Climate-ready Restoration

Some practical guidelines for plant restoration in an uncertain future

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Contents

We recommend using this guide to inform ‘Step 5: Design interventions to maintain values’ and ‘Step 6: Adaptive implementation’ in The NRM Adaptation Planning Framework: six steps to transform NRM planning under global change (Ryan et al. 2016)

1. Introduction

Climate change is likely to alter the way we restore plant communities.

Climate change in the Murray Basin NRM Cluster is expected to impact on our environment in many ways. How these changes may influence biodiversity are briefly outlined in the "Climate change and biodiversity in the Murray Basin NRM Cluster region – how will it affect your region?" fact sheet (https://www.terranova.org.au/repository/murray-basin-nrm-collection/climate-change-and-biodiversity-in-the-murray-basin-nrm-cluster-region-2013-how-will-it-affect-your-region).

Some of the more important climate predictions for the near future (i.e. by 2030) for the Murray Basin NRM Cluster that are likely to influence how we undertake restoration include:

- higher temperatures
- hotter and more hot days and fewer frosts
- less rainfall in the cool season but no changes for the warm season
- an increase in heavy rainfall events and more time in drought
- a decrease in humidity over winter and spring
- increased evaporation rates and reduced soil moisture (Timbal *et al.* 2015).

The purpose of this document is to outline potential strategies to help planners and land managers adapt their current restoration planning and practice to climate change. Although NRMs have their own planning processes for deciding when, where and how to plant, the 'Climate-ready Restoration – Guidelines for identifying restoration priorities to support biodiversity conservation under a changing climate' (Rogers *et al*. 2016) provides information you may wish to consider when making important decisions regarding how to commit your restoration resources.

Many planners and land managers already use the idealised restoration timeline outlined in Figure 1 (left) but under climate change we need to consider some additional steps in order to maximise the success of our projects and to ensure that we make the most of our precious restoration resources (Figure 1, right). The first of these would be to try and broadly evaluate the likelihood of success prior to the start of any project. For example, if El Niño projections suggest that plant losses will be higher than in wetter years, then evaluating whether it is appropriate to plant species if seed stocks are low or if species are rare and threatened will be critical. This is discussed further in Section 1.1. In addition, if restoration is being undertaken by contractors, NRMs will need to be clear about what their short- and long-term expectations of the project are to ensure that contractors are capable of meeting your requirements. Another important consideration is to carefully evaluate the success of a project over time frames that are relevant to the vegetation being restored as well as to the animals that are expected to use them. Longer-term changes (5-10 years) are usually beyond the time frame and resources of most restoration projects but are nonetheless important. It will therefore be important to develop ways to do this despite limited funding and other resources. As climates change, we will need to be more vigilant about critically evaluating the likelihood of success at each step in the restoration process and be prepared to postpone activities if you consider the likelihood of success is too low. The Adaptation Pathways approach (see Dunlop *et al*. 2016) may be a useful way of exploring options for helping to make some of these restoration decisions across long time frames.

This document will briefly outline the likely major changes that will influence future restoration practices and provide potential strategies to help adapt to this change. It will also highlight knowledge gaps where strategic NRM co-investment in research may be helpful. Three broad areas of restoration actions will be considered – 1. Forecasting success, 2. Planning and preparation and 3. Monitoring and evaluation. Where possible, information specific to Australia has been used throughout the document with international findings used only when these were deemed useful and appropriate for Australian conditions.

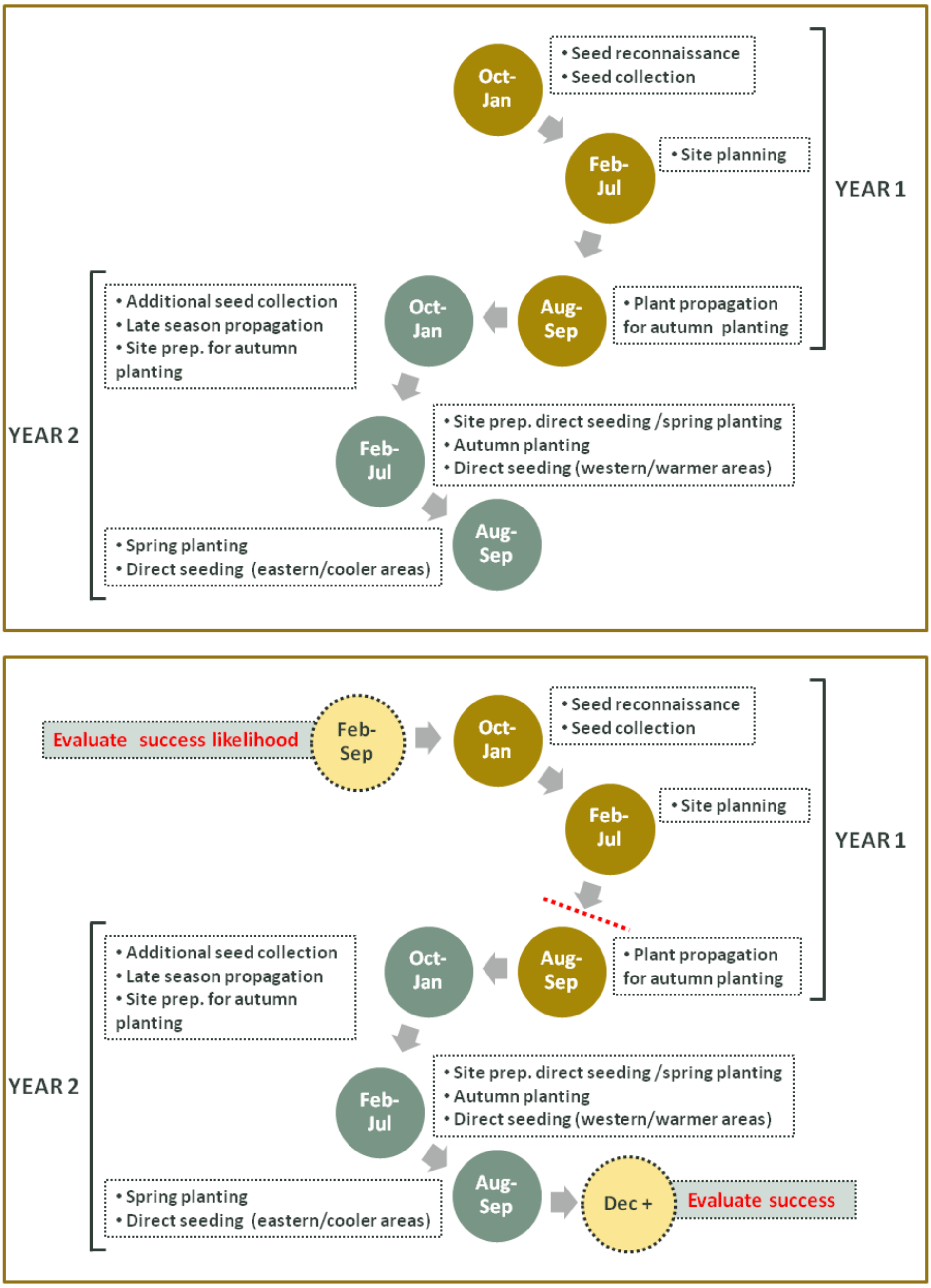
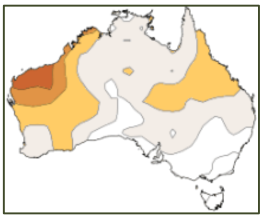


Figure 1 – Example of a typical restoration timeline for autumn planting currently used by many land managers (top, courtesy Bindi Vanzella, Greening Australia), and, additional steps required to improve restoration outcomes under climate change (bottom); dashed red line indicates decision point to abort project if conditions are unsuitable.

Additional resources and tools that may be useful for making decisions regarding restoration in the Murray Basin NRM Cluster include:

- 3C Modelling – Murray Basin (https://www.terranova.org.au/repository/3c-modelling-east-coast-central-slopes-and-murray-basin-nrm-collection/3c-modelling-murray-basin
- 3C Modelling – Biodiversity adaptation Revegetation Benefits 1990-2050 (https://www.terranova.org.au/repository/3c-modelling-east-coast-central-slopes-and-murray-basin-nrm-collection/biodiversity-climate-adaptation-revegetation-benefits-1990-2050
- Other 3C Modelling products available at https://www.terranova.org.au/
- 'Identifying prospective areas for forest carbon farming' (Cox *et al*. 2015)
- 'Impact of climate change on runoff and recharge in the Murray Basin' (Crosbie *et al*. 2015).

