land use (agriculture, protected areas, etc), ancillary data (roads, towns, etc) or water bodies (rivers, etc), floodplain, irrigated agriculture, dry land agriculture (cleared land), land tenure (public/private). This data can be visualised and explored within all of the different planning interfaces and may be central to final planning decisions.

Agricultural production — managing food and fibre production

This interface supports spatial planning for food and fibre production enabling the exploration of production limits under different climate and market scenarios. It provides a systems approach to spatially explore and understand agricultural production and the potential effects of climate change on yields. The software also enables the exploration of variations in the costs of production and commodity price.

The interaction of warmer and dryer climates with increased carbon dioxide concentrations will have spatially variable effects on production yields as illustrated in Figure 6.

Many agricultural districts within a region are likely to experience declining productivity due to hotter conditions and reduced rainfall. However, some districts may experience increased yields due to improved growing conditions. For example, in high rainfall areas, water may remain non-limiting for agricultural production and the combination of higher temperatures and increased carbon dioxide concentrations in the atmosphere will encourage increased yields.

Irrespective of changing yields, economic conditions can significantly affect the viability of different land uses and the inclusion of cost and price scenarios allows the user to explore this. Our systems approach provides estimates of yield that feed into economic models such that the user can understand how the changing production levels might interact with changing market conditions. Thus, marginal declines in production can easily be mitigated by lower input costs and or higher commodity prices. Alternatively, increased productivity might be offset by increasing costs, reducing the economic viability of different agricultural systems. Importantly, all of these combinations are explored spatially.

Within agricultural production alone, there are 64 combinations of climate, cost and price scenarios that enable a detailed exploration of climate and market conditions. Thus, the user can develop a much more informed understanding of the interactions within the different scenarios and how these are expressed spatially. There is also the opportunity for users to develop a greater sense of the sensitivity of the different driving variables as well as the response trends as climate and prices change.

Conserving biodiversity – managing remnants and restoring corridors

This interface supports spatial planning for the establishment of revegetation plantings and the management of remnant vegetation communities. The software enables consideration of biodiversity benefits under different climatic conditions as well as potential economic trade-offs from restoration and conservation actions under different climate conditions. This interface also enables the user to integrate landscape futures information with their own knowledge and experience to evaluate options for managing remnants and establishing areas of revegetation.

This interface enables the user to examine the projected distributions of 300-400 individual native species in both NRM regions under different climate scenarios. They can bring up single or multiple species distributions and explore how they are projected to migrate under climate change. Importantly, the user can also examine a landscape prioritisation developed from combining all of these individual species to explore how projected conservation priorities are likely to move under climate change. This conservation prioritisation identifies areas in the landscape that are a priority for vulnerable species, or those species that are adversely affected by climate change.

A typical goal within this module would be to identify areas for management and restoration that minimise the loss to agricultural production, or are achievable within budget or policy restraints. In considering these investment and allocation options, a user can also explore the various ecological, economic and policy trade-offs under potential climate change scenarios. For example, a user may wish to understand the potential cost of different conservation options such as increasing links between existing conservation areas. They could use this module to identify and maximise the biodiversity benefits of different corridor options but also examine the potential costs from lost agricultural production over the different options.

Managing weeds – targeted monitoring of future invasion risk hotspots

This interface supports the targeting of pest plant activities and weed management, including weeds that affect high-value agricultural enterprises (economic weeds) and native ecosystems (ecological weeds). A particular focus of this interface is the identification of areas that become potential hotspots for weed invasion risk under climate change. Individual weed species can be analysed separately or hotspots involving multiple species can be developed.

We take a risk mitigation approach where we combine spatial layers of the likelihood with the consequence of weed invasion.

- Likelihood is derived from modelled weed species habitat suitability and dispersal layers such that the greater the suitability of weed habitat under climate change nearer to known locations, the greater the likelihood of invasion (Crossman et al. 2011).
- Consequence is derived from the potential value-at-risk from weed invasion. For agricultural weeds, the highest consequences are in the high-economic-return agricultural areas.

For ecological weeds, the highest consequences are in those areas of high-value remnant patches or those cleared areas that are of high priority for environmental plantings and ecological restoration. The risk layer is multiplicative such that high-risk areas are those that have both a high likelihood and a high consequence.

This interface can enable regional natural resource managers to target investment and effort in specific areas in order to address the threat of invasive species to both agricultural and native ecosystems under future climate change. This will enable the user to target monitoring, management, extension, and the provision of specific and targeted information to local landholders, farmer groups, community groups, and conservation agencies.

Examples of screen downloads from the LFAT

Figure 22: Opening screen for user login and registration.

Figure 23: Select NRM region of interest (Eyre Peninsula in this case) showing town locations and roads.

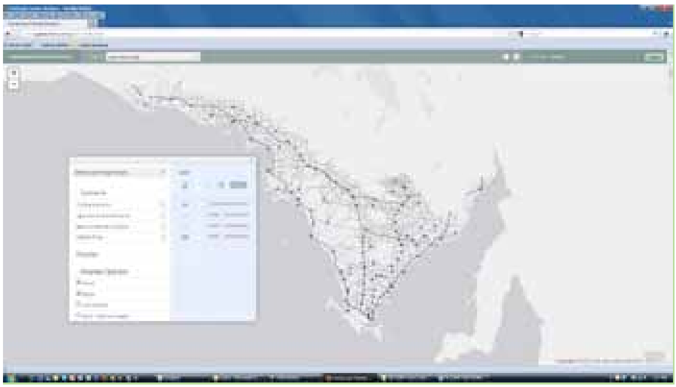


Figure 24: Select the Planning Module of interest (carbon sequestration in this case). The information layer choices are shown in the content pallette on the left and the layer information window on the right.

Figure 25: Select an output variable from the list (carbon value in this case) associated with the Scenario case. The information for the display layer is in the right hand window.

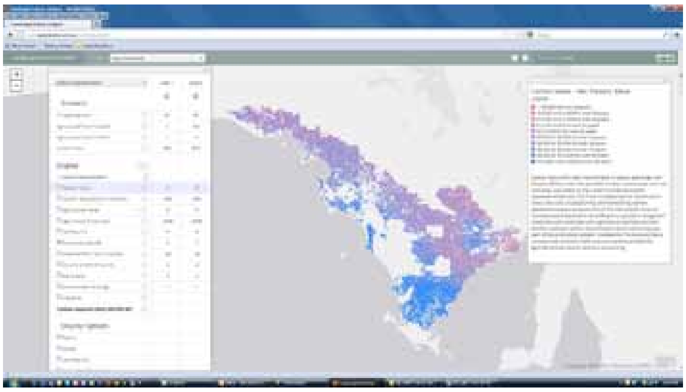
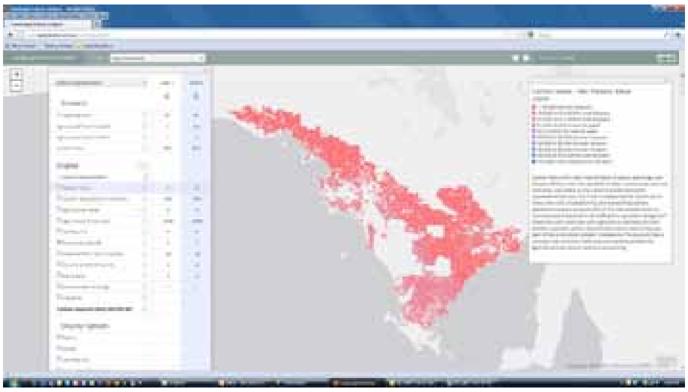


Figure 26: Choose a second case (in this case an extreme climate and price scenario) to enable quick visual comparison between the cases.



Storing carbon – finding the best places for carbon plantations

This planning module interface supports spatial planning for the reforestation of carbon plantations—monocultures of fast-growing Eucalyptus species for the sequestration of carbon in biomass. This interface takes a planning approach akin to the traffic light approach developed for planning the reconfiguration of irrigation districts (Crossman et al. 2010).

Response surfaces of modelled tree growth under the different potential climate change scenarios allow the user to identify areas in the landscape that are suitable (or not) for carbon plantations. That is, areas of high productivity, where the carbon sequestration benefits from tree plantings would be maximised, and areas of low productivity, where the sequestration benefits would be marginal.

