Climate-ready revegetation

A guide for natural resource managers. Version 2

Overview

This Guide represents a first attempt at compiling online tools available to assist natural resource managers incorporate the inherent uncertainties associated with climate change when planning revegetation activities. The information in the Guide is based on the premise that survival and resilience will be enhanced for species and local populations with large, genetically diverse populations. Species differ in their vulnerability to climate change. Species that cannot evolve and adapt to new environmental conditions *in-situ* as fast as the climate changes, or disperse to more suitable climes, will be more vulnerable than those with the evolutionary potential and/or the capacity to disperse. In theory, plants with wide distributions are more likely to cope with climate change than those with narrow distributions. However, even if a species' distribution indicates that it is able to tolerate a broad range of climate conditions, survival of local populations is not guaranteed. Small populations may require genetic rescue (incorporating non-local genetic material) to boost their capacity to adapt to a rapidly changing environment.

The Guide provides step-by-step instructions on where to find and how to use climate projections and how to consider the suitability of species and provenances for revegetation projects (Figure 1). The consideration of factors other than climate change to determine the suitability of species and provenance selection (e.g. soil characteristics, topography and aspect) are covered in other publications and are not addressed in this Guide (e.g. the Standards for the Practice of Ecological Restoration in Australia (SERA) **http://www.seraustralasia.com/pages/standards.html**, or look for regional examples such as **www.biodiversitygateway.com.au/SWSR_Guide/home.html**).

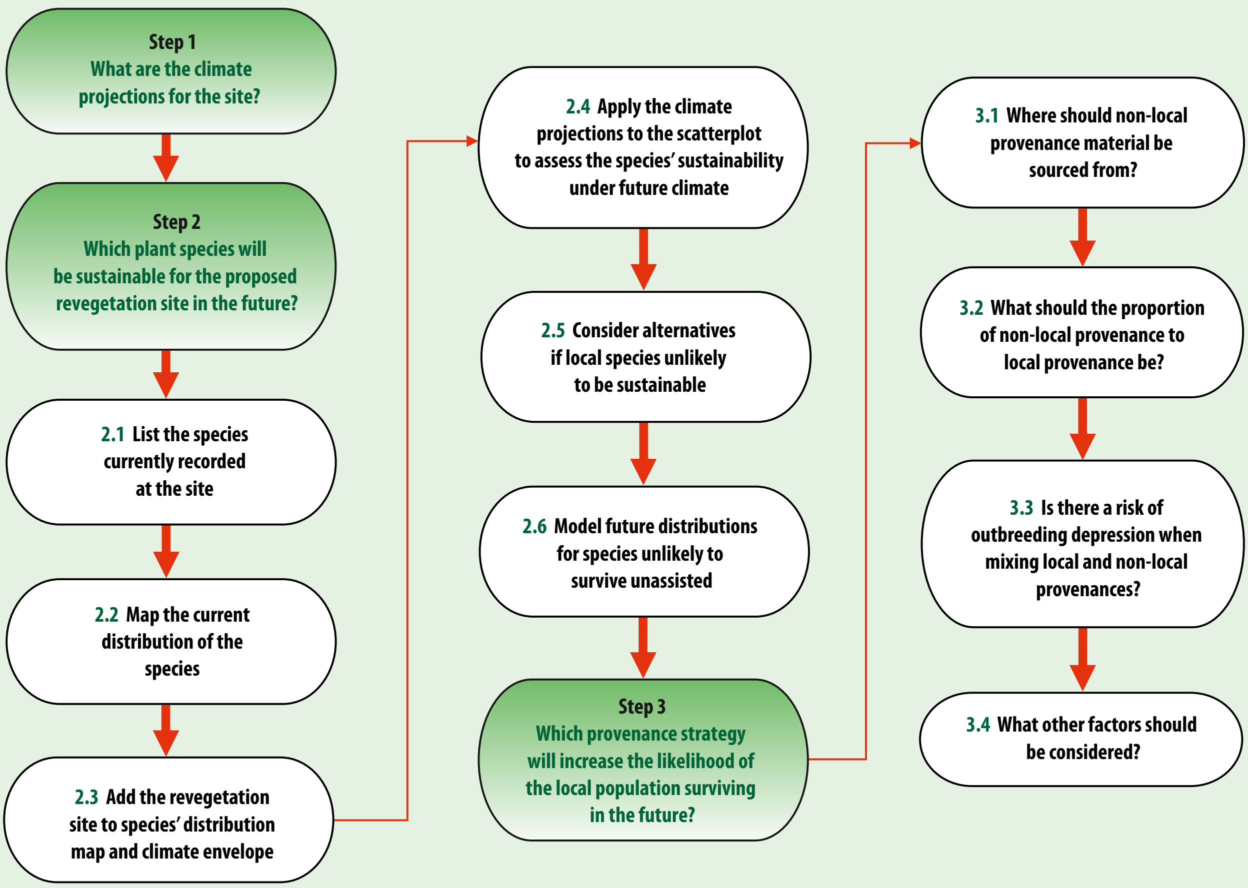


Figure 1. Steps 1–3 (1) Where to find and how to use climate projections; (2) How to consider which plant species will be sustainable for the proposed vegetation site; and (3) How to consider an appropriate provenance strategy.