1.1 Forecasting to improve restoration success



NRMs already have a large store of knowledge about how to restore their regions, however, climate change will influence how this will be most effectively done in the future. Understanding what these changes might look like and how they might influence what we already do is important to help adapt our restoration practices to meet new these challenges. Future projections of higher temperatures, hotter days, lower rainfall, increased evaporation and reduced soil moisture will significantly influence what we plant and where, and may even change when and how we plant.

As with potential climate impacts for agriculture (Howden *et al.* 2008), one of the major changes for restoration is likely to be a shift in the timing of planting seasons. Studies of some WA *Banksia* species indicate that increased soil warming can reduce germination and slow growth (Cochrane *et al.* 2015). Data from the Gondwana Link project in Western Australia has highlighted the influence that a dry Mediterranean-climate summer can have on seedling emergence with only half of the seedlings that emerged surviving summer conditions (Hallett *et al.* 2014). Most of the seedlings that did emerge were acacias, eucalypts and allocasuarinas (Hallett *et al.* 2014). Not unexpectedly, consecutive summer droughts can also be detrimental for seedling establishment as although seedlings may survive the first year they can subsequently die in the second (Benigno, Dixon & Stevens 2014). Rainfall has been noted to directly impact on the germination of *Santalum spicatum* (Sawyer 2013) but it remains unclear how this influences other Australian species. A strong experimental understanding of how temperature and rainfall relate to the restoration success of native Australian species is limited and results can be highly unpredictable (Standish *et al.* 2012).

Seasonal variability influences plant responses such as germination and growth, both critical life stages that plants need to pass through for restoration to be successful. Being able to predict the likelihood of planting success will be important to help maximise the use of our future seed and financial resources. Unlike farmers who have an array of tools to help make decisions about which crops to plant and when, no such resources are available for restoration planners and practitioners. Some climate change tools that might be useful for NRM planners can be found on the Australian Bureau of Meteorology website (http://www.bom.gov.au/climate/ahead/) while more specific information for agriculture and natural resource management is available at (http://www.bom.gov.au/watl/index.shtml). Three monthly outlook maps can provide important information about key variables such as rainfall and frost, to help decide whether planting should go (Figure 2).

Figure 2 – Examples of BoM information for Climate outlooks (left), Agriculture and Natural Resource Management (middle) and Rainfall outlooks (right).

The BoM Climate Change and Variability pages (Figure 3) track Australia's climate and severe weather season (http://www.bom.gov.au/climate/change/) and include maps of trends for temperature, frost and rainfall (http://www.bom.gov.au/climate/change/index.shtml#tabs=Tracker&tracker=extremes-trend-maps).

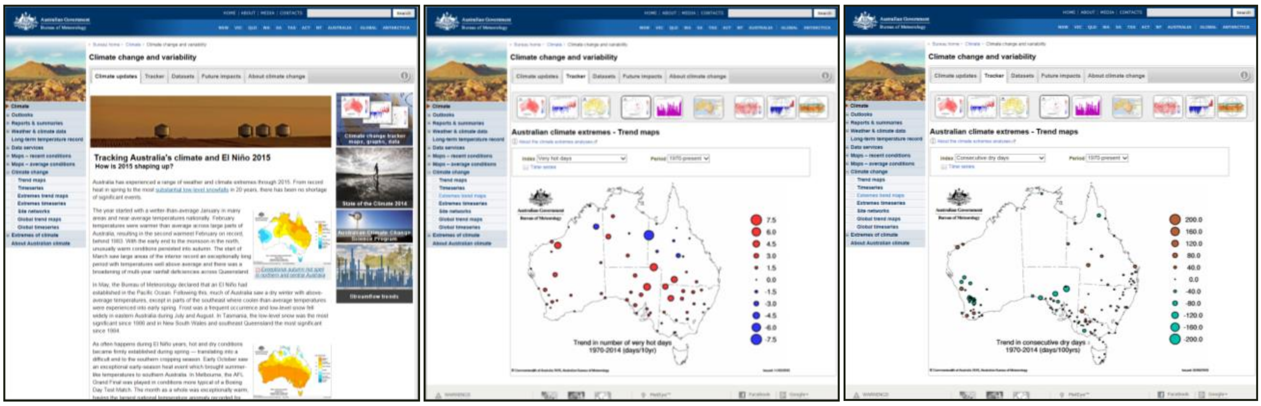


Figure 3 – BoM Climate change and Variability website (left) and examples of Australian climate extremes – trends map for "Very hot days' (middle) and 'Consecutive dry days' (right).

The El Niño-Southern Oscillation (ENSO) can have a strong influence on southern Australia's climate. Both summary and detailed information about the likely impacts of ENSO changes are available at http://www.bom.gov.au/climate/model-summary/ (Figure 4). Information about the four drivers that influence climate is available through the 'Climate Dogs' website developed for Victoria (http://www.depi.vic.gov.au/agriculture-and-food/farm-management/weather-and-climate/understanding-weather-and-climate/the-climatedogs-the-four-drivers-that-influence-victoriaas-climate) and NSW (http://www.dpi.nsw.gov.au/agriculture/resources/climate-and-weather/variability/climatedogs. While no information exists to determine how ENSO influences restoration success in Australia, rainy ENSO events in north-central Chile and northwest Peru can enhance tree recruitment in arid and semiarid ecosystems (Holmgren *et al.* 2006).

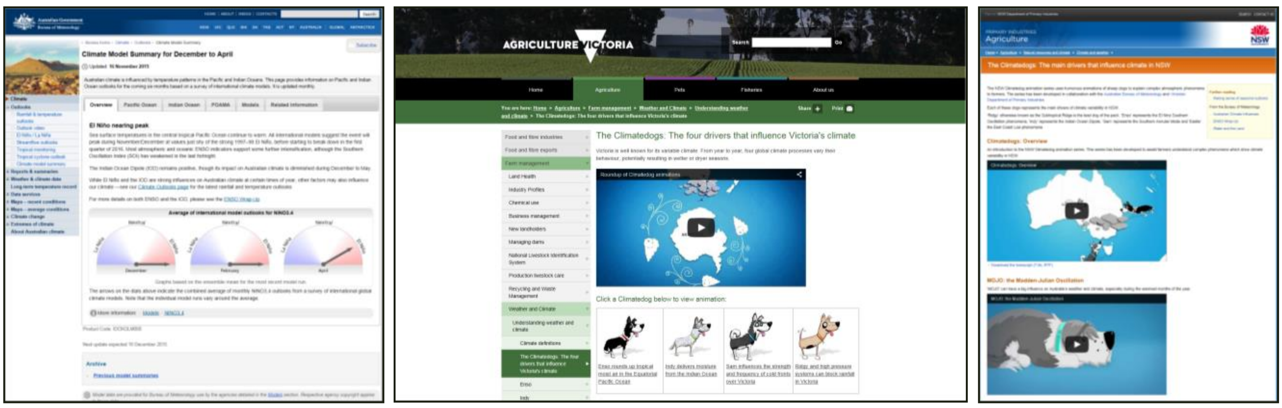


Figure 4 – Examples of BoM information for the El Niño-Southern Oscillation (left) and 'Climate dogs' information pages from Victoria (middle) and NSW (right).

Box 1 Adaptation options – Forecasting restoration success

While using climate forecasts will not guarantee the success or failure of a restoration project, they can help to make decisions about the level of risk involved, most especially for the next planting season.

For example, if ENSO is predicting a hot, very dry summer then NRMs could assess the risk of proceeding and determine whether it is appropriate to:

1. Accept the risk and proceed with business as usual. This may lead to project failure if seed fail to germinate and/or seedlings cannot cope with conditions and die. The ultimate outcome is restoration failure and a loss of seed and financial resources.

2. Scale back projects to conserve seed and financial resources but still undertake some restoration. This could include:

i). reducing the number of species being planted to only the most hardy that are more likely to cope with difficult conditions;

ii). plant at fewer sites where conditions may be less harsh (e.g. riprain zones or sheltered areas with sufficient soil moisture);

iii). reduce the area being planted.

3. Defer projects entirely until conditions are more suitable although this could imact on funding agencies and communtity expectations unless carefully managed.