Within this analysis there are a range of other data sets and information that may be relevant in understanding the various trade-offs associated with different land use options. For example, the user can incorporate queries about potential agricultural production and related economic potential of the land under different climate change, cost and price scenarios.

Alternatively, users may want to identify areas that satisfy some combination of being privately-owned, with higher carbon sequestration potential, are at risk of wind erosion, do not affect water resources, are not prime agricultural land, do not preclude future restoration in high biodiversity priority areas, have significant economic potential, and do all this under a range of possible climate futures.

Thus, in a typical work flow, additional datasets are available and may be considered in the analysis. This interface also enables the user to integrate landscape futures information with their own knowledge and experience to evaluate options for locating carbon plantations.

3.3.3 Interface features and functionality

The objective of LFAT is to provide a platform to facilitate the delivery of derived geographical data to be accessed by employees in the Eyre Peninsula and South Australian Murray Darling Basin Natural Resources Management agencies. As such, the interface provides basic GIS functionality as well as the integration of landscape futures information as described above.

This GIS functionality allows for the loading and display of a range of spatial layers including primary datasets and the derived landscape futures information (discussed above). However, once displayed there are also a series of standard GIS tools that allow for the various datasets to be explored and analysed to extract useful information. These tools include: panning and zooming which allows for data examination at different geographic scales and extents.

There is an identification tool that facilitates data queries so that different elements in the scene can be identified and their attributes listed. A selection tool allows for individual elements to be selected and highlighted, and multiple elements to be grouped together and for their attributes to be summarised. There is also a dynamic buffer tool that enables the creation of distance buffers around points of interest so that elements within a certain distance can be identified and attributes summarised.

There are a range of export and reporting functions that allow outputs to be taken from the computer and software domain and circulated as the user requires. Maps can be exported at suitable scales and resolutions and results can be tabulated for communication and reporting.

The LFAT User Manual provides an overview of the file structure with descriptions for each set of layers and the modelling processes involved. This provides users with an understanding of where underlying data has been sourced and how the final layers have been created. If further validation is required, the data layers, underlying datasets and metadata can be made available upon request.

3.4 Phase 4 – Promote and publish

Much of the initial promotion was carried out during the consultation phase with the staff and some community members of the two NRM regions. Every opportunity was taken to interact with other NRM regions and with the responsible state agencies (DWLBC, DEWNR, PIRSA) during the project development.

As the LFAT became operational an awareness brochure was developed. This brief is at Attachment 19.

Discussion of the results and outputs

4

4.1 Reflections on the learning from the previous planning process

Previous reviews of Australian NRM planning and implementation processes have identified significant limitations in the success of well-intentioned actions.

A comprehensive review by Williams et al. (2008a) concluded that "the current Australian NRM (is a) ritual-driven approach". This conclusion was reached after review of the documented development of NRM from the late 1980s. Essentially, the evidence is that the programs have had quite limited success in achieving the often ambitious goals. This was summarised as "there was a lack of a strategic investment framework, long time frames for progress in decision-making and administrative processes, small-scale nature of most projects and a focus on on-ground outcomes. The scope of community development and resource condition improvement has been limited due to these and other shortcomings."

The responses recorded from the consultation with the NRM Boards and staff, as indicated in Section 6.1.2, are consistent with this ongoing trend in limited effectiveness of current planning and implementation. This is despite the regional planning being largely directed by regulatory requirements from the responsible State agency. These processes and requirements have presumably been informed by current best practice.

Hence there is previous and current evidence that continuation of existing planning and implementation practices will not generate outcomes that are as good as they could or should be. We should take heed of the quote from Albert Einstein: "We can't solve problems by using the same kind of thinking we used when we created them." This project tried a different approach. This was the rationale for experimenting with the envisioning process as the information and analyses needs of the regions were identified.

4.2 The role of envisioning in progressing from aspiration to implementation

Two points stand out when considering the incorporation of science into NRM planning:

- it is not easy
- it is increasingly divorced from implementation.

Over years of engagement with NRM Boards, researchers have noted that it is not easy to gain traction for science that will benefit the community. This experience is not unique and reflects a broader trend since WWII, where scientists have moved from a position as experts offering valued technical advice (often in a production or industrial setting) to 'expert-citizens' partnering with 'citizen-experts' to generate improved outcomes for the greater good – and where process is at least as important as desired outputs.

In many cases, overly bureaucratic approaches and an administrative requirement to 'tick the box' take the passion from planning and leave stakeholders disenfranchised. In some cases, regional planners have come to see their task as simply completing a 'planning' process (largely divorced from implementation) that meets the requirements of regulation or 'the Minister'.

There is a tendency for NRM Boards and key stakeholders to become familiar with working with each other and preferring it to remain this way – in a sense 'protecting' their local communities from engaging with the hard facts or in the hard decisions. This 'protection' allows the protected to avoid the adaptive work that is required to enable new ways of seeing and doing emerge.

There is also a more fundamental problem – the linear or Newtonian structure of plans and their inability to deal with complexity and uncertainty. Current accepted practice for planning identifies a pathway of milestones leading to specific strategic goals that reflect a succinct statement of 'the vision'. This assumes that we can accurately predict the outcome, achieve a specific result over long time frames and tell people what to do in order to implement the plan. This linear process breaks the plan down into discreet parts, each to be delivered by a different part of the organisation. The assumption being that the whole is merely the sum of the parts.

The assumptions underpinning the conventional strategic planning process are fundamentally at odds with the behaviour of complex adaptive systems, which are inherently unpredictable over the longer term and subject to indirect and non-linear causation. We propose a new role for vision as a 'cradle' for the entire process of planning and implementation. It constantly informs and is informed by the process, as communities learn more about how to bring their desired future into being.

The vision we are describing is a values-rich story that continues to evolve as people experience their emerging future and reprioritise their own values over time. We perceive visions as being proactive and scenarios as being more reactive in stance. 'Envisioning' has been used to achieve that and to supplement other planning and consultation processes.

The 'envisioning process' is a four-stage process (detailed in the User's Guide), involving:

- a shared vision
- core messages
- indicators
- action learning, with LFAT scenarios.

This envisioning process assumes:

- non-linear cause and effect and offers a framework within which experiments may be undertaken in order to learn about the behaviour of the system and how best to influence it
- inherent unpredictability, especially over longer time frames and larger spatial areas; it avoids setting specific targets or SMART goals, and instead employs qualitative lead-indicators
- agents within the system are unable to control the system, but can influence it by learning how to work with the powerful self-organising forces already at work within it
- from the often unrecognised self-organising comes emergent properties that are specific to the system
- starting points ('sensitivity to initial conditions') and history ('path dependence') are important and different in each NRM region, so the process needs to respond to these differences.

The envisioning process commences with the development of a shared vision through a discussion about 'how we really want to experience the landscape'. It places participants, and their values, at the centre of the process to make their own meaning and exercise their own leadership to respond to climate change in ways that make sense to them.

It is critical that the regional planning community develops the capacity to keep the shared vision present, both as a means of orientation in a complex environment and as a guide to future action. The vision also has an important role to play when using LFAT. The vision:

- provides a focus for investigations, shaping the types of queries to be explored
- helps set boundaries to contain the breadth of scenarios considered – which is important given the capacity of LFAT to generate innumerable options
- remains 'alive' throughout the use and application of LFAT, helping ensure that implementation leads to the realisation of community expectations.

The vision enables the best science (through the LFA) and expert knowledge from other sources to be integrated in making decisions about the future shape of the landscape. From our experience, and given that a working example of the LFAT using data sets from SAMDB and EP NRM regions is now available, we suggest introducing LFAT early in the process; raising awareness regarding what LFAT is capable of and how it might be used to aid decision making.

Experience with the envisioning and planning process indicates that everyone appears to be short of time and yet we know that time is required to adapt. It is apparent that if we are to make the transformational changes required, a commitment is needed to devote time to the process, to thinking and to learning. The process must be allowed to dictate the time, rather than the time dictating the process.

Ironically, our team suffered from a lack of a clear and shared vision for the project. This was largely a result of our interdisciplinary composition that meant that it took time for us to develop the necessary shared language and understandings, and we lacked the time in the early stages for internal communication. We learned from each other as we progressed and the principal researcher held the vision for the team. The feedback and evaluation suggests the team functioned well with regard to other facets.