Glossary

Adaptive capacity: The ability to evolve and adapt to a new environment

Adaptive management: Used in situations where despite uncertainty, decisions and actions must be made and acted upon. The process acknowledges that the information used to make these decisions is incomplete and therefore may be incorrect. Emphasizes learning from the outcomes of these decisions to inform future decision-making

Ecosystem services: Processes or services provided by species and ecosystems, e.g. crop pollination by insects

Evolutionary potential: The potential to evolve

Germplasm: Seed or other regenerative material

In-situ: In the original place

Niche space: Realized niche space – the area that a species occupies vs **Available** niche space – the area that is suitable for that species to occupy (but the species is not present)

Introduction

Climate change is no longer just a concern for the distant future. Australian temperatures have increased by almost 1°C since 1910[1] while rainfall, and the intensity and frequency of extreme weather events such as floods and droughts, are also changing. We are already witnessing shifts in species' distributions and changes in life cycles, populations and physiology, consistent with responses to the relatively modest climatic change of the past few decades. As species continue to respond to the changing climate, we will see accelerating changes in the composition and structure of ecological communities and the ecosystem services they provide.

Rapid environmental change presents challenges and uncertainties for landscape managers. Many restoration and revegetation practitioners recognize that changes to current practices are needed, based on understanding habitat conditions expected in the future, rather than the historical baseline of the past[2]. But how should natural landscapes be managed when the magnitude and direction of projected changes are uncertain and the conditions projected for local sites may not have been previously experienced?

This Guide provides information on how to use on-line tools to gauge if existing vegetation (species and local populations) are likely to be sustained as the climate changes. To make these decisions, information on climate projections for the revegetation site, the climatic tolerances of the existing species (as indicated by species' distributions), and the likelihood of survival of local populations are required. The Guide provides step-by-step instructions on how to (1) find and use on-line regional climate projections for a local site; (2) evaluate which plant species may be sustained at the site in the future; and (3) consider which strategy for selecting provenances will increase the likelihood of the local population surviving in the future (Figure 1).

These steps are designed to acknowledge uncertainties about the nature and scale of physical change and to support the development of strategies that are as robust and climate-ready as possible, given our current knowledge (see Box 1). The focus is on maintaining the adaptive potential of species and vegetation communities, through careful species and provenance selections, and through maximizing genetic diversity. The Guide should be used to refine a provisional planting list that has considered all other aspects of suitability (such as soils and propagule availability).

Box 1

Robust decision making for an uncertain future

A major challenge for planning climate-ready revegetation is that we cannot know exactly what the future climate at a particular time at a particular site will be, or precisely how any individual species will respond. However, we do know that change will continue to occur and that we need a flexible decision-making process based on the best available science. The greenhouse gases already emitted have most likely locked the world into at least another degree of warming over the next few decades, although the climate in the second half of the century will depend on the success of emissions reduction strategies. But even if greenhouse gas emissions were to cease immediately, impacts on the climate may still be felt for many decades, possibly centuries, to come[3]. Uncertainty cannot be an excuse for inaction or for business-as-usual, because decisions made now will have long-term consequences.

There are several ways in which decisions can be made more robust to the uncertainty inherent in planning for the future[4]. Wherever possible, we need to select options and strategies that:

1. Enhance resilience and adaptive capacity;
2. Will be effective under a range of possible future climates;
3. Have multiple benefits and are low or no-regret;
4. Promote adaptive management and contribute to improved understanding;
5. Allow flexibility.

Box 2

Emissions scenarios

Future greenhouse gas emissions will be affected by a complex array of interacting factors, including changes in human population size and demography, technology developments, and policy changes by governments. The Intergovernmental Panel on Climate Change (IPCC) has developed a set of emissions scenarios to underpin climate projections, based on four alternative combinations of global trends. These are called Representative Concentration Pathways (RCPs) and range from RCP2.6 (lowest) to RCP8.5 (highest) emissions scenario with RCP4.6 and RCP6 representing intermediate pathways[6].

Global emissions are currently tracking at the higher end of the RCP8.5 pathway[12]. This pathway does not include any mitigation target, resulting in considerable increases in greenhouse gas emissions over time, and a radiative forcing (amount of energy reaching the earth's surface) of 8.5 W/m^2 by the end of the century. RCP8.5 projects increases in global mean temperatures of 2.6–4.8°C for 2100 (relative to 1990). If the most recent pledges for emissions reductions of nations that are signatories to the UNFCCC are met, the world is on track for warming of 2.7–3°C in the latter half of the century[13].

Climate trends in Australia

Australia has experienced warming of 0.09°C per decade since 1911[5], and mean temperatures are projected to continue rising this century[6]. By 2030, the annual mean temperature in Australia is projected to increase by 0.6–1.3°C (compared to 1986–2005), with little difference between emissions scenarios (see Box 2). The magnitude of change later this century depends on the trajectory of global emissions. At the current rate of emissions, temperatures are projected to rise by as much as 2.8–5.1°C by 2090[7]. Even if a strong mitigation policy led to emissions peaking around 2040 before declining, temperature increases of between 1.4 and 2.7°C are projected[7].