Currently, funding agreements often force NRMs to plant irrespective of the level of risk to the success of a project. Adopting an adaptive approach such as that suggested above will require a policy shift that is more appropriate to restoring biodiversity over biologically realistic time frames (Broadhurst *et al.* 2015a). The impacts of climate change, however, indicate that this approach will be essential if NRMs are to adaptively manage restoration under climate change. Some of the possible outcomes associated with undertaking climatic assessments prior to planting are outlined in Figure 5.

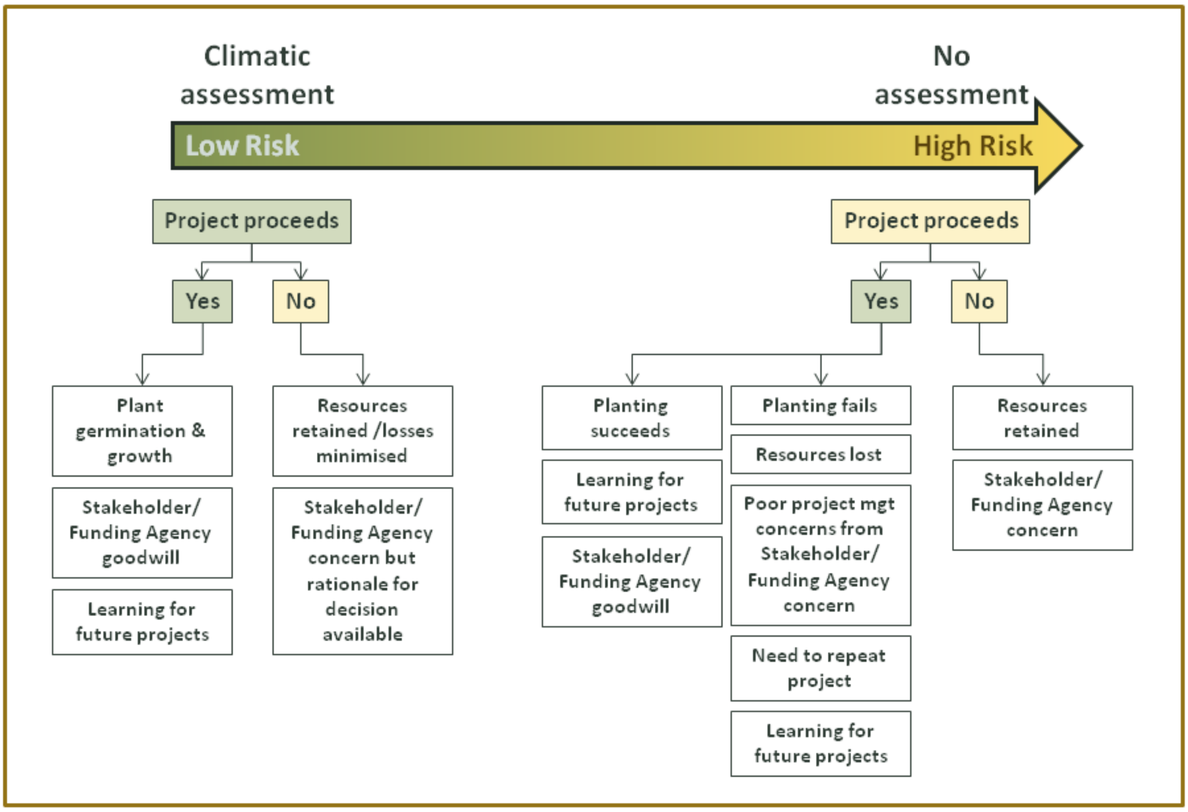


Figure 5 – Possible restoration outcomes associated with assessing climatic risks prior to a project commencing.

1.1.1 Knowledge gaps and recommendations

At present we have little information regarding how climate change will impact on the success of restoration projects. Some of the key gaps and our recommendations are listed to improve our restoration practices are listed in the box below.

Box 2 NRM Knowledge Gaps

GAP: NRMs have a wealth of knowledge about restoration in their own regions but very little of this has been aggregated and shared.

Recommendation: Develop a mechanism that allows NRMs to readily share their restoration knowledge and experience. This is especially important to facilitate the movement of plant species from one NRM region to the next as conditions change. This will not only benefit current restoration projects but also those undertaken in the future as NRMs adapt their practices to ongoing change.

GAP: The success of restoration projects hinges on interactions among many diverse factors such as seed quality, weed removal, soil preparation and water availability. Understanding the role of seasonal variability and climate change in this success is necessary to maximise restoration success.

Recommendation: Disentangling these interactions is complex and beyond the resources of most NRMs and requires the development of long term (>10 year) partnerships between researchers and NRMs.

GAP: Currently measures of restoration success are vague and often judged by the responses of single species or key groups (e.g. woodland birds).

Recommendation: Clarity regarding how NRMs should measure restoration success is required. This should include assessing whether restored sites are being used by animals as well as determining whether the plants themselves are producing seed and seedlings.

GAP: Currently there are no resources to help NRMs use current climate information to forecast success similar to those available in the agricultural sector.

Recommendation: A proof of concept study to gauge the feasibility of creating such a resource as well as the expected utility of such a tool for NRMs is required.

1.2 Planning & preparation

Most restoration practitioners already plan and prepare their project to maximise success but as climates rapidly change it will be necessary to rethink and adapt our strategies. This is likely to include making decisions about not progressing with projects when environmental conditions are poor or seed for some species is unavailable. For NRM planners and their stakeholders this is likely to be initially challenging, especially for funding agencies that desire onground action irrespective of the likelihood of a project's long term success. But climate change does provide us with an opportunity to educate stakeholders and agencies that restoration is a very long term process and that success will be measured over decades not short-term funding cycles. For example, short planning cycles for restoration projects fail to recognise the cyclic nature of seed produced by wild populations and the impacts that this subsequently has on species choice and the places where we can effectively restore complex plant communities (Broadhurst *et al.* 2015a). Presented here are some of the expected impacts of climate on restoration activities as well as some potential adaptation strategies that may be useful in the future.

1.2.1 Seed collection

Seed availability and quality

The availability and quality of seed collected from wild populations is already unpredictable and often influences the number and type of species we choose for restoration (Broadhurst *et al.* 2016). Higher temperature, a greater number of hot days and reduced rainfall in the Murray Basin NRM Cluster are likely to impact on how much seed is produced as well as the quality of that seed. Higher temperatures can change the time at which plants flower and the amount and length of this flowering while reduced water availability reduces the number of seed produced and their size as well as increasing rates of seed abortion (Morgan 1984; Hegland *et al.* 2009). There are also some indication that climate change is impacting on the number and behaviour of plant pollinators, which will in turn influence how much seed is produced by wild populations (Farre-Armengol *et al.* 2014). Another possible consequence of climate change is increased contamination by invasive species as weeds are expected to become more problematic in agricultural areas (Peters, Breitsameter & Gerowitt 2014), potentially invading remnant vegetation in these regions as well. Increases in the frequency of extreme events such as storms and fire will also affect seed availability. Consequently, we may see fewer years with good wild seed production, limiting the amount of restoration that can be undertaken. These changes to seed availability and viability will require us to more effectively source and use seed. Two possible options to help overcome these constraints are outlined in Box 2.

Box 3 Adaptation Options – Seed Stockpiling and Seed Production Areas

Seed Stockpiling is one way of managing unpredictable seed resources in a changing world. If fewer good planting years occur it will probably be necessary to stockpile seed until planting conditions improve and the likelihood of restoration success increases. However, stockpiling seed requires an understanding of seed storage requirements, infrastructure to hold seed under appropriate storage conditions, an accurate and a searchable database to track seed collections and where it has been used in the landscape. This requires a significant investment in resources which is likely to be beyond those of any one NRM. However, collective investment in regional seed storage facility will spread both the cost and risk of this investment. It will also provide a regional mechanism for both sharing seed resources as well as restoration experience such as the ability of particularly species or seed collections to cope with particular conditions.

Seed Production Areas (SPAs), also known as seed orchards, are one way of helping to overcome shortfalls in seed supply and quality, especially for rare or hard to collect species. Growing plants under horticultural conditions removes many of the impacts that water and nutrient availability can have on seed production in wild populations. SPAs can therefore produce large amounts of high quality seed for restoration on a regular basis. This also reduces the need to collect from wild populations, leaving more seed for animals that rely on this as a food source, and for natural regeneration of remnant vegetation. But SPAs require significant financial investment to establish and maintain and it may take several years for some species (e.g. eucalypts) to begin producing seed. The costs associated with SPAs may also to rise as climate changes if more water and fertilizer are required to maintain seed production under drier conditions. Changes to pollinators associated with climate change predicted for wild populations may also impact on SPA seed production.