Much energy was expended trying to find a 'hook' to motivate the NRM boards to engage with this process – they believed that they had nothing more to learn about the science and art of planning and were really most interested in the LFAT. This highlights the need to assess willingness to change, or dissatisfaction with the status quo, before doing anything else – not everyone will be willing at the same time or in the same way.

Envisioning has the capacity to identify common ground among diverse stakeholders and to build relationships. This 'common ground' is important in terms of group dynamics and developing a willingness to collaborate, not only between regional participants, but also with practitioners contributing expert knowledge – science, farming experience, and indigenous wisdom. It encompasses values such as transparency, participation, respect, honouring different kinds of knowledge (local, indigenous and scientific) and autonomy to respond to complex bio-socio-economic environments. Many participants do not experience planning in this way.

The process recommended also provides for capacity building in the form of exposure to complexity theory and its implications for management and planning. This will influence the 'structure of the system', as it raises awareness of existing mental models and deeply held beliefs and assumptions about how the world operates.

Core principles to support the process are:

1. Envisioning operates as a bridge between science and decision making that can integrate more than just 'the science' – it can bring together and integrate the contribution from multiple stakeholders with diverse perspectives, and bring to bear 'wisdom' from various sources.
2. One size doesn't fit all – we must be able to adapt the process to local variations in the social, political, agricultural and natural landscape. Even the dominant local land use has an effect on the dynamics of regional planning, e.g. large cropping and grazing holdings versus smaller horticultural holdings.
3. The process must reconnect the notions of planning and implementation. Planning must be seen as part of an integrated process, directed to action on the ground, rather than an end in itself, ticking the regulatory box.
4. The role that time plays must be understood and respected. This was the least anticipated but, perhaps, most important principle to emerge from our work. The adaptive work demanded by the shift to a fundamentally different way of understanding planning and implementation in a complex socio-political environment requires time, and a willingness to devote time. It does not happen overnight. Adaptive work can be uncomfortable and lack of time can be used as a method of avoiding the adaptive work required.

Time is also required to develop the capacity within NRM boards and their communities to exercise leadership for change.

The existing structure of the broader NRM system and its impact on planning in the regions cannot be overlooked – it is all interconnected. The organisational structure, hierarchy, locus of control, and management paradigm all affect the ability of local communities to bring their vision into being and make the changes required. Change at the regional level requires thoughtful and supportive changes in management. This includes sensitivity to the balance between state-based policy making and autonomous regional planning and implementation.

For more information on the need and justification for an envisioning process, see Appendix 2.

4.3 Agricultural productivity modelling

The potential impacts of climate change on wheat yields on the Eyre Peninsula relied on maping yield outputs from a one-dimension crop simulation model to a two-dimensional space. Validation of both the mapping and simulated yield outputs was done in conjunction with expert knowledge provided by local growers and agricultural consultants. Where possible, further validation came through the use of annual yield data for specific soil characterisations, and at a larger sub-regional scale through published yield estimates.

Applying the S1 Climate Change (CC) scenario across the Eyre Peninsula gives an indication of what potential climate could be in the next ten years or later if significant mitigation efforts are undertaken globally. Results showed increases in wheat yield due to the increase in temperature and CO_2 level and limited reduction in rainfall across the identified low, medium and high rainfall zones.

Applying the S2 CC projections that could reflect a possible climate for 2030 or later if significant mitigation efforts are undertaken globally, showed reductions in average yields for the low rainfall zone regions. Differences in soil texture, a graduation from coarser to finer textures, showed an increase in yields for the coarser textured soil in the medium and high rainfall zones. There was variation in the impacts of the CC projections on yield across all rainfall zones.

Applying the S3 CC projection showed large yield reductions in the low rainfall area, especially on the finer textured soils. In medium rainfall zones, slight increases are recorded in yield on coarser textured soils but yield reductions (10-30%) were simulated across the finer soil types. In higher rainfall areas, similar simulated yield trends are apparent with yield increases (0-20%) simulated on coarser soils and yield reductions (0-20%) estimated on finer soil types.

The simulation of wheat yields over the three scenarios acts as a regional indicator for the impact of climate change on the region. The results showed that there are a variety of spatially varying impacts with the interactions of temperature and carbon dioxide increases, rainfall reductions and soil types within each climate defined region. The reduction in simulated yields in regions where rainfall is growth limiting outweigh the beneficial influence of increased temperature and carbon dioxide. In areas where rainfall is not growth limiting, simulated yields have been shown to increase – however, this is dependent on soil type.

While the soils mapping is quite coarse, regional predictions about the impacts of climate change are still relevant and informative allowing the targeting of climate change adaptation strategies to specific areas.

These results suggest that the opportunities and options available for climate change adaptation will vary across the Eyre Peninsula and within the low, medium and high rainfall regions. Opportunities within the region rest on the adoption of different management regimes or changes in land use on soil types identified as being negatively impacted by climate change.

The method identified in this project has used state of the art crop simulation modelling and soils mapping. Further improvements in this area are dependent on two issues.

- Increased empirical and geographic validation and subsequent refinement of simulation models for other crops which make up the Australian farming system is needed. The wheat model in this project was used because it has been tested in different climatic and geographic situations. Further testing is needed on the outputs of the model to ensure reasonable simulation confidence in any future modelling.
- The spatial distribution of the simulation results is limited by the current coarse resolution of the South Australian Soil's database. Further improvement in the spatial discrimination of soils at a higher resolution could be made through the application of remote sensing information.

4.4 The most vulnerable species and ecosystems

A climate change vulnerability framework was used to identify complementarity-based spatial conservation priorities.

- Plant species distribution models were used to identify and quantify the potential exposure of species to climate change.
- Those species most adversely affected were identified and attributed sensitivity weights from the projected changes in species' distributions under climate change.
- Finally, dispersal kernels were developed to quantify migration and dispersal ability, and provide a spatially explicit measure of adaptive capacity.

These three components (exposure, sensitivity and adaptive capacity) were combined into a landscape prioritisation that enabled the identification of high priority areas for conservation actions to reduce species vulnerability to climate change in the Eyre Peninsula (e.g. Figure 10) and Lower Murray (e.g. Figure 13) study areas. Complementarity-based landscape prioritisation using Zonation provided a minimum representation for each element (species) within the landscape (Ferrier and Wintle, 2009, Moilanen and Kujala, 2008a).

In both the Eyre Peninsula and Lower Murray regions, conservation priorities identified using the vulnerability framework were concentrated in more southern latitudes and higher altitudes (western priority areas). Typically, these areas have cooler and wetter climates and are generally projected to decrease in area with expected climate change. Similarly, the localised priority areas in the western districts of the Eyre Peninsula study area would typically have higher rainfall than the more inland central districts. The prioritisation of these areas (cooler, wetter) as important in reducing species vulnerability is consistent with the findings in other studies (Carvalho et al., 2010, Engler et al., 2011, Garzón et al., 2008, Thuiller et al., 2005).

These results are likely to have significant practical implications for conservation agencies, as they provide an effective, quantitative, repeatable and geographically transferable methodology to prioritise conservation and restoration under climate change. We advocate the use of this methodology, using the climate change vulnerability framework (exposure, sensitivity, and adaptive capacity), for targeting spatial conservation with the aim of reducing species vulnerability to climate change (see also Crossman et al., 2012, Summers et al., 2012). However, in advocating this methodology it is important that the assumptions and limitations of such an approach be recognised. For example, the use of a generic dispersal factor is a first approximation as is the analysis based on individual species rather than ecological communities. This is an area of research that needs much more development. Future modelling that incorporates more comprehensive adaptation processes can be included in the LFAT framework.

Despite the benefits for vulnerable species outlined here, our results show that targeting vulnerable species is not without costs. For example, there are trade-offs between a focus on sensitive species and levels of representation of other species (for a full discussion of these trade-offs see Summers et al., 2012). Nonetheless, these trade-offs highlight the importance of complementarity-based spatial prioritisation and represent a significant advance over previous studies (e.g. Crossman et al., 2012). These trade-offs are also the central theme in the various arguments around conservation triage (e.g. Wilson et al., 2010), including whether or not to undertake cost-effective allocation of conservation funds or whether to focus investment on priority species.

There are complex trade-offs in conservation and species prioritisation that have significant implications for restoration and conservation investment. Conservation actions such as land acquisition, pest species eradication, ecological restoration, and fencing and livestock removal are expensive and need to be spatially targeted to achieve efficient outcomes (Wilson et al., 2010). The methodology presented here provides a quantitative and repeatable means to prioritise conservation and restoration under climate change. The methodology minimises the trade-off, maximises representation of all species, and ensures the prioritisation of areas that are important for vulnerable species.