The magnitude and rate of current and projected climate change varies among regions. Future temperature increases are projected to be higher in inland Australia and the Australian Alps, and lower in coastal areas and islands, including Tasmania. Changes to rainfall are also projected to vary between seasons and regions, but generally, wet areas are projected to become wetter and dry areas to become drier[7]. Topography will influence the changes in climate experienced at a local site or microhabitat scale.

As average temperatures continue to increase, changes in the frequency and/or intensity of extreme events will also continue. Extreme hot days are already more frequent, as is the frequency, intensity and length of heatwaves. Extreme rainfall events will continue to increase, with more intense rain falling in shorter periods, increasing runoff and soil erosion[7]. Changes in extreme events, especially for hot days and periods of drought, rather than changing average conditions, are critically important for plant mortality. In ecosystems such as coastal wetlands, acceleration of sea level rise also needs to be considered, as well as the associated increases in the frequency and severity of coastal flooding during storms.

The risk of extreme fire danger weather, especially in southern Australia is increasing[8], driven by increasing temperatures and long-term declines in cool season rainfall[9]. The Australian fire season is also lengthening[10], with significant implications for the ability of fire management agencies to conduct hazard reduction[9]. Increasing frequency and severity of fire regimes is very likely to be one of the most important drivers of ecosystem change in coming decades[11].

Step 1. What are the climate projections for the proposed revegetation site? Where to find and how to use climate projections at the regional level

A variety of on-line tools are available to assist natural resource managers to plan for plausible climate futures at a regional level, although the level of spatial resolution varies between tools developed in different States and regions. It is not possible, nor desirable, to use a single value for the change in temperature or rainfall at a particular site for a particular time period, because there will always be uncertainty associated with projections[14]. The values derived from the tools will depend on the emissions scenario (see Box 2) and climate model chosen, and the range of uncertainty will be greater for some variables. For example, projections of future rainfall are generally more uncertain than those for temperature. Indeed, in some instances, projections of rainfall at a site not only vary considerably in magnitude but also in direction.

One approach is to consider both a 'worst case' and 'best case' scenario, where 'worst' and 'best' are defined in relation to existing climate (e.g. a dry location projected to be drier). The Climate Projections for Australia website has a tool that demonstrates this approach (see Box 3) and Figure 2 illustrates the ranges provided on the NARCLiM website (Box 3).

1. Go to Box 3 and find the climate projection for the region of interest. Box 3 provides a list of web-based tools, developed at both the national and State level that can be used to project environmental conditions at the regional level. If projections at the regional level are not available for the particular State, the CSIRO and Bureau of Meteorology website (Regional Climate Change Explorer) will be the most useful.

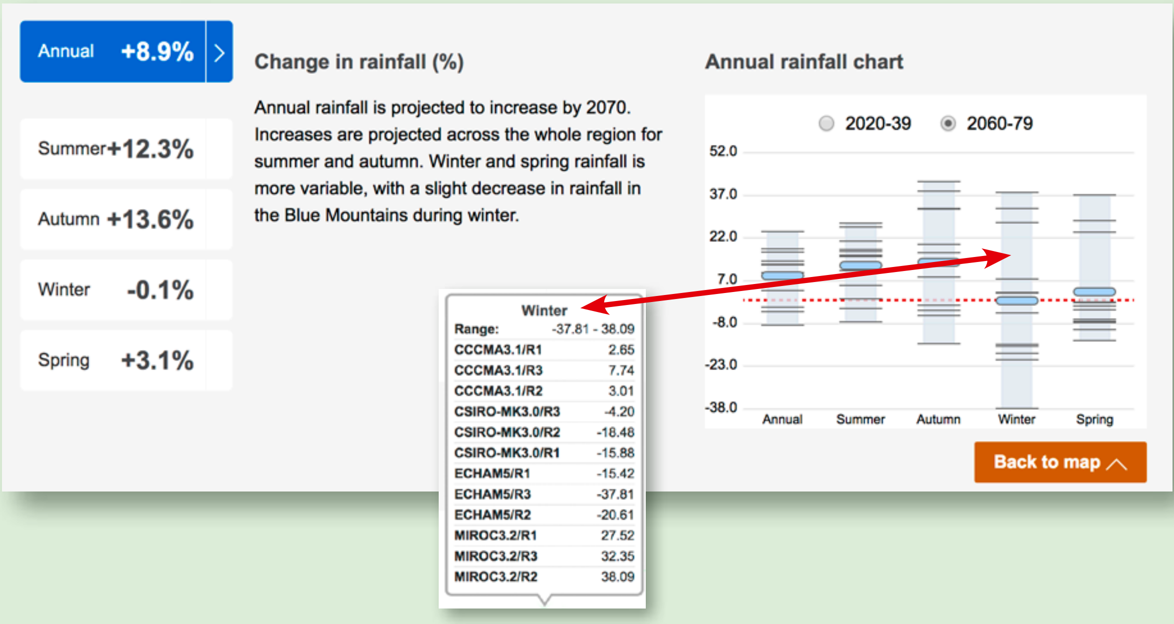


Figure 2. Range of rainfall projections, 2060–2079, compared to the baseline climate (1990–2009) for the Metropolitan Sydney region (taken from http://www.climatechange.environment.nsw.gov.au). Note that the variation in projections for winter span both drying and wetting, ranging from a decrease of 37.8% to an increase of 38%, with a mean of -0.1%. In contrast, the majority of the models agree that rainfall in autumn will increase.