Figure 6 below outlines some of the possible restoration outcomes associated with seed stockpiling and seed production areas.

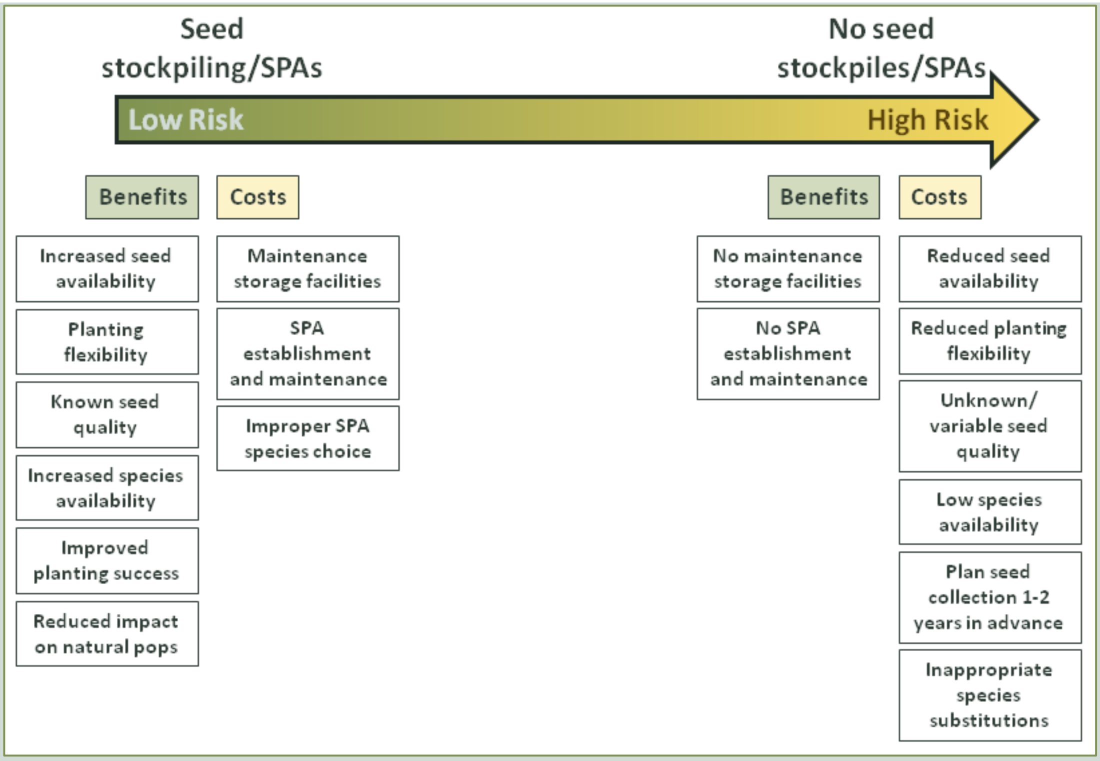


Figure 6 – Possible restoration outcomes associated with seed stockpiling.

1.2.2 Species choice

Despite considerable discussion regarding species selection for future climates, there is little information available to help NRMs make informed decisions for their regions. Even before deciding on which species to use several questions need to be asked early in the planning stage including:

- "What is the purpose of the restoration? Is it:
  - Planting a few species as a windbreak?
  - Adding species diversity to a high conservation areas?
  - Working in a 'novel' habitat (e.g. a salt scald or recently retired paddock)?"
- "Should we be past- or future-focussed? Or possibly both?"
- "What climate change scenario do we think these plants will be experiencing?"

Despite our desire to model plant restoration on what we already have in our landscapes, some researchers are suggesting that climate change, invasive species and human activities make using the “past as prologue” is becoming increasingly problematic (Hiers *et al.* 2012). Some approaches that may be helpful when thinking about what species to plant where in our landscapes include:

- The dynamic reference concept (Hiers *et al.* 2012) selects reference sites against which restoration projects are quantitatively assessed to capture both temporal and spatial change. Quantifying reference ecosystems at the same time as restoration sites may highlight changing conditions in the reference sites that indicates the need for a change in species choice for the restored sites.
- The change-resilience conceptual framework suggests that identifying the individual components of resistance, resilience and adaptability at relevant scales may help to explicitly highlight the strengths and weaknesses of natural systems to temper the effects of change (Prober *et al.* 2012).
- The plant persistence under climate change model predicts the relative ability of plants to migrate into suitable areas including dynamic processes such as dispersal and reproduction as well as landscape characteristics such as connectivity and fragmentation (Renton, Shackelford & Standish 2012). The model may be useful for planting corridors to link fragments that will increase species persistence rates or determining which species may require assisted migration (Renton, Shackelford & Standish 2012).

Regardless of the approach adopted there will be inherent risks such as:

1. Plants from new areas may be poorly adapted to current conditions or fail to germinate.
2. Maintaining current species and not bringing in seed from future climates could leave landscapes wanting when change does occur.
3. Moving species outside of their current distribution may release them from natural enemies such as herbivores and diseases, allowing them to become weedy. Colonising species with high seed production and persistent seed banks such as *Acacia* spp. could fit in this profile.

Box 4 Adaptation options – Choosing species

It is challenging to contemplate which species we would choose to replace those we consider will not be able to tolerate future conditions. Important questions we might want to consider include "Do we substitute a eucalypt for another eucalypt or do we use an acacia because we know it can better tolerate dry conditions?", "What is the purpose of the restoration?", "Is the project seeking to maintain a particular species in the landscape irrepsective of the change that is occurring or do we want to maintain functionality (e.g. provide shrubs that flower all year around to help maintain animals in the landscape)?". One of our big concerns is that if we want longer-lived species to be functional (or at least partly functional) by the time strong climatic effects have taken place (e.g. tree hollows have formed to help maintain birds and animals in the local landscape) then we need to be choosing and planting these species now. But there is no clear method for choosing these species. ***One approach might be to start planting a range of different species in an experimental site or range of sites and watch how these perform in the coming years.***

Another important and often overlooked fact is that establishing only plants does not restore total functionality to a landscape. Successfully restored populations must become self-sustaining and this requires more than just plant survival and growth. ***Plants have many important associations with other species such as pollinators, symbionts and micro-organisms so it is critical to consider these when choosing your species.*** Important questions in this regard include "Do you know what organisms are important to the species you want to use?" and "Are these species already in your landscape?", "If not, are they likely to arrive in the future (i.e. they are mobile) or are they unlikely to arrive and need to be translocated with your plant species?".

Figure 7 below highlights some of the possible outcomes when thinking about choosing species for future climates.