4.5 Carbon sequestration and plantation growth

$3PG_2$ was used to model the biomass productivity of a hardwood plantation and environmental plantings for carbon sequestration over 64 years under a baseline and three climate change scenarios in the Eyre Peninsula and Lower Murray regions. Likewise, oil mallee was modelled over 6 years in these same regions and under the same climate scenarios to simulate biomass production. Similar spatial patterns are observed across both study-site regions with higher productivity and carbon sequestration rates in areas of greater rainfall, typically the more southern latitudes and higher altitudes. Nonetheless, all three land uses displayed high spatial variability in both regional study areas.

In the Eyre Peninsula region, under the current climate there were higher productivity levels at the southern tip of the peninsula extending, to varying extents, along the coast to the west. There is also a small area of high productivity around the 'Cleve Hills' in the north east of EP. Hardwood plantations and environmental planting have a greater concentration of higher yields in the south, with most of the northern half of the peninsula having very low yields over the 64 years (Figure 17). Because the oil mallee is only modelled over six years the actual yield values are much lower, although overall patterns observed are much the same (Figure 18). Nonetheless, higher productivity levels, relative to other areas, extend further along the coast to the west and also further north, and thus into low rainfall areas, than occurs with hardwoods and environmental plantings.

There was some variability in the productivity of the different tree plantings under the different climate change scenarios.

- Average carbon sequestration rates decreased substantially for hardwood plantations under increased warming and drying with larger reductions in low rainfall areas (Figure 17).
- Environmental plantings had lower productivity and sequestration rates overall but experienced a slight increase in yield under the mild warming and drying scenario before decreasing again under the moderate and severe climates (Figure 16 and Figure 17).
- Biomass production of oil mallee also displayed an increase in average growth rates under mild climate change, and more significant decreases under moderate and severe climate change (Figure 18). However, despite these average decreases with increasing climate change, there are some areas that experience increased productivity with increasing warming and drying. This is particularly evident in the oil mallee productivity with substantial increases in yield under areas of high rainfall (Figure 18), due to improved growing conditions resulting from a warmer climate in areas where, despite reduced total rainfall, water does not become totally limiting.

In the Lower Murray region, under the current climate, there were higher levels of production along the eastern face of the Mount Lofty Ranges (western edge of study area), around the lower lakes (south western corner of study area) and along the southern edge of the Wimmera CMA (southern edge of study area). These are areas of higher rainfall and lower temperatures that are generally more conducive to plant growth. Hardwood plantations and environmental plantings have relatively high yields extending almost to the Murray River on the north east border of the study site (Figure 19). Relative to its overall distribution, oil mallee has a higher concentration of its high yields in the south with much lower yields further north (Figure 21).

Under the mild, moderate and severe climate change scenarios average carbon sequestration rates decrease for hardwood and environmental plantings over the 64 years. Similarly, the oil mallee experienced reduced productivity under each climate change scenario over the 6 year modelling time frame. There was no combination of increased temperature and reduced rainfall that resulted in increased yields as observed on the Eyre Peninsula. This is likely the result of differences in soil type and the depth of soil affecting the water balance.

The $3PG_2$ modelling demonstrates the spatial variability of tree growth and carbon sequestration. It highlights the influence of water balance and soil type in biomass production and thus the amount of carbon sequestered. This interaction of water balance and soil type can result in positive outcomes from a warming and drying climate in localised areas. However, it is clear that overall production would be reduced from increased warming and drying.

The modelling also examines some of the trade-offs associated with different targets. For example, trees grown purely for carbon (hardwood plantations) have a higher yield than those plantings that also have some biodiversity benefit (environmental plantings).

4.6 Bringing LFAT together and interacting with the regional planners

The discussion above indicates the extent and depth of the spatial and process modelling that has formed the core of this project. The detail of possible changes and responses to climate change can provide significant insight that should inform regional planning that can be demonstrably ‘climate ready’. However making this information available in a form that allows learning, assimilation and translation into regional planning and operations is not straight forward. Making the vast amount of information available in an easily accessible form was the design intent of the LFAT. The success of the availability of such a tool is highly dependent on the willingness and receptiveness of the regional planners and also increasingly on the acceptance of the regional communities. Recognition of this nexus was the reason for the project experimentation with the envisioning engagement process.

With the LFAT being available via the Web, interaction with the regional planners and NRM Board staff is planned. Their response to the tool and how they plan to use it in their community engagement will be documented and added, as a supplement, to this report.

5

Gaps and future research directions

Of most relevance to this research is the dynamic interaction shaped, on the one hand, by the legislated requirement, overseen by the relevant state government department (DEWNR), for NRM Boards to write regionally based climate change adaptation plans that need Ministerial signoff (top down planning) and, on the other hand, the need for implementation and adaptation at the NRM regional and local (grass roots) level.

This represents a complex 'whole systems' change, but we argue that the planning process itself is founded on an older worldview or paradigm (Kuhn, 1962) and requires transformation at the institutional level if it is to enable more rapid adaptation at the landscape level.

It could be argued that conventional strategic planning processes are 'Newtonian' or 'mechanistic' in their underlying assumptions of consistency and predictability, and of linear and direct cause and effect (Mowles, et al., 2008; Wheatley, 1999). These assumptions have promulgated a generally top-down approach that separates planning from implementation and imposes controls in an attempt to ensure that the planned strategies are implemented.

In conventional planning cycles, vision is seen as a broad, very high level goal – a first step, which is often left behind as the more detailed and concrete work of planning strategies and actions is commenced. The detailed planning identifies a pathway of milestones leading to specific strategic goals that reflect the vision. It assumes that we can accurately predict the outcome, achieve a specific result over long time frames and tell people what to do in order to implement the plan. Even the implementation process reflects a Newtonian 'reductionist' approach – a linear process that breaks the plan down into discreet parts, each to be delivered by a different part of the organisation. The assumption being that the whole is merely the sum of the parts.

This project has gathered evidence that a different process is called for if NRM regions are going to adapt rapidly to the coincidence of environmental, economic and social drivers.

To start this process, every NRM region in Australia should implement LFA as a fundamental method to assemble the basic bio-physical, social and economic information of their region. This would require an audit of the regional data that is likely to exist within regional, state and federal agencies. The data would need to be checked for completeness and currency and assembled in a GIS compatible form. With this, the models used in this project can be applied and regional validation undertaken as part of the process to build credibility within the region, including NRM staff, State agency staff and regional land managers. A parallel process using the methods outlined in the envisioning process is needed to increase the opportunity for genuine regional engagement and on-going ownership. Once current data and projected options are assembled and displayed in consistent map form it is then predisposed for use in assessing planning and management options, informed by projections developed from the environmental and social drivers.

While this logic seems self evident from a scientific and technical perspective, it clearly does not happen, because of the less-logical intervention of people and their preferences. Future research needs to continue the exploration of more effective ways of developing and using biophysical information to inform, together with greater understanding of people's values which determine what is done.

It is also evident that any planning and implementation process together with supporting information tools need to be easily and readily updated. This requirement is met with the processes that are part of the Landscape Futures Analysis and displayed in the LFAT. With a future that is not unknown but is uncertain there will be the need to update the information base, to improve the representation of the key driving processes in the models and to modify the way information is presented to improve its usefulness in decision making. This is the advantage of the processes and tools that have been further developed in this project.

The LFAT provides a unique visual representation of future land use options as they relate to agricultural management, biodiversity management, carbon sequestration and weed management under different future climate, input /output prices for farming and carbon price. Use of the tool has achieved a major breakthrough in terms of being able to engage end users in the process of building alternate future landscape scale management options. However, further work is needed to:

- expand the LFAT to other regions in Australia, starting with agricultural cropping regions in South Australia such as in the Northern and Yorke, Adelaide Mt Lofty Ranges and South East NRM Regions;
- include measures of agricultural productivity beyond wheat yields, such as was done for the South Australian MDB region;
- provide sufficient training to ensure that regional NRM planners have sufficient understanding of the structure and functioning of the tool to deliver it without the need for continuous support from the research team;
- develop a number of standard scenarios for awareness raising presentations, retaining the more complex scenarios for regional planning purposes;
- include layers for plants and animals important to current and past on-ground management actions;
- consider invasive species composition based on the potential for new species to enter from other regions under future climate rather than just current species distribution under future climate;
- provide regions with another layer of information to guide program development i.e. where to direct biodiversity effort with landholders, where to support local government with change of land use;
- link modelled and actual distribution of local/indicator species using regularly updated field monitoring data; and
- conduct further work on entering property specifics and then remodelling through scenario's for smaller areas.