Box 3

What will the site be like in the future? A toolbox of resources

Climate projections for Australia (CSIRO and Bureau of Meteorology)

Go to **www.climatechangeinaustralia.gov.au**. Support and guidance on how to use the website is available at **http://www.climatechangeinaustralia.gov.au/en/support-and-guidance/**. This website provides access to a wide range of tools, datasets and guidance material. These tools include:

- **Regional climate change explorer**

  To obtain a regional climate change projection:

  1. Go to **http://www.climatechangeinaustralia.gov.au/en/climate-projections/about/modelling-choices-and-methodology/regionalisation-schemes/**
  2. Click on the 'Cluster Search Tool' link (an excel spreadsheet) to determine which cluster represents the region of interest:
  3. Click on the link 'Cluster report': **http://www.climatechangeinaustralia.gov.au/en/publications-library/cluster-reports/**
  4. Click on the link for the region of interest.

- **Thresholds calculator**

  Users can explore projected changes in the annual-average number of days above or below selected thresholds for maximum and minimum temperatures at over 100 sites. **http://www.climatechangeinaustralia.gov.au/en/climate-projections/explore-data/threshold-calculator/**

- **Australian Climate Futures**

  A tool that tabulates projected changes in two climate variables, selected from a list of up to 16 variables. It shows the clustering and spread of projections produced by up to 40 climate models, for selected years and emission scenarios. This information can guide the selection of a small subset of climate models for use in impact assessment. Users can select a 'worst case' scenario, a 'best case', or a 'maximum consensus' case that is relevant to their context. **http://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-futures-tool/introduction-climate-futures/**

- **Map explorer**

  This tool allows users to produce a map of climate projections for individual climate models across a range of variables, time periods and emissions scenarios. Users can zoom into regions of interest and download data in different formats. Click on Explore data | Map explorer **http://www.climatechangeinaustralia.gov.au/en/climate-projections/explore-data/map-explorer/**

- Other tools on the site include the **Climate Extremes** explorer (to view projections for cold nights, hot days and extreme rainfall) **http://www.climatechangeinaustralia.gov.au/en/climate-campus/climate-extremes/** and the **Marine Explorer** (for sea level rise and other oceanic variables) **http://www.climatechangeinaustralia.gov.au/en/climate-projections/coastal-marine/marine-explorer/**

- Further information about climate science, climate models, projections and data can be found in the **Climate Campus** **http://www.climatechangeinaustralia.gov.au/en/climate-campus/**, designed to build knowledge in key climate science areas.

State-based climate change tools

NSW & ACT

NARCliM has produced an ensemble of regional climate projections for south-eastern Australia that can be used to plan for the range of likely future changes in climate (2030 and 2070).

Go to: **http://www.climatechange.environment.nsw.gov.au/Climate-projections-for-NSW/About-NARCliM**

To obtain projections for the region:

Either

1. **Download a pdf:**
   a. Go to: **http://www.climatechange.environment.nsw.gov.au**
   b. Click on the 'Climate projections for NSW' tab | Climate projections for your region

Or

2. **Access detailed projections (recommended action):**
   a. Go to: **http://www.climatechange.environment.nsw.gov.au**
   b. Click on the 'Climate projections for NSW' tab | interactive map
   c. Click on the 'Region view' tab
   d. On the interactive map, click in the region of interest
   e. Select the appropriate climate variable and time range from the list on the right hand side of the map (e.g. temperature and click on the arrow)
   f. Click on 'Read more'
   g. Click on the bars on the graph to see the range of projected highs and lows (see Figure 2 for an example)

Tasmania

Climate Futures for Tasmania: Dynamically downscaled climate projections for Tasmania are based on six global climate models under two emissions scenarios (high emissions scenario – A2; and lower emissions scenario – B1) Climate information is available for the period 1961 to 2100 at ~10 km resolution. The summary reports consider changes to mean and extreme climate conditions, runoff and hydrology, and fire danger. **http://acecrc.org.au/climate-futures-for-tasmania/**

Western Australia

The Western Australian Local Government Association has developed a toolkit to help local governments adapt to climate change. **http://walga.asn.au/Policy-Advice-and-Advocacy/Environment/Climate-Change/Additional-Climate-Change-Resources.aspx**

Victoria

Regional climate projections are available from **http://www.climatechange.vic.gov.au**

Queensland

Climate projections are available at **https://www.longpaddock.qld.gov.au**. Users must register on-line to receive the data.

Step 2. Which plant species will be sustainable for the proposed revegetation site in the future?

This section is a basic guide on how to assess the sustainability of plant species for revegetation projects as the climate continues to change. Checking species distribution maps and scatterplots can provide an indication of the climatic tolerance of species. This information can also suggest if future climatic changes may put a species at or beyond its limits of climatic tolerance.