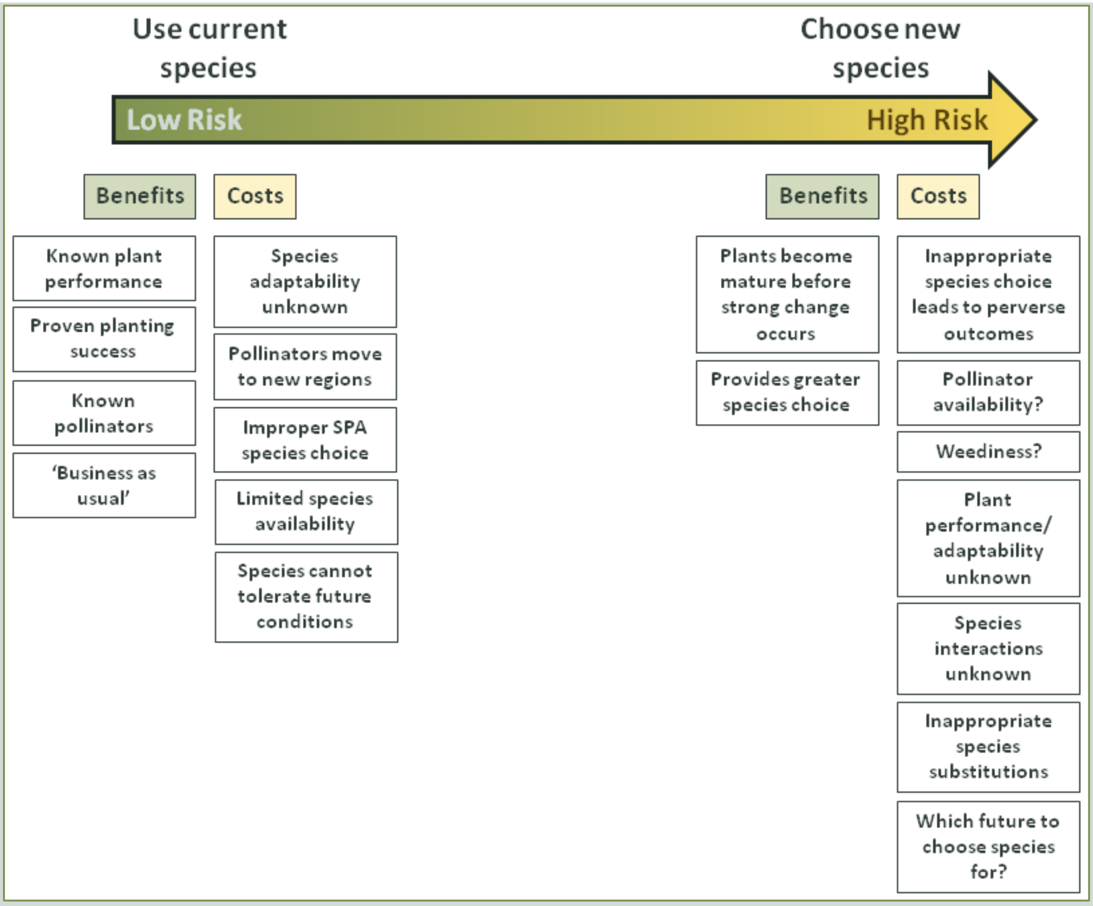


Figure 7 – Possible restoration outcomes associated with species choice.

1.2.3 Genetic considerations

Using local seed for restoration is presumed to prevent negative outcomes that may arise through: (1) maladaptation of introduced seed to local conditions; (2) intraspecific hybridisation resulting in outbreeding depression, i.e. seedlings are less fit than either of their parents; (3) superiority of introduced genotypes that subsequently become invasive; and, (4) impacts on associated organisms, e.g. differences between bud burst and herbivore emergence. But evidence of negative outcomes associated with local adaptation in Australian species are scarce and the results mixed. For example, Hancock *et al.* (2013) found little suggestion that local provenance plants grew better than distant provenances in six species ranging from herbs to trees (Hancock, Leishman & Hughes 2013). In contrast, Harrison *et al.* (2014) observed significant differences in seed weight and germination among *Eucalyptus ovata* provenances but these responses were variably linked to differences in altitude (Harrison *et al.* 2014). Evidence for local adaptation in the herb *Rutidosis leptorrhyncoides* was also highly variable and unpredictable (Pickup *et al.* 2012). Interestingly, Whalley *et al*. (2013) argue that distinct adaptive advantages may be gained by sourcing non-local provenance seed for Australian native grasses, especially when these are matched to the environment of the revegetation site, the restoration purpose, the degree of environmental modification of the site and the characteristics of the species of choice (Whalley, Chivers & Waters 2013).

Perhaps of more importance for restoring vegetation under climate change will be to use seed with a broad genetic base (Broadhurst *et al.* 2008). Using large healthy populations as primary seed sources for restoration is important as these populations are most likely to hold the largest amounts of genetic diversity and have fewer negative effects associated with inbreeding. This is not to say the small populations are not important as these may hold some types of genetic diversity not found in larger populations. But small populations should not be the only seed sources used, rather they should be mixed with seed from larger populations.

Genetic risks

Genetic risks that may impact on the long term future of restoration projects include:

1. Differences in chromosome number within species – if these plants interbreed there is a risk of no seed being produced due to chromosomal malfunction during cell division. Alternatively, seed may germinate and grow to maturity but the adults are either sterile and cannot produce seed or produce seed than is not viable.
2. Hybridisation between closely related species may occur if species that do not normally co-occur are brought together. In some cases, changes in the proportion of species can increase hybridisation rates such as when *Eucalyptus aggregata* is outnumbered by *E. viminalis* (Field *et al.* 2009). The consequences of this are unclear but one can be 'genetic pollution' which may a significant risk to small or remnant populations (Potts *et al.* 2003).
3. Introducing weedy (invasive) genotypes of either the wrong provenance of the target species or a new species that outcompete local genotypes.
4. Outbreeding depression where plants from different genetic backgrounds mate and produce seedlings that are less fit that either of their parents.
5. Differential survival and/or fitness of plants of different species results in incorrect/inadequate species diversity.

A useful tool to assess genetic risks in restoration projects is the decision-making tool developed by Byrne *et al*. (2011) that incorporates taxonomic, biological and geographic/planting variables (Byrne, Stone & Millar 2011). Options for choosing seed sources are outlined in Box 5.

Box 5 Adaptation options – Choosing seed sources

Choosing seed for current and future climates remains controversial. It is always recommended to collect seed from large populations (>200 plants) to capture high genetic diversity but if these are unavailable, pooling seed from smaller populations is appropriate (Broadhurst *et al.* 2008). A provenancing strategy that includes confidence in climate models and population genetic structure and/or environmental differentiation is available (Breed *et al.* 2013) as are guidelines for choosing seed from Australian grasses (Whalley, Chivers & Waters 2013). Current seed sourcing approaches have been summarised by Prober *et al*. (2015) and are outlined in Figure 8.

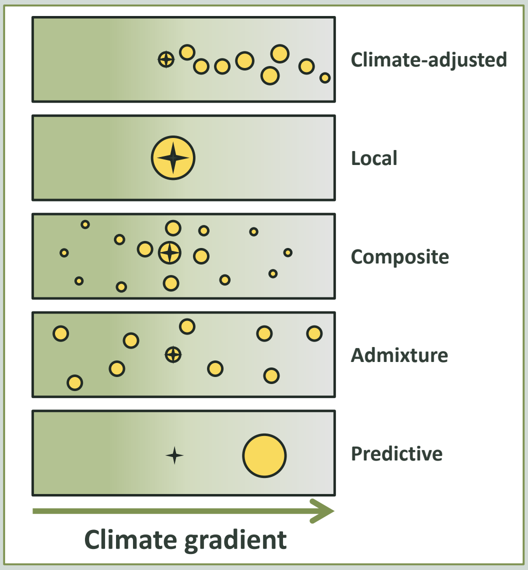


Figure 8: Current approaches to seed sourcing. The cross represents the restoration site, the circles indicate where seed should be sourced according to each approach with circle size representing the proportion to be included in the seed mix. The arrow indicating the direction of climate change (e.g. increasing aridity). Diagram developed from (Prober et al. 2015).

Another tool that can help chose seed from different future climates is available through the Atlas of Living Australia (http://www.ala.org.au/):

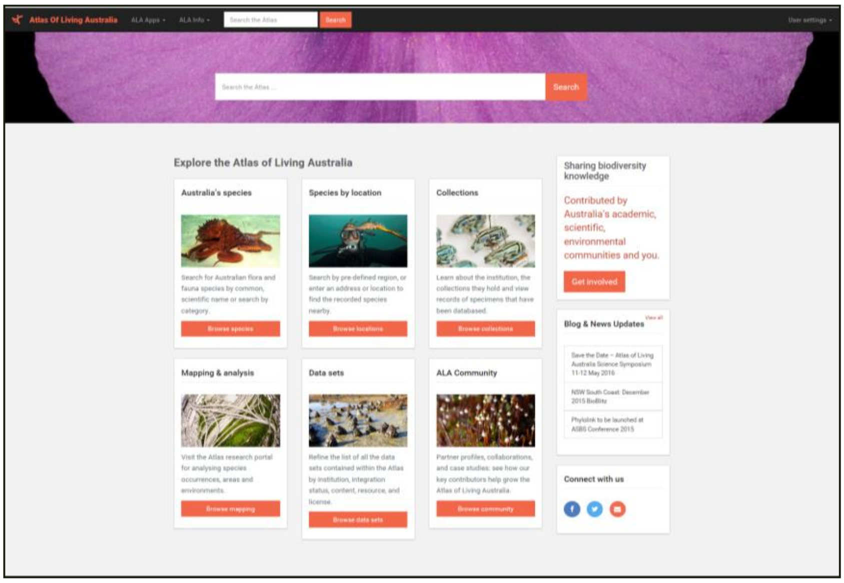


Figure 9 – Home page of the Atlas of Living Australia.