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Appendices

1. APSIM parameters

The sowing window was set to between 1 May and 1 July of each year. Sowing occurred when cumulative rainfall over three consecutive days was greater than 10mm or when the end of the sowing window was reached. Sowing density was set to 180 plants/m^2, sown to a depth of 40mm and at a row spacing of 220 mm. Surface residue was assumed to be wheat stubble and initialised to 1 t/ha. Soil organic carbon level was reset to the starting value for the soil. The ratio of carbon to nitrogen was set to 80. Wheat grain was harvested at maturity. The soil moisture, soil nitrogen and surface organic matter were reset at 1 January each year to remove the impact of the previous crop and season on the following crop. Resetting soil N and organic matter also avoided problems such as fertility rundown in a continuous wheat monoculture which would make interpretation difficult. Soil moisture was set to 30% of maximum available water for each soil characterisation which was evenly distributed down the profile. This followed the method used by Luo et al.(2009) who set moderate soil water values to ensure reasonable emergence rates (17-36%) to eliminate modelled crop failures in order to trace and detect the patterns of climate change impact.

One difference between our study and those previous was that we set our soil water parameter to reset at 1 January rather than at 30 March. This choice was made to include the influence of the projected reduction in summer rainfall caused by climate change on the summer rainfall analogue.

The mapped definition of soils through particle size (texture) differences allowed us to distinguish variations of soil evaporation parameters in the model. These variables U which is the amount of cumulative evaporation in mm, since soil wetting, before soil supply becomes limiting and CONA which is the coefficient used to calculate subsequent soil evaporation in stage 2 that is a fraction of the square root of time since the end of first stage evaporation can be changed for each soil characterisation. We linearly adjusted the soil evaporation values based on minimum and maximum values of U and CONA from the APSOIL database for the Eyre Peninsula and the degree of variation across the textural differences in the soil types. See Table 2, Table 3 and Table 4 for the values used in these model settings.

Table 2: Cona and U values by soil texture used in the APSIM model.

Soil texture	Description	Cona	U
A	More than 60% sand	2.00	2.00
F	More than 30% sand	2.18	2.36
B	More than 60% loamy sand	2.45	2.91
C	More than 60% sandy loam	2.73	3.45
CC	More than 30% sandy loam - Coarser	3.09	4.18
CF	More than 30% sandy loam - Finer	3.18	4.36
D	More than 60% loam	3.27	4.55
E	More than 60% sandy clay loam	3.36	4.73
EC	More than 30% sandy clay loam	3.82	5.64
F	More than 60% clay loam	3.91	5.82
FC	More than 30% clay loam	4	6

Table 3: Values of applied nitrogen (kg/ha) at sowing and at certain phasic development stage (Zadok stage 30-32) for the low, medium and high rainfall zones.

Rainfall Zone	Nitrogen at sowing (kg/ha)	Nitrogen at Zadok stage 30-32 (kg/ha)
Low (3 driest sub regions)	10	0
Medium	13	12
High (2 wettest sub regions)	16	34

Table 4: Initial nitrogen and ammonium values (kg/ha) across rainfall zones, rooting depth and texture variables.

Rainfall zone	Root Depth (cm)	Nitrogen (kg/ha)						Ammonium (kg/ha)					
		Texture						Texture					
		More than 60% sand	More than 60% loamy sand	More than 60% sandy loam	More than 60% loam	More than 60% sandy clay loam	More than 60% clay loam	More than 60% sand	More than 60% loamy sand	More than 60% sandy loam	More than 60% loam	More than 60% sandy clay loam	More than 60% clay loam
Low	0-100	32	36	42	50	58	58	10.56	11.88	13.86	16.5	19.14	19.14
Medium	0-100	42	48	58	62	64	64	13.86	15.84	19.14	20.46	21.12	21.12
High	0-100	48	54	64	74	82	82	15.84	17.82	21.12	24.42	27.06	27.06
Low	0-60	24	28	34	40	46	46	7.92	9.24	11.22	13.2	15.18	15.18
Medium	0-60	32	38	45	50	52	54	10.56	12.54	14.85	16.5	17.16	17.82
High	0-60	40	46	54	62	70	80	13.2	15.18	17.82	20.46	23.1	26.4
Low	0-40	16	20	24	28	32	34	5.28	6.6	7.92	9.24	10.56	11.22
Medium	0-40	30	32	36	38	44	48	9.9	10.56	11.88	12.54	14.52	15.84
High	0-40	36	42	48	54	60	66	11.88	13.86	15.84	17.82	19.8	21.78
Low	0-20	12	14	16	20	24	24	3.96	4.62	5.28	6.6	7.92	7.92
Medium	0-20	16	18	22	26	30	32	5.28	5.94	7.26	8.58	9.9	10.56
High	0-20	24	28	32	36	40	44	7.92	9.24	10.56	11.88	13.2	14.52

2. The role of envisioning in progressing from aspiration to implementation

Context of the 'envisioning process'

The broader context for including a process of community engagement such as 'envisioning' as explored in this research, was driven initially by the research team's observations over years of engagement with NRM Boards and in other contexts, that gaining traction for science for the benefit of the community is not easy. This experience is not unique and reflects a broader trend since WWII, where scientists have moved from a position as experts offering valued technical advice (often in a production or industrial setting), to 'expert-citizens' partnering with 'citizen-experts' to generate improved outcomes for the greater good and where process is at least as important as desired outputs (Martin et al., 2010). In particular, Martin et al. (2010, p37) state: "The literatures do strongly indicate that if the goal of research is effective, adoption of a substantial number of variables have to be managed. Good science and good project management are necessary but far from sufficient conditions for success."

Within this specific NRM research context, it became apparent that – in addition to presenting the LFAT in a manner that is informative, relevant, easy to use and engaging – success in 'climate ready' strategic planning was as much about implementation as planning. This realisation led to additional capability (skills and knowledge) being added to the inter-disciplinary research team in the areas of organisational sustainability, transformational change, leadership, management and complex adaptive systems. The need to incorporate the understanding of complex adaptive systems into modelling of this kind has been recognised (e.g.Dearing et al., 2012; Nicholson et al., 2009) and our approach to linking the LFAT modelling with the socio-economic system is also founded on principles derived from complexity science.

The 'envisioning' explored in this research is a process rather than a single event and was being developed and employed by this projects researchers within organisations prior to this research. Previous research has explored visions and scenarios in a number of ways (Lynam, 2007). In fact the literature in the natural resource management field tends to conflate these two ways of looking forward: to envision or to project scenarios (e.g. Lynam et al., 2007; Rounsevell & Metzger, 2010). However, we make a distinction between visions as being co-created with a pro-active intention to influence the future in a certain desired manner, and scenarios as being created with the intention of understanding the dynamics of certain relationships and how they might unfold in a manner that may be responded to but not necessarily influenced. So we perceive visions as being proactive and scenarios as being more reactive in stance.

The challenge identified in the literature is to link the vision of the desired future, developed at the NRM regional and subregional scale, with the computer model at the global scale (Lyle, 2013; Rounsevell et al., 2012). The current research attempts to address this issue by linking the LFAT computer model and a desired future enunciated during the 'envisioning process'. As explored later in this report, this linkage was one of the most challenging facets of the research in the field.

The 'envisioning process' was also explored because:

- Within the field of community engagement for sustainability, it has been widely recognised that collective envisioning of a desired future does something important – it brings people together (Meadows, 1994; Senge, 1994; Woolcock & Brown, 2005). Within a sphere as contentious as planning for an uncertain future, where some stakeholders continue to deny climate change as a phenomenon, while others are motivated to respond urgently to climate change, a process that unites people at the most fundamental level of their values appeared a useful starting place.
- We recognised the need for a process within which to embed the science outputs (LFAT) in a way that would influence adaptive change more successfully than in the past.

Four important facets of the 'envisioning process'

The following points provide an overview of important and distinguishing features of the 'envisioning process'.