The Atlas of Living Australia (ALA) is an extremely useful resource for visualizing species' distributions in relation to different environmental, including climatic, variables (see[15] or http://www.ala.org.au/wp-content/uploads/2015/02/Belbin_Spatial-Portal-Manual.pdf for examples). We note that some browsers function better than others for some of the ALA functions. Firefox and Chrome tend to give consistent results across all platforms. Occurrence records in the ALA have not been checked for accuracy (i.e. 'cleaned') and this has implications for output and analysis (see Step 2.2 (3) and Box 4). For NSW plants, www.nswnichefinder.net uses only cleaned data from the Australia Virtual Herbarium and also performs some of the functions detailed below.

2.1 List the species currently recorded at the site:

1. Go to the ALA main menu http://www.ala.org.au.
2. Under the 'Explore by location' option, click on 'location', and enter the latitude and longitude of the site or the site's name into the search bar. As an example, enter 36.01S, 146.95E, for a site north of Albury. The 'Explore your area' page shows the location of the site on a satellite map and lists the species.

Download http://www.ala.org.au/education-resources/teachers-guides-2/ Guide #1 for screen shots to assist with this step

3. Further information on particular species can be obtained by clicking on a species of interest from the list, e.g. *Eucalyptus melliodora*; a map of occurrences of that species in the target area appears. Click on 'Species profile' to access summary information about the species or the 'List of records' for more information about the record.

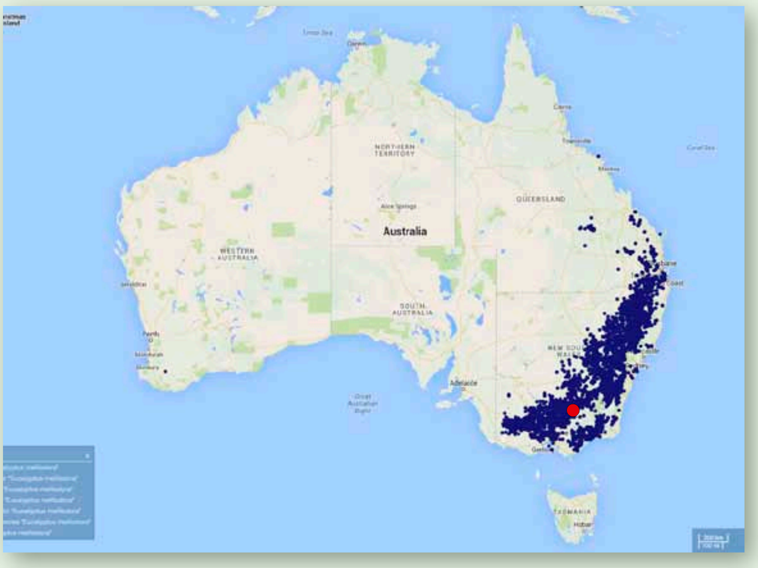


Figure 3. Distribution (Australia) of *Eucalyptus melliodora* (blue dots) and location of proposed revegetation site (red dot). Reproduced from the Atlas of Living Australia.

2.2 Map the current distribution of the species:

1. Go to the main ALA menu http://www.ala.org.au and under 'Mapping & analysis' click on 'Spatial Portal'.
2. Select 'Add to map | Species' and enter the species name, e.g. *'Eucalyptus melliodora'*

Download http://www.ala.org.au/education-resources/teachers-guides-2/ Guide #2 for screenshots to assist with this step and for detailed instructions, including how to view two species at the same time

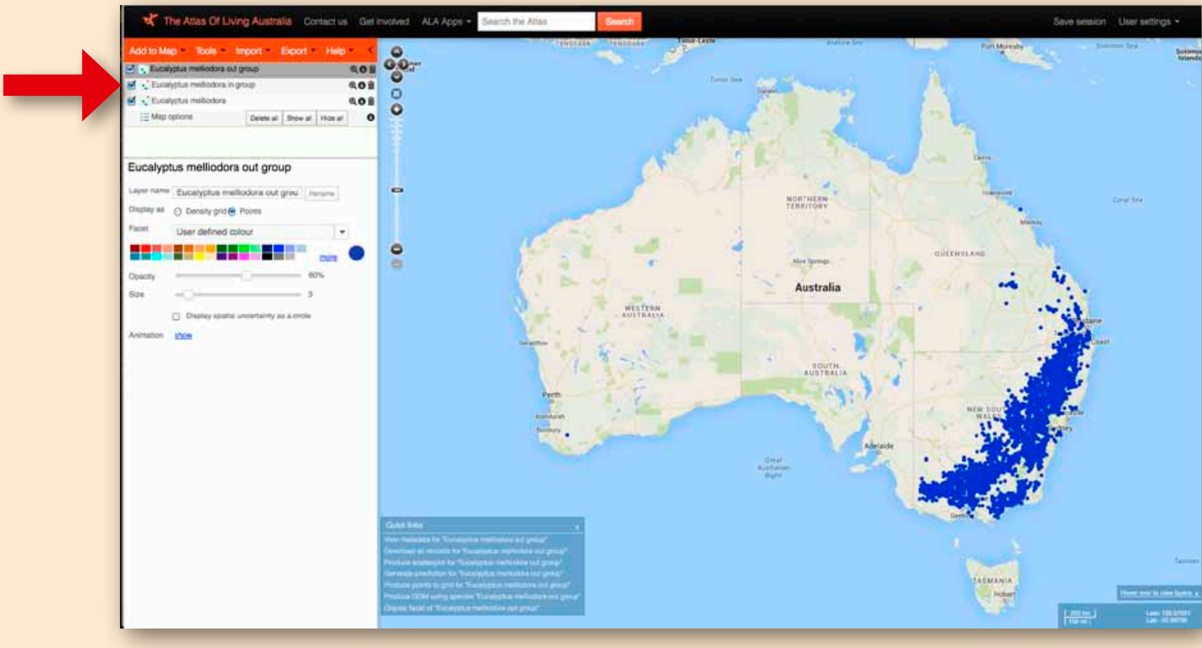
3. Using the example of *E. melliodora*, the species occurrence map (Figure 3) shows that the species has a wide distribution from Victoria to the Gladstone region in Queensland, and also occurs in New Zealand. To check that any 'outliers' are credible records, click on that occurrence dot and then select 'Full record | View details' to display detailed information about the record. If you are not confident that the record is credible, the record can be removed (see Box 4). There is some value in leaving in cultivated locations, and locations where the species has naturalized or has been planted overseas (especially eucalypts[16]) because this gives some indication of the thermal tolerance of the species. However, these records should not be used to indicate rainfall requirements because the plants may be artificially watered.