This website can be used to map a species distribution based on specimen collections from AustralianAsian Herbaria:

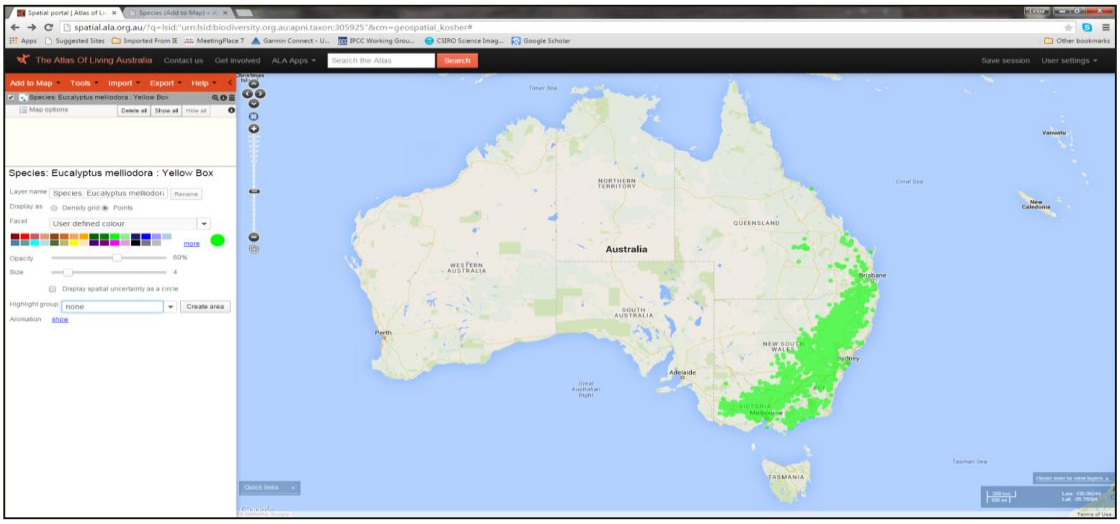


Figure 10 – Eucalyptus melliodora distribution from the Atlas of Living Australia.

You can also zoom in to see a species distribution in more detail, including more information about each record by clicking on a particular point:

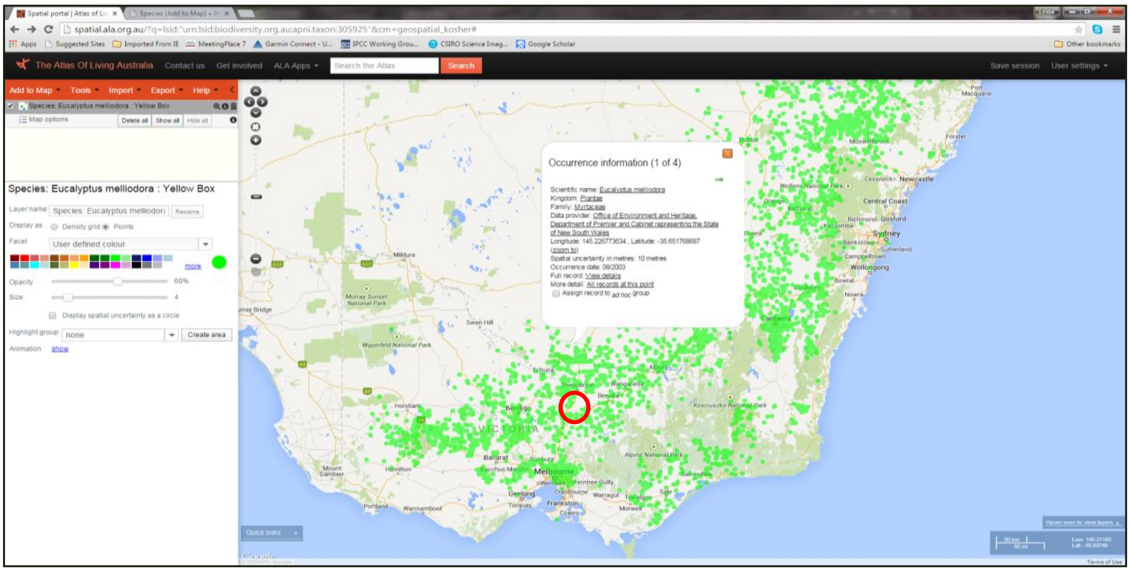


Figure 11 – Example of information for a Eucalyptus melliodora specimen from the Atlas of Living Australia

The ALA can also be used to look at the environmental and climate distribution of a species. In the example below Yellow Box specimens are plotted according to temperature and rainfall (arrows):

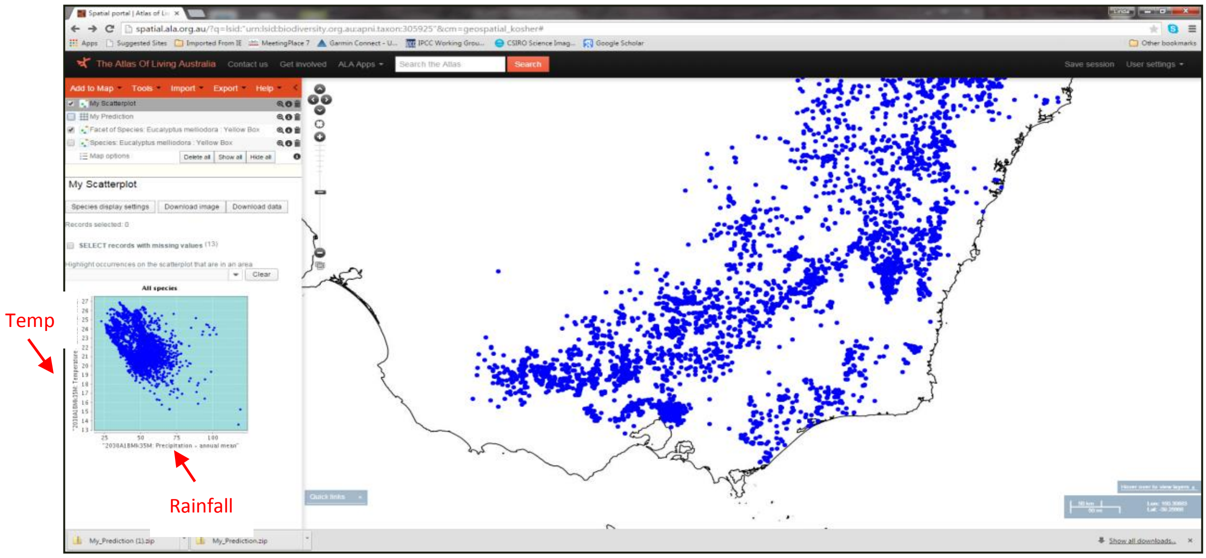


Figure 12 – Example of scatter plot for Eucalyptus melliodora from the Atlas of Living Australia.

You can then draw on the plot what conditions you might like to plant for in the future. In the diagram below higher rainfall and lower temperature have been highlighted by the black box (circled). The locations of these specimens are then highlighted in red on the map of the species distribution:

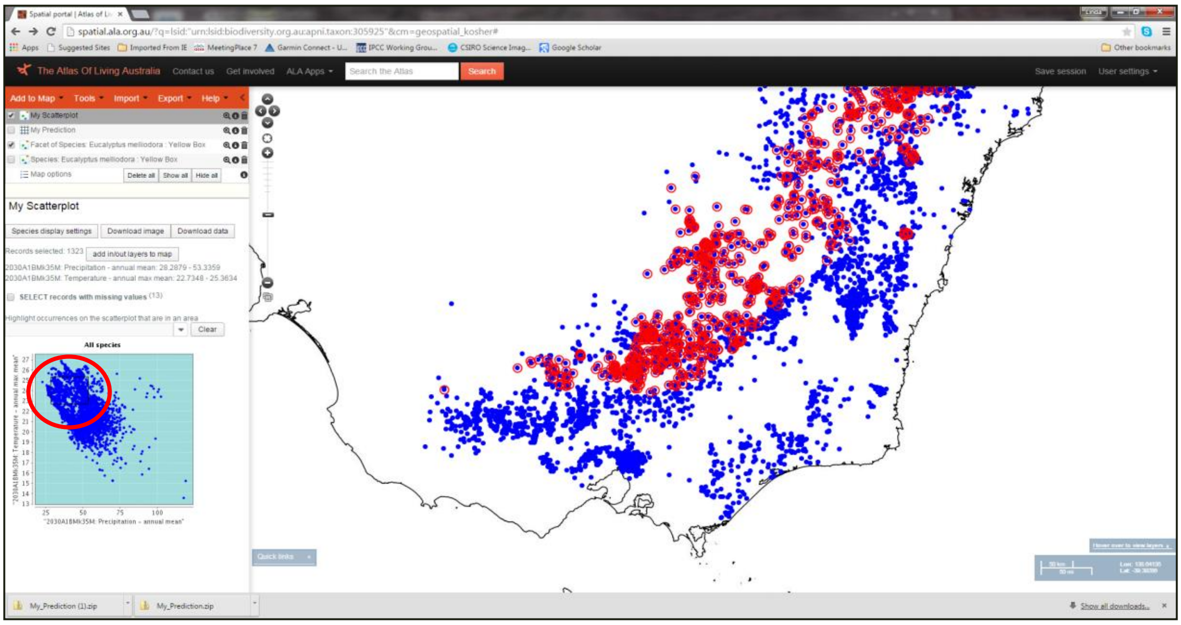


Figure 13 – Example of Eucalyptus melliodora specimens for hotter and drier conditions from the Atlas of Living Australia