A systemic approach founded upon principles of complex adaptive systems

The 'envisioning process' is consistent with environmental management research which suggests that influencing the landscape, on the scale and in the time frame required if it is to adapt to climate change, demands an appreciation of complex adaptive systems and a greater understanding of the interaction between social and ecological systems (Dearing, et al., 2012). Although the intention behind such calls for greater understanding has been to aid in the development of scenario modelling to improve its predicative power and accuracy, our approach in the 'envisioning process' is to integrate a management tool that is founded upon the principles of complex adaptive systems. It is an innovative approach as has been called for in responding to climate change (Cross et al., 2012), and experimental in its application in the NRM regional context, having originally been designed for, and successfully applied in, a corporate organisation context.

The innovation represented by the 'envisioning process' traces its source to the principles of complexity upon which it is founded. This is consistent with an emerging theme in organizational management literature as it responds to the growing scientific understanding of complexity in organizational life (Boyatzis, 2006; Capra, 2002; Ecoliteracy, 2011; Hämäläinen & Saarinen, 2008; Hock, 1995; Marion, 1999; Mowles et al., 2008; Paul, 2007a; Rhodes, 2008; Rowe & Hogarth, 2005; Stacey, 1995; Styhre, 2002; Uhl-Bien, Marion & McKelvey, 2007).

Current accepted practice for planning identifies a pathway of milestones leading to specific strategic goals that reflect a succinct statement of 'the vision'. This assumes that we can accurately predict the outcome, achieve a specific result over long time frames and tell people what to do in order to implement the plan. This linear process breaks the plan down into discreet parts, each to be delivered by a different part of the organisation. The assumption being that the whole is merely the sum of the parts.

The assumptions underpinning the conventional strategic planning process are fundamentally at odds with the behaviour of complex adaptive systems, which are inherently unpredictable over the longer term and subject to indirect and non-linear causation. We propose a new role for vision as a 'cradle' for the entire process of planning and implementation. It constantly informs and is informed by the process, as communities learn more about how to bring their desired future into being. The vision we are describing is a values-rich story that continues to evolve as people experience their emerging future and reprioritise their own values over time (Meadows, 1994).

The 'envisioning process' is a four-stage process (detailed in the Instruction Manual) that reflects the behaviours of complex adaptive systems and has been heavily influenced by the work of Donella Meadows (Meadows, 1994, 1998, 1999, 2001, 2004; Meadows, Meadows, Randers, & Behrens III, 1972). This envisioning process assumes:

- Non-linear cause and effect and offers a framework within which experiments may be undertaken in order to learn about the behaviour of the system and how best to influence it.
- Inherent unpredictability, especially over longer time frames and larger spatial areas. It avoids setting specific targets or SMART goals, and employs qualitative lead-indicators instead.
- Agents within the system are unable to control the system, but can influence it by learning how to work with the powerful self-organising forces already at work within it.
- That from the often unrecognised self-organising comes emergent properties that are specific to the system (Harris, 2007).
- Starting points ('sensitivity to initial conditions') and history ('path dependence') are important and different in each NRM region, so the process needs to respond to these differences.

We expect this framework to cause unease among some scientists and other stakeholders with a background in NRM as the process represents a very different way of 'planning'; a different paradigm. However, it may be the type of experimentation required to deliver change on the ground, in response to global challenges such as population growth, water scarcity, food security, growing energy requirements and climate change (Beddington, 2009; Meadows, Randers, & Meadows, 2004; Turner, 2008) – the perfect storm that our existing institutional practices have, to date, struggled to grapple with.

A process as a container for 'adaptive change' – planning and implementation

The researched process of envisioning was intended to engage farmers and land managers, as well as NRM practitioners. This reflects an understanding of the dynamics and nature of 'adaptive change', which is defined as a change in the minds and hearts of people, requiring both new learning and a reprioritisation of values (Heifetz, 1994; Heifetz et al., 2009; Heifetz & Laurie, 1997; Heifetz & Linsky, 2002). Heifetz's adaptive leadership and change framework is one that has been developed with an appreciation of complexity and is consistent with the principles outlined above.

Heifetz describes adaptive change as a process over time requiring people to undergo a personal appraisal of the values that have served them well in the past (this links to the climate change adaptation literature exploring issues of identity and values (Adger et al., 2009; Alexandra & Riddington, 2007)) and personally weighing these against those values which will serve them well in the future. Values in this context mean those qualities of life that are held as important to individuals and the society in which they live. Heifetz proposes that facilitating this assessment and choice through conversations enables people to reprioritise (not change) values and make adaptive changes. It is expected that this is an emotional process that takes time and the outcome is unpredictable as people hear concerns or priorities from others within the system of interest and weigh this against their own interests.

In addition, neuroscience research has increased the understanding of the dynamic of learning to which Heifetz refers in his framework. Learning (and so adaptive change) is also associated with the development of new neural pathways that are strengthened over time (by increasing the density of attention) to create new thinking habits (Schwartz & Rock, 2006). This research also reveals that new neural pathways are best formed by offering opportunities for personal insights or 'ah-ha' moments that need reenforcement over time. Questions are often more helpful in this process than providing pre-packaged solutions or answers.

The major implications of this understanding of the nature and dynamic of adaptive change for increasing the 'traction of the science' are:

- adaptive change is unlikely to result from the single act of 'communicating' the science as new information
- adaptive change requires the creation of a series of facilitated conversations where the scientific information can be considered by each individual, in the context of the core values shared by all stakeholders, to allow a collective 'solution' to emerge from the system.

The 'envisioning process' we explored in this research is therefore a series of conversations targeted at those who need to undertake the adaptive work and the exact nature of that work may vary in different contexts and for different purposes.

Not 'adaptive management'

It is important to distinguish Heifetz's adaptive leadership and change framework as explored in this research, from 'adaptive management' as has been researched, practiced and discussed in NRM since the 1970s. Allan and Stankey define adaptive management as "the purposeful and deliberate design of policies in such a way as to enhance learning as well as to inform subsequent action" (Allan & Stankey, 2009) p3).

The commonality between the approach we are exploring and adaptive management is that both recognise the importance of experimentation for learning. There are many differences between the two processes but the most salient for our purposes here are:

- 'Adaptive change' is a process undergone by those who need to embrace shifts at the level of personal values and new learning in order to change the way they see and do things (land managers, and NRM planners in this research). 'Adaptive management' is targeted at learning about appropriate policy settings to resolve troubling NRM problems.
- Within the adaptive leadership and change framework, two types of challenge are recognised.
    - The 'technical problem': This is defined as a problem that can be easily defined and solved – the learning (which may be many different types of learning ranging from scientific learning through to engaging with the community) has already been done and it is known how to solve this type of problem. Because the learning and the thinking required to understand has already been done, and the solution is widely available, it is often easy and appropriate to use 'authority' to tell people what to do. For a technical problem this approach is generally effective. It is quick, easy and tidy. Passing legislation and creating government policy is a 'technical' approach, that tells or signals people what to do, and it will work most effectively if the challenge is a 'technical' one.
    - The 'adaptive challenge': This is defined as being difficult to define, requires substantial learning to solve and being a type of challenge where the people with the problem are the problem – and the solution. The 'envisioning process' by providing a process of engagement within which to engage with the science, and engaging land managers and NRM planners who make decisions and need to learn, is an adaptive change process. (Indeed, traditional strategic planning, within the context of the challenge presented by climate change, undertaken at a higher level of authority, with actions passed down the line to be implemented, is a technical approach to an adaptive challenge, and it is not surprising, then, that it tends to be ineffective.)
- There is a place for both the 'adaptive management' approach and the 'adaptive change' approach as embodied by the 'envisioning process', because the challenge of developing climate ready plans for NRM Boards that will be actioned on the ground (one of the issues identified in this research), is a combination of an adaptive challenge and a technical problem.
- The appreciation of the difference between 'technical problems' and 'adaptive challenges' (Table 5) that is embedded in the 'envisioning process' underpins a fundamental change in approach that this research intended to explore.

Table 5. Distinguishing technical problems and adaptive challenges (from Heifetz, et al., 2009, p20).