Box 4

Cleaning the data is an important step

To remove an occurrence record in the ALA, click on the point on the occurrence map – an 'Occurrence information' box appears. Click in the 'Assign record to *ad hoc* group' option. Click on the X at the top of the box to exit. On the left of the screen, click on the 'Add in/out layers to map' option within '*Ad hoc* selection'. The map is revised with the selected point in a different colour (in the distribution map below, the most northerly record is now a different colour). At the top left of the screen (see red arrow on the screenshot below), you have the choice of analysing the data (e.g. scatterplot) with the point removed (the 'out' group) or with the point retained (the 'in' group).

Alternatively, if there is a group of points that you want to exclude, click on 'Add to map' and then 'Areas'. Select 'Draw polygon' and draw a polygon around the points **you want to include**. A new map with only those points is then available.



Reproduced from the Atlas of Living Australia.

2.3 Add the revegetation site to species' distribution map and climate envelope

2.3.1 Add the location of the revegetation site to the distribution map

The location of the revegetation site can be added to the distribution map but this step requires a log in to import the site's decimal latitude and longitude (see https://www.ala.org.au/spatial-portal-help/import-or-upload-points/). However, sometimes simply viewing the species distribution is all that is required to visually assess if the species is likely to have the adaptive potential for a wide range of climatic conditions and thus a suitable candidate for the proposed revegetation site. For instance, if the proposed site corresponds to the hottest or driest range boundary of a particular species, the species may not persist at that site in the future. More detailed analysis of the climate envelope that the target species currently occupies and its likely persistence under future climates can be viewed via a scatterplot (see below).

2.3.2 Prepare a scatterplot to show the species' current climate envelope

To find the decimal latitude and longitude and current environmental values (e.g. mean annual temperature and annual precipitation) of the proposed planting site:

1. Go to http://www.ala.org.au and under 'Mapping & analysis' click on 'Spatial Portal'.
2. Click on 'Add to map | Layers'. Go to 'Add from search' box, type in 'Bio12' and click on 'Precipitation – annual (Bio12)' when it appears from the drop down menu, and '1 layer selected' will appear at the bottom. Go back to the box and type in 'Bio01' and click on 'Temperature – annual mean (Bio01)' and '2 layers selected' appears. Click 'Next'.
3. Decrease opacity to improve map readability. Double click on map to get closer to the site. On the bottom right hand side of the screen, as you hover over the site, the values will appear. Write the values down, close this window and return to the window with the distribution map (Step 2.2).

To add the proposed revegetation site to the scatterplot:

1. Go to 'Add to map | Areas' (see Figure 4). Under 'Searching', click 'Create radius from point | Next'.
2. Enter the lat/long for your site (e.g. 146.95 for longitude and -36.01 for latitude) and then select radius (e.g. 3 km) | Next. (Distances <3 km may be difficult to see on the map).
3. In the top left hand corner, a heading for a new map called 'My area' will appear (Figure 4).

To produce a scatterplot:

1. Go to 'Tools | Scatterplot'.
2. *Step 1:* select 'Current extent' (select 'Next' after each step);

   Step 2: select the species (e.g. *Eucalyptus melliodora*);

   Step 3: 'My area';

   Step 4: temperature and precipitation will probably be the most useful climate variables for plants. In this example, type 'Bio12' into the 2nd box (Add from search) and click on 'Precipitation – annual (Bio12)' when it appears in the drop down menu. Go back to the box and type in 'Bio01' and click on 'Temperature – annual mean (Bio01)' when it appears and two layers will be selected;

   Steps 5 and 6: leave as defaults.