More information about how to use these and other functions in the ALA can be found at http://www2014.ala.org.au/spatial-portal-help/getting-started/.

1.2.4 Using seed now and into the future

As with predictions for agriculture (Howden *et al.* 2008), one of the major changes for restoration in the future may be a shift in the timing of planting. This may be especially important for species that are sensitive to planting time or method (Bakker *et al.* 2003; Larson *et al.* 2011; Frischie & Rowe 2012). Studies of Australian species indicate that increased soil warming can reduce germination rates and slow growth (Cochrane *et al.* 2015) with evidence from the WA Gondwana Link project also indicating that soil conditions and dry Mediterranean-climate summers strongly influence seedling emergence and survival over summer (Hallett *et al.* 2014). Simulated drought conditions over two summers (biphasic drought) has also been shown to be detrimental to seedling establishment in Mediterranean ecosystems (Benigno, Dixon & Stevens 2014). Increased seed mass has been found to improve plant survival and growth (Hallett, Standish & Hobbs 2011). Natural plant regeneration from soil stored seed may be influenced by increased soil temperatures possibly accelerating the decline of seed viability, reduced rainfall influencing recruitment success and increased fires compromising the persistence of plants that are dependent on long-lived seed banks (Ooi, Auld & Denham 2009; Walck *et al.* 2011; Ooi, Auld & Denham 2012; Tozer & Ooi 2014).

Changes to the timing and amount of rain as well as an increase in the number and intensity of heavy rainfall events will also influence many aspects of the way we undertake restoration projects in the future. To use seed effectively and efficiently in the future, i.e. planting when and where it will eventually germinate and not simply perish in the soil seed bank, may require shorter planting windows and/or a re-alignment of planting programs to better match favorable environmental conditions (Broadhurst *et al.* 2015b).

Seed dormancy

Little information on how to overcome dormancy or specific germination requirements are available for the majority of Australian species. In addition, there is almost no information on how climate change may influence these traits. But the temperature and moisture experienced by seed as it matures can affect the depth of dormancy, the rate at which this dormancy declines over time, and how seed subsequently respond to environmental conditions or stress (Donohue 2009; Walck *et al.* 2011). Consequently, any shifts in temperature and moisture associated with climate change are highly likely to influence how seed will germinate (Walck *et al.* 2011). Pre-treatments such as physical scarification (Turner *et al.* 2013) and smoke (Roche, Koch & Dixon 1997) to alleviate dormancy in some species have been successfully scaled up to field levels but this success is somewhat unpredictable (Daws *et al.* 2014; Tormo, Moreira & Pausas 2014) as there are many biotic and abiotic factors that influence seed germination and establishment in the field.

Direct seeding

While direct seeding can sow large areas of seed relatively quickly, we have limited information of how efficient and effective this is at creating complex plantings. It also uses large quantities of seed with little information available on how effective planting rates, species mixes and planting methods are. Planting design may be an important but overlooked component of long term restoration success as it can influence seed set (Morgan & Scacco 2006). The use of symbiotic organisms has also been shown to improve survival and growth of restoration plantings (Thrall *et al.* 2005) although not always (Ruthrof & Dell 2011). But many natural soil microorganisms are depleted or missing from agricultural soils (Barrett *et al.* 2009). Techniques such as ripping, even in deep sandy soils, can reduce soil compaction and alter moisture availability within the soil profile, promoting deeper root growth and thus increasing revegetation success in these degraded Mediterranean ecosystems (Ruthrof *et al.* 2013). Any changes to seed availability associated with climate change are likely to have a flow on effect on direct seeding.

Tube stock

The use of tube-stock is also likely to be influenced by climate change if seed availability is reduced while planting out under unsuitable conditions when plants are unlikely to survive and establish will waste precious seed resources. Optimising nursery nutrient regimes may increase root-growth potential, assisting in improving plant establishment in restoration programs (Griffiths & Stevens 2013). Nursery hardening is vital for planting into dry soils and sites. Short term survival of transplanted shrub seedlings in arid and semi-arid sites in Colorado was improved by adding hydrogel to the root zone or creating microsites (Minnick & Alward 2012). In Mediterranean systems, early seedling establishment has been improved through the use of tree guards and addition of water and nutrients although interactions between rainfall and nutrients can be unpredictable (Ruthrof *et al.* 2010; Standish *et al.* 2012; Ruthrof, Renton & Dixon 2013).

Some adaptation options are outlined in Box 6 and knowledge gaps in Box 7.

Box 6 Adaptation options – Restoration actions

1. Longer term planning programs (i.e. planning across decades) will be key to ensuring the effective use of seed into the future.

2. Although choosing seed sources can be challenging ***dormancy*** may help NRMs to bet-hedge their restoration projects to meet future climate change. For example, seed with hard coats such as acacias, is often scarified before direct seeding but some NRMs leave a portion of this seed unscarified. This creates a small soil seed bank that germinates over time in a similar manner to natural populations. A similar approach could be used for seed sourced from populations predicted to represent future climate scenarios. While some of this unscarified seed may decline in the soil over time, there should still be some available to germinate when conditions close to those from which it was originally derived occur in the restoration site. This would require extremely good tracking of seed sourcing and use.

3. Seed coating, which can slow germination (Turner *et al.* 2006), may provide a similar mechanism for other seed types. Varying the thickness of coating would spread the time over which germination occurs.

4. Seed balls, which are mixes of seed in a matrix such as clay or non-toxic polymer, may provide a means of spreading germination over time and may be particularly useful if seed ball size and species composition are varied.

5. Restoration to be undertaken in an ***experimental framework*** to enable long term monitoring and evaluation and adaptation to change.

Box 7 Knowledge gaps

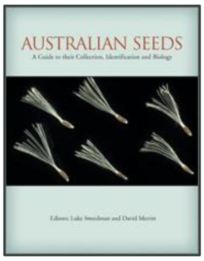
Several knowledge gaps constrain our current ability to undertake restoration for the range of species required including:

1. A lack of knowledge of the germination and storage requirements for most species used for restoration. This is limiting our ability to restore diverse ecosystems efficiently, a situation that is likely to be exacerbated in the future.

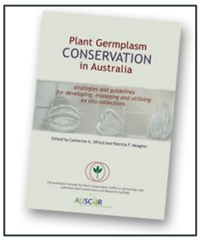
2. Understanding how well field practices are meeting our current restoration needs and will these be appropriate in the future. For example, we know almost nothing about sowing rates and seed wastage.

This will require strong support through direct research investment to ensure that restoration programs can increase the diversity of species used, improve germination and establishment rates in the field, and build plant communities that are able to adapt to the challenges of climate change.