Kind of challenge	Problem definition	Solution	Locus of work
Technical	Clear	Clear	Authority
Technical and Adaptive	Clear	Requires learning	Authority and Stakeholders
Adaptive	Requires learning (unclear)	Requires learning	Stakeholders

Not 'communication'

There is a growing literature exploring how to foster engagement in behaviour change in response to climate change, that is focussed on the messaging of climate change information (Moser & Dilling, 2007; Ockwell, Whitmarsh & O'Neill, 2009; Scannell & Gifford, 2013). The approach explored here goes beyond messaging (which is a 'technical approach') to an engagement with stakeholders (adaptive approach), with the science (and knowledge from other sources) made available as a part of the process. (It is true however that enrolling participants into the process requires insightful messaging to gain their participation.)

Not just 'physical limits'

Adger et al. (2009) discuss and explore how the limits of adaptation to climate change may be determined, not only by physical, economic and technological limits, but also from within a society and be dependent upon "goals, values, risk and social choice".

"These limits to adaptation are mutable, subjective and socially constructed. How limits to adaptation become constructed, rather than how they are discovered, becomes the operative question." (Adger et al., 2009, p338). The 'envisioning' process, as conceived here, can also be viewed as an attempt to expand the endogenous limits of adaptation to climate change.

A process to aid strategic decision making

How people make decisions to respond to climate change has been a focus of research for some time and the envisioning process recognises that the decision a land manager makes to experiment with or adopt new practices in response to changes in climate (actual or prospective) are influenced by many variables such as personal beliefs, values, household beliefs, social bonds with peers and community, in addition to lived experiences of the impact of climate change (Colliver, 2011; Lyle, 2013).

The envisioning process, commencing as it does with a discussion about 'how we really want to experience the landscape', is intended to work at the level of individual and collective values and does this within a social and local systemic context. It is intended to place participants at the centre of the process to make their own meaning and exercise their own leadership to respond to climate change in ways that make sense to them. As reported above, our experience has reflected the finding of Meadows (Meadows, 1994), that at the level of deeply held values, most people want the same things.

The envisioning process also reflects research into strategic decision-making within an organisational context and incorporates suggestions to allow access to tacit knowledge, which we refer to as wisdom. These strategies include the use of personal reflection, sharing reflections with others to explore the underlying assumptions and beliefs and mental imagery (Brockmann, 2008).

Community Engagement Principles

The entire envisioning process displays the elements found necessary for effective action within a water resource management context by Gasteyer et al (2002) cited by Woolcock & Brown (2005) in their literature review of community engagement in natural resources in Australia. The 'envisioning process' fulfils all the required elements as reported by Gasteyer et al. (2002). Further, the envisioning process is also consistent with the Bellagio Principles for monitoring sustainable development (International Institute for Sustainable Development, 1996). The elements and principles are listed in short form in Table 6.

It should be noted, also, that the envisioning process is consistent with the International Association of Public Participation's (IAP2) spectrum on public participation and the emerging trend towards "collaborative governance" (Martin, et al., 2010).

Table 6: Brief listing of the elements and principles identified as needed for effective action associated with water resource management.

	Gasteyer et al (2002)	Bellagio Principles (1996)
Context	Community participation in water protection	International Institute for Sustainable Development – local to global contexts
Elements or Principles	Context specificity	Guiding vision and goals
	Diverse perspectives	Holistic perspective
	Collective vision	Essential elements
	Neutral facilitators	Adequate scope
	Group inquiry	Practical focus
	Participatory contract	Openness
	Monitoring	Effective communication
	Sustained systematic learning	Broad participation
	Evaluation	Institutional capacity

The envisioning process employed in the research detailed here, is consistent with these principles although time constraints meant that we were unable to participate as broadly or deeply at the community (grass roots) level as we had intended.

The envisioning process comprises four interconnected phases as shown in Figure 27 (principles from Table 6 are shown in brackets at the end of each phase of the process):

- **Envisioning:** How do you really want to experience your landscape? A holistic approach to envisioning (context specificity, holistic perspective, collective vision, guiding vision and goals).
- **Core Vales:** Embedded in the vision, core values address relationships with other people and with the landscape.
- **Indicators of Progress:** A combination of qualitative indicators and quantitative measures as appropriate, to enable monitoring of progress and act as prompts to action. (Monitoring, collective vision and goals).
- **Action Learning:** an ongoing iterative cycle of planning action, taking action and reflecting upon what lessons have been learned about the complex social-environmental ecology (system) the community is attempting to influence; employing the LFAT as a crucial source of climate change science to inform but not dictate decision making. (Sustained systematic learning, evaluation, practical focus).

The manner in which the process is employed within the community and then facilitated was intended to meet the remaining principles of diverse perspectives, neutral facilitators, participatory contract, openness, effective communication, and broad participation.

Summarising the rationale and justification for using an 'envisioning process'

The envisioning process as a whole is detailed in the 'Instruction Manual' rather than this report. In detailing the process however we are not suggesting that this process is the 'cure all' or the only process that may meet the critical identified need. It is a process that meets a range of needs as outlined above.

The need that we explore here is for a community/ stakeholder engagement process that facilitates the development of a collective strategic approach to the adaptive challenge of shaping the future landscape in response to changing climate. In a complex socio-ecological context, involving long time horizons and large geographic distances, this engagement process looks to facilitate collaborative decision-making by all the stakeholders in a manner that integrates the best that science can offer.

Figure 27: Relationship between envisioning (reflecting core values) and Landscape Futures Analysis (LFA).

Key findings and team learning from the 'envisioning process'

1. The first round of workshops, which focussed attention on how workshop participants wanted to experience the NRM planning process, revealed commonalities that contrast with how the process is currently experienced. All participants wanted an inclusive and holistic process but the research of the current planning process suggests that this is not experienced by all.
2. It was possible to implement the envisioning process without explaining its underlying theoretical foundation in the science of complexity, which is often conceptually challenging for many people. However, our observation of participants in the process is that the lack of explanation and understanding may have contributed to their sense of confusion because the process is familiar in some respects but also quite different to more traditional strategic planning processes.

   We did not provide the envisioning process as an alternative to traditional strategic planning but as an additional option that may also assist community engagement. Our records indicate that the two groups responded differently to this tool as a possible engagement opportunity which may also be a reflection of the different composition of the groups. The SAMDB group seemed very interested in its capacity not just to aid planning and reduce the range of options opened up by the use of LFAT, but also as a way of catalysing change at the grass roots level. The interest on EP was much more 'technically' focussed on the use of LFAT in the traditional planning process and this may also have been influenced by the longer time we spent with them employing the process to examine how people wanted to experience the planning process. We may have exhausted their patience.
3. We delivered the envisioning process before the LFAT tool partly in response to the time required to collect data, but also partly influenced by our preconceived idea that the process would logically flow from 'envisioning' (understanding what you want) to 'understanding the options' as assisted by LFAT to making decisions. In hindsight however, it may have been more helpful to both NRM Boards if we had been able to engage in some awareness raising of the option-generating capacity of LFAT before engaging in the envisioning process. This would have helped participants understand the function of the envisioning process – to use the vision as a way of narrowing down the range of possible futures.
4. The research team suffered, as do many other research teams pursuing engaged scholarship (Martin, et.al., 2010), from an inability to lay out the entire process to participants before, or as we commenced, the research. This reflects the very nature of research. Although the team was clear about what questions we were researching, the path was unclear. The success factors identified by Martin et.al.'s (2010) literature review of successful engaged scholarship processes (where research aims to develop a collaboration with a community to solve real problems) are:
   - relationships/trust
   - vision/clear mission
   - participants in design
   - funding
   - agreed roles and structure
   - measurable outcomes
   - leadership
   - communication/common language

Ironically, our team suffered from a lack of a clear and shared vision for the project. This was largely a result of our interdisciplinary composition that meant that it took time for us to develop the shared language and understandings.

Would we do things differently if we had our time again? It is hard to know because the time constraints imposed by the funding model really precluded the team from taking the time (perhaps weeks of discussions) to develop the shared understandings of the context and specific key terms. We learned from each other as we progressed and the principal researcher held the vision for the team. The feedback and evaluation suggests the team functioned well with regard to the other facets.

5. Time was a recurrent theme during the research. The funding body, NCCARF, had time limits imposed on it that were transferred into the research timetable. The research partners at EP and SAMDB faced their own planning timetables and time constraints – and their constituents face their own time constraints.