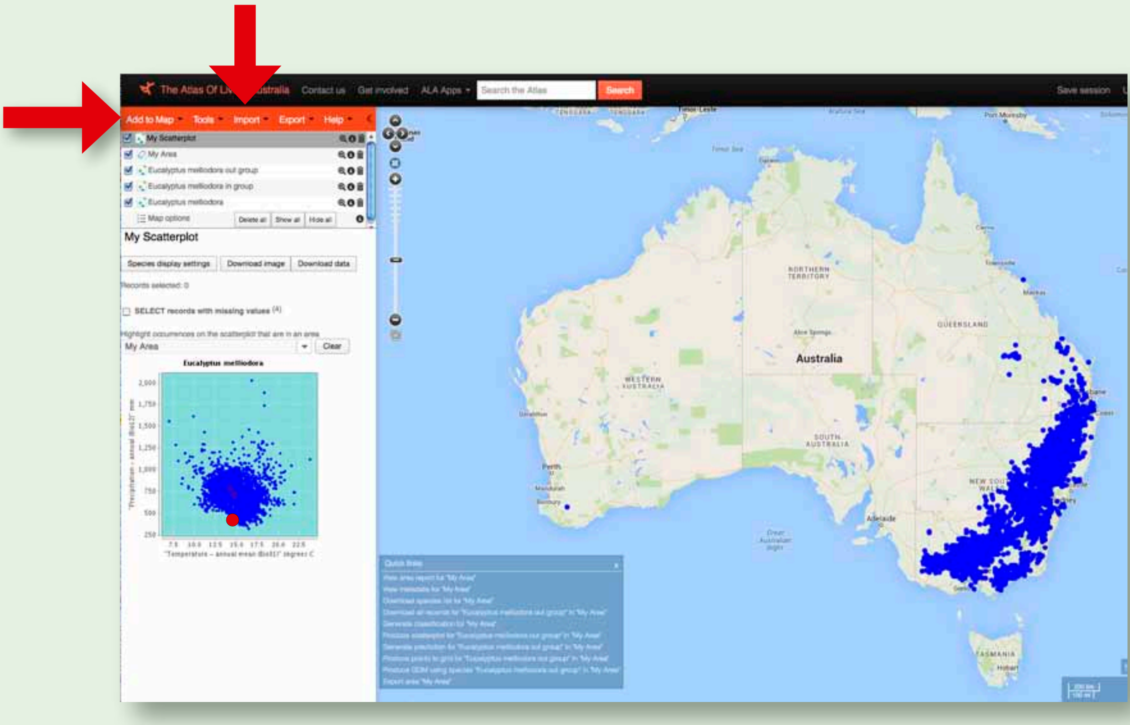


Figure 4. Screen shot of Atlas of Living Australia page after completing all the steps in 2.3. Arrows indicate the tabs to click to perform functions for 2.3.1 and 2.3.2. Note that the red dot has been enlarged in the scatterplot.

We recommend that other variables, such as annual maximum mean temperature and moisture availability, are also analysed for consideration of extreme weather events.

A worked example of a scatterplot with screenshots, using a different species, is available at http://www.ala.org.au/spatial-portal-help/scatterplot/

3. The scatterplot shows the climate envelope the species currently occupies. In this example, the majority of the occurrences of *E. melliodora* are between ~12° and 17.5°C mean annual temperature and 500–1000 mm precipitation (Figure 5). The graph also shows the position of the proposed revegetation site within the climate envelope (i.e. 14.5°C and 730 mm). N.B. using the mouse we can select locations on the scatterplot and they will appear as red circles on the species occurrence map.

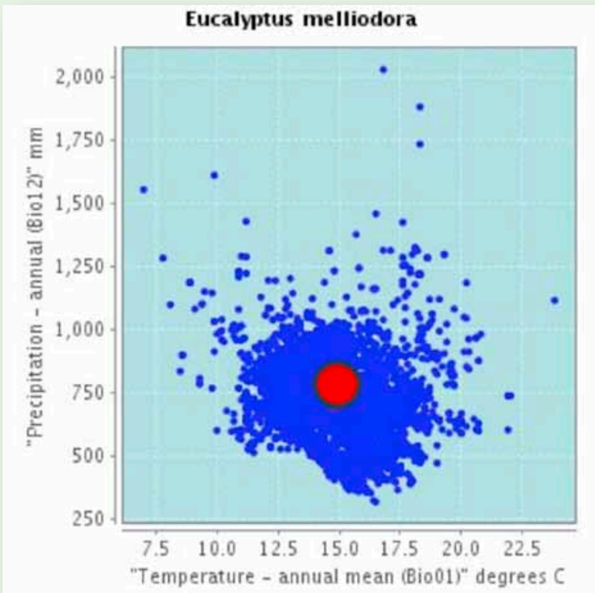


Figure 5. Scatterplot of annual mean temperature and annual precipitation for *Eucalyptus melliodora* occurrences with location of proposed revegetation site. Reproduced from the Atlas of Living Australia. Note that the red circle has been enlarged.