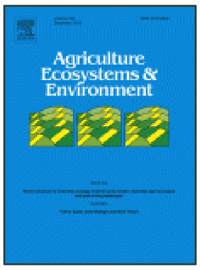
1.2.5 Useful Resources



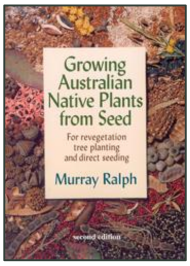
Australian Seeds This book is about the biology, collection, storage and use in conservation and restoration of seeds of native Australian plant species, with emphasis on those that occur in Western Australia (Sweedman & Merritt 2006) More information is available at http://www.publish.csiro.au/pid/5281.htm



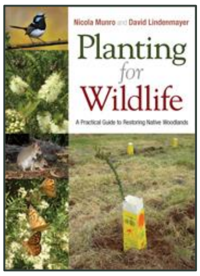
Plant Germplasm Conservation in Australia: Discusses priority setting, collection, storage, seed banking, germination/dormancy, tissue culture and cryopreservation of plant germplasm(Offord & Meagher 2009). Available at: http://www.anbg.gov.au/anpc /publications/germplasm.html



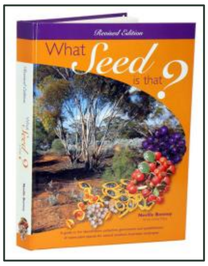
"This special issue highlights agro-ecological land restoration within Australia with emphasis on land use and ecological function, and its impact on biodiversity interactions and species conservation. Topics include: reforestation of degraded agricultural landscapes with Eucalyptus; carbon sequestration, biodiversity and salinity management in agroforestry systems; use of arbuscular mycorrhizas in extensive cropping systems; use of insect diversity for determining land restoration development; rehabilitated grassland assessment; post-mined land rehabilitation; and ecohydrological feedback as land restoration tool." (Audet, Mulligan & Tibbett 2012). Available at http://www.sciencedirect.com/science/journal/01678809/163



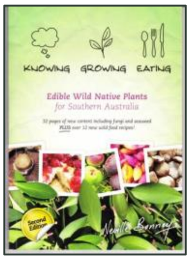
Growing Australian Native Plants from Seed: Outlines methods used to propagate native species from seed for large scale revegetation, trees planting or direct seeding projects. Available at http://www.publish.csiro.au/nid/18/pid/3719.htm



Planting for Wildlife: "Planting for Wildlife provides the latest information on restoring woodlands, with particular emphasis on plantings as habitat for wildlife. Key topics include why it is important to revegetate, where to plant, how to prepare a site, how to maintain and manage plantings, and how they change over time. The authors focus on the south-eastern grazing region where domestic livestock grazing and/or cropping have been prominent forms of land use. These agricultural landscapes have suffered widespread land degradation and significant losses of biodiversity. Revegetation is a vital step towards solving these problems." (Munro & Lindenmayer 2011). Available at http://www.publish.csiro.au/pid/6716.htm).



What seed is that? A field guide to the Identification, Collection and Germination of Native Seed in South Australia by Neville Bonney.



Knowing growing eating edible wild plants for South Australia by Neville Bonney.

1.3 Monitoring & evaluation

Monitoring and evaluating the effectiveness of restoration projects is already a considerable challenge for many NRM groups with too little money and time. In addition, while considerable data is often collected to fulfil reporting requirements, this does not necessarily answer the question "Did the restoration project achieve what was expected?" Three types of attributes are most commonly found in the scientific literature for assessing the success of restoration – diversity and abundance, vegetation structure, and, ecological functioning (Wortley, Hero & Howes 2013). Of these, diversity and abundance are most commonly used as these are considered to reflect habitat suitability but can also indicate the state of succession and ecosystem services; these measures are often favoured when resources are low (Wortley, Hero & Howes 2013).

1.3.1 Planning and purpose

Good planning is already the key to ensuring that M&E produces data that are relevant and can be analysed. As with any planning, having clearly defined questions and measures of success are necessary prior to the start of a project. Since we currently have a limited understanding of how climate change will influence restoration success, it is possible that existing M&E approaches will continue to be useful. However, developing adaptation strategies to highlight changes to future M&E processes to ensure that important information is not missed, may be prudent. The 'Exploring Adaptation Pathways in the Murray Basin' (Dunlop *et al*. 2016) approach may be helpful in this regard.

1.3.2 Some resources

Many NRMs work in partnership with researchers to undertake M&E. But it is important to recognise that once a project has finished, ongoing monitoring using the same approaches may not necessarily continue to fit your requirements. Some funding agencies also have specific M&E requirements which are important for their reporting, but do not provide the amount or type of data NRMs need to measure the long term success of their projects. Despite the importance of M&E there are relatively few practical resources available but some that might help guide M&E are listed below.

The ADAPTNRM website (left; http://adaptnrm.csiro.au/) has information that you may find useful for monitoring (right; http://adaptnrm.csiro.au/adaptation-planning/the-nrm-adaptation-checklist/monitoring/):

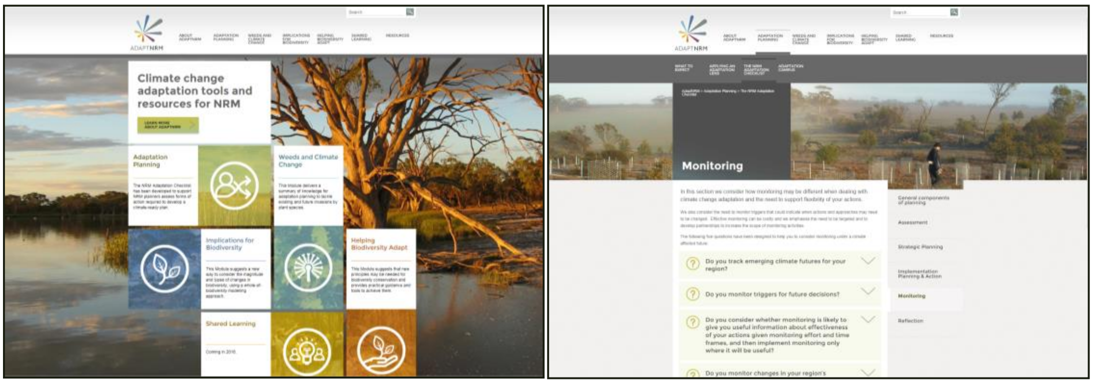
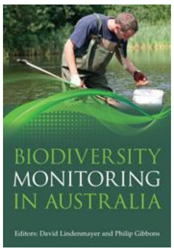
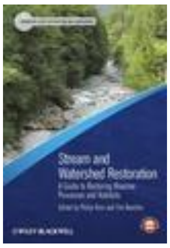


Figure 14 – Climate Change in Australia website pages

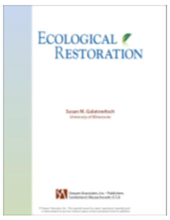


Biodiversity Monitoring in Australia. Available at http://www.publish.csiro.au/pid/6770.htm

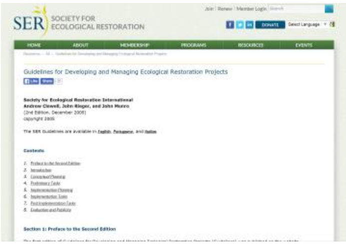
Vegwatch Manual. Available at http://www.act-vegwatch.com.au/Download_Manual



Streams and Wetland Restoration. Available at http://onlinelibrary.wiley.com/book/10.1002/9781118406618



Society for Ecological Restoration (SER) Guidelines. More information available from http://www.sinauer.com/media/wysiwyg/tocs/EcologicalRestoration.pdf



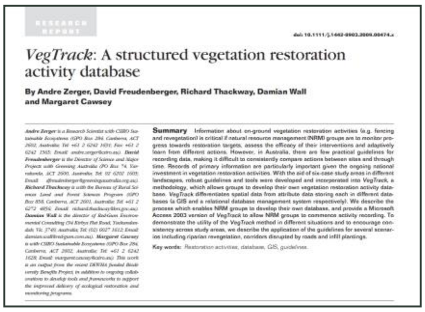
SER SOCIETY FOR ECOLOGICAL RESTORATION

Guidelines for Developing and Managing Ecological Restoration Projects

Available at http://www.ser.org/resources/resources-detail-view/guidelines-for-developing-and-managing-ecological-restoration-projects

NATIONAL STANDARDS FOR THE PRACTICE OF ECOLOGICAL RESTORATION IN AUSTRALIA

Draft Australian Standards for Ecological Restoration (SERA) scheduled for release in March 2016. Available at http://www.seraustralasia.com/pages/SERARestorationStandards_15dec2015.pdf



VegTrack: A structured vegetation restoration activity database

By Andre Zerger, David Freudenberger, Richard Thackway, Damian Wall and Margaret Cawsey

VegTrack. Ecological Management & Restoration Vol. 10, Issue 2, pages 136-144. http://onlinelibrary.wiley.com/doi/10.1111/j.1442-8903.2009.00474.x/epdf

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