Everyone appears to be short of time and is unable to devote time, and yet we know that time is required to adapt. It appears that if we are to make the transformational changes required, somewhere and somehow, a decision to devote time to the process, to thinking and to learning is required. The process must be allowed to dictate the time, rather than the time dictating the process.

6. Stakeholders come to the table with a wide variety of perspectives, practical priorities, regulatory obligations, subordinate briefs and individual personalities. We found that if we started by asking questions like "How do we want to experience the planning process?" or "How do we want to experience our landscape?", then we engaged at a level that goes beyond political or personality differences. This is a level of deeply seated values and tells the story of what we really want, not what we'll settle for.

When stakeholders engaged at this level, the envisioning workshops confirmed what previous research predicted - that there is substantial common ground and that in a co-created, shared vision of this kind there is a lot more connecting stakeholders than separating them. If the envisioning process enables participants to operate from and articulate the level of values, then the analytical mind tends not to intrude at the level of more superficial differences. The shared vision or story that emerges ultimately gives rise to Indicators of Progress, which are, themselves, prompts to action. A co-created vision of 'what we really want' can act to enrich the dynamics of planning and implementation.

The capacity of the envisioning process to transcend personal or political differences was clearly demonstrated in the first workshop in Adelaide. The perceived diversity in personality and agenda had given rise to some pre-workshop apprehension about the ability to find common ground. In the event, an independent observer, unaware of some of the potential clashes of personality and political priorities, commented that it had been impressive to experience the sense of harmony and common purpose produced by the process.

Recommended process for engaging with NRM boards

The recommended process for engaging with other NRM boards has evolved from the key issues we faced in engaging with the two pilot NRM boards and lessons we learned in the process. Importantly, we learned that a one-size-fits-all process or model that reflects a blueprint for action is unlikely to produce the desired results because of the highly variable and complex circumstances of each board and community.

The recommended process for engaging that is outlined below (Figure 28). It presents a way of becoming aware of those circumstances and tailoring or customising the approach for each board based on principles derived from the understanding of complex adaptive systems and requirements for adaptive change.

Figure 28. Diagrammatic representation of an engagement and influencing process that recognises socio-ecological complexity and the importance of values influencing planning, decisions and actions.

Key findings, learnings and issues for process design

Figure 28 reflects the six key findings, learnings and issues that emerged in the course of the envisioning work:

1. Raise awareness of LFAT capability

From our experience, and given that a working example of the LFAT using data sets from SAMDB and EP NRM regions are now available, we suggest starting the process by raising awareness regarding what LFAT is capable of and how it might be used to aid decision making.

2. Willingness to change

Much energy was expended trying to find a 'hook' to motivate the NRM boards to engage with this process – they believed that they had nothing more to learn about the science and art of planning and were really most interested in the LFAT. This highlights the need to assess willingness to change, or dissatisfaction with the status quo, before doing anything else, incorporating insights from Roger's innovation diffusion curve (Houlder et al., 1999) – not everyone will be willing at the same time or in the same way. The process needs to engage its participants at the appropriate level of 'willingness' and considerable time and energy may be invested in this phase of the process.

3. Regional locus of control

Local planners' perceived locus of control vis-à-vis the state planning bureaucracy – the dynamics of local versus central power – will be one important source of variation between regions. The process needs to address perceived local constraints or limitations, especially where regional planners have come to see their task as simply completing a 'planning' process (largely divorced from implementation) that meets the requirements of regulation, or of 'the Minister'.

4. Who represents the regional system?

As this process sets about "bringing the whole system together"[1], attention must be given to the relationship between regional planners and their local community. Some local communities will feel well represented by the NRM Board, some will feel mistrustful, some will feel no connection at all. Consideration must be given to whether the NRM Board, alone, is the appropriate conduit for community engagement in the planning process. Should other stakeholder groups be included, e.g. Land Care groups? This is another source of regional variation that the process needs to accommodate. Further, our research revealed a tendency towards NRM Boards becoming familiar with working with each other and preferring it to remain this way, in a sense 'protecting' their local communities from engaging with the hard facts or in the hard decisions. This 'protection' is often a dynamic that can be understood as serving both the protected and those who are willing to accept responsibility for protecting – but it serves to allow the protected from undertaking the adaptive work that is required to see new ways of seeing and doing emerge (ASRIS, 2007). The process should invite and welcome everyone who is willing to participate and this will contribute to it taking longer, being more contentious and facilitating the adaptive change required.

5. Capacity Building, Complexity and the Role of Envisioning

Envisioning has the capacity to identify common ground among diverse stakeholders and to build relationships. This is important in terms of group dynamics and developing a willingness to collaborate, not only between regional participants, but also with practitioners contributing expert knowledge – science, farming experience, and indigenous wisdom.

It is critical that the regional planning community develops the capacity to keep the shared vision present throughout an iterative action learning cycle, both as a means of orientation in a complex environment and as a guide to future action. The vision provides a cradle within which the best science (through the LFA) and expert knowledge from other sources can be integrated in the making of decisions about the future shape of the landscape.

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[1] Bringing the system together is another principle of change (or response to stimuli) from the study of autopoietic systems, a subset of complex adaptive systems (Wheatley 1999).

6. Influencing the Systems of Planning and Implementation

It is apparent that all levels of the planning 'system', from state public servants to farmers, want the planning process experienced in the same way. This common ground encompasses values such as transparency, participation, respect, honouring different kinds of knowledge (local, indigenous and scientific) and autonomy to respond to complex bio-socio-economic environments. Nevertheless, it is clear that many participants do not experience planning in this way.

The process of planning and implementation built on and informed by co-created vision is designed so that it can deliver the experience of these core values to all participants.

The process recommended also provides for capacity building in the form of exposure to complexity theory and its implications for management and planning. This will influence the 'structure of the system', as it raises awareness of existing mental models and deeply held beliefs and assumptions about how the world operates.

Core principles to support the process

1. Envisioning operates as a bridge between science and decision making that can integrate more than just 'the science' – it can bring together and integrate the contribution from multiple stakeholders with diverse perspectives, and bring to bear 'wisdom' from various traditions of knowledge.
2. One size doesn't fit all – we must be able to adapt the process to local variations in the social, political, agricultural and natural landscape. Even the dominant local land use has an effect on the dynamics of regional planning – e.g. large cropping and grazing holdings versus smaller horticultural holdings.
3. The process must reconnect the notions of planning and implementation. Planning must be seen as part of an integrated process, directed to action on the ground, rather than an end in itself, ticking the regulatory box.
4. The role that time plays must be understood and respected. This was the least anticipated but, perhaps, most important principle to emerge from our work. The adaptive work demanded by the shift to a fundamentally different way of understanding planning and implementation in a complex socio-political environment requires time, and a willingness to devote time. It does not happen overnight. Adaptive work can be uncomfortable and lack of time can be used (and we witnessed it being used) as a method of avoiding the adaptive work required.

   Time is also required to develop the capacity within NRM boards and their communities to exercise leadership for change – leadership informed by an understanding of complexity and emergent change, and open to new ways of working with regional communities to plan and implement strategically. Urgency is no substitute for effectiveness. Sufficient time must be built into funded action research; local processes for capacity building and adaptive change; ministerial/political expectations in relation to regional planning and implementation.
5. The existing structure of the broader system and its impact on planning in the regions cannot be overlooked – it is all interconnected. The organisational structure, hierarchy, locus of control, and management paradigm all impact upon the ability of local communities to bring their vision into being and make the changes required. Change at the regional level requires thoughtful and supportive changes in management. This includes sensitivity to the balance between state-based policy making and autonomous regional planning and implementation.

Attachments

These attachments can be obtained as PDF's at:
http://www.adelaide.edu.au/environment/lfp/research/afl/

1 Future Landscape project description

2 Project overview paper for communication purposes

3 Eyre Peninsula NRM Region planning review findings

4 SA Murray Darling Basin NRM Region planning review findings

5 About our envisioning approach

6 SA MDB (Karoonda) shared vision

7 Eyre Peninsula shared vision

8 Milestone 2 report

9 LFA Tool specs – preliminary meeting

10 LFA Process illustrated

11 Adapted Future Landscapes – Tool spec and trial

12 LFA Tool description

13 LFA Tool Specs EP workshop

14 LFA Tool Specs MDB workshop

15 LFA Tool – actions

16 SA MDB Region data

17 EP Region data

18 Land condition monitoring using remote sensing information

19 Landscape Futures Analysis Tool (LFAT) brochure