2.4 Apply the climate projections to the scatterplot to assess the species' sustainability under future climate

1. Refer to the future climate projections for the region of interest. Using the example of *E. melliodora* and the Albury site (Step 1, Box 3) (http://www.climatechangeinaustralia.gov.au/en/publications-library/cluster-reports/), a mean warming of 2.7–4.5°C in 2080–2099 (using RCP8.5), with rainfall projected to vary between seasons i.e. -40% to +5% in winter is projected.
2. Compare the climate projections with the information derived from points 2 to 4, particularly the scatterplot. For *E. melliodora* at the Albury site, by the end of the century, the projected rise in mean annual temperature and a 30% decline in annual precipitation is likely to put conditions at the Albury site at the outer limits of those that are currently experienced within the natural distribution of the species (Figure 3). Under those conditions, *E. melliodora* may not be a suitable species and monitoring of distribution changes would be advisable.

2.5 Consider alternatives if local species are unlikely to be sustainable

After completing Steps 2 and 3, if the persistence of existing species is doubtful under changing climatic conditions, plants from outside the local area may need to be considered for the proposed revegetation site. This is particularly important for key species such as those needed to recreate functioning ecosystems. There are many factors to consider if species from outside the local area are included in a planting list and in addition to industry standards (e.g. the SERA Standards for the Practice of Ecological Restoration in Australia), consideration should be given to factors such as:

- Is there a risk of the species becoming invasive?
- Can the species disperse or migrate naturally to the proposed revegetation site?
- Are there any common species at the proposed revegetation site and an analogue town (Box 5)?
- Are the soil types compatible?
- Have any 'new' species already migrated to the proposed revegetation site?

To view a list of species that are currently present in locations with current climates similar to those that a selected location may experience in the future (Box 5):

> Go to: http://www.ala.org.au | Species by location, and follow the instructions set out in Step 2.1.

2.6 Model future distributions for species unlikely to survive without assistance

Species with limited climatic tolerances that cannot adapt to a changing climate *in-situ* or disperse naturally to more favourable climes will be vulnerable to population decline and potentially even extinction. Planning should include the translocation of these species to cooler and wetter (if applicable) locations outside their current range, if these locations exist. More detailed climate analysis can be undertaken in ALA using MaxEnt software. Species' potential distributions are modelled using several environmental layers. This function is not detailed here and we recommend further reading on MaxEnt http://www.cs.princeton.edu/~schapire/maxent/ and examples of modelling[17] before undertaking this step.

A NOTE OF CAUTION **When using tools that only evaluate climate parameters, other determinants of past and future distribution such as soil, aspect, topography and interactions with other species (such as competitors and herbivores) should also be considered. Helpful websites include http://spatial.ala.org.au/ (Add to map | layers) and for NSW plant species, www.nswnichefinder.net**

Box 5

Imagining future changes in vegetation communities

As the climate changes, some plant species may become increasingly unsuited to a particular local site. Changes in the population sizes and distributions of individual species will progressively lead to changes in the characteristics of vegetation communities. For example, shrubby vegetation may progressively replace grasslands in some areas. The Climate analogues tool, available at CSIRO and Bureau of Meteorology Climate projections for Australia website (**http://www.climatechangeinaustralia.gov.au/en/**) provides a useful way of envisioning the magnitude of potential vegetation change at a site under a particular future climate. In brief, the tool is used to find locations in Australia with current climates similar to those that a selected location may experience in the future.

The website provides detailed instructions on how to use this tool, but here we provide an example. Let us suppose that a revegetation project for a site in the vicinity of Melbourne is being planned and we wish to envision what type of vegetation that site might support in the period 2040 to 2059:

1. Go to **http://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-analogues/analogues-explorer/**
2. Either select Melbourne from the dropdown box (left side, bottom of map) or click on Melbourne on the map.
3. Use either the 'Configure data' or 'Preset scenarios' option. To use the preset option, select the cluster Melbourne belongs to (**http://www.climatechangeinaustralia.gov.au/en/climate-projections/about/modelling-choices-and-methodology/regionalisation-schemes/**); the emissions scenario (we use the highest, RCP8.5, see Box 2); time period and the future climate description (see Figure 6).
4. The temperature and rainfall ranges projected under those parameters then appear under 'Configure data', and on the map, arrows point to analogue towns (a list of towns appears below the preset function).
5. Under the parameters selected here, in 2050, Melbourne is projected to have the climate conditions currently experienced in Cootamundra, Nuriootpa, Wangaratta, Keith, Clare, Corowa, Shepparton, Jerramungup, Wagga Wagga, Bordertown, Port Lincoln, Naracoorte, Esperance, Adelaide, Kojonup, and Young. This list of analogue towns will change, depending on the variables that you use.
6. By researching the vegetation types typical of these sites currently, the potential for future vegetation changes at the Melbourne revegetation site of interest can be envisioned.

The caveat to bear in mind is that this tool is a potential source of ideas, rather than a method to simply obtain a list of species that should be planted at the site in question. The tool does not match other potentially important aspects of local climate (e.g. frost days, microclimates) or soil types. However, species from those areas may be appropriate if factors other than climate change are also considered to determine the suitability of species selection. Step 2.5 outlines how to find a list of species from the towns identified in the analogue tool, but we recommend firstly assessing which of the existing species will be sustainable in the future (Steps 2.1–2.4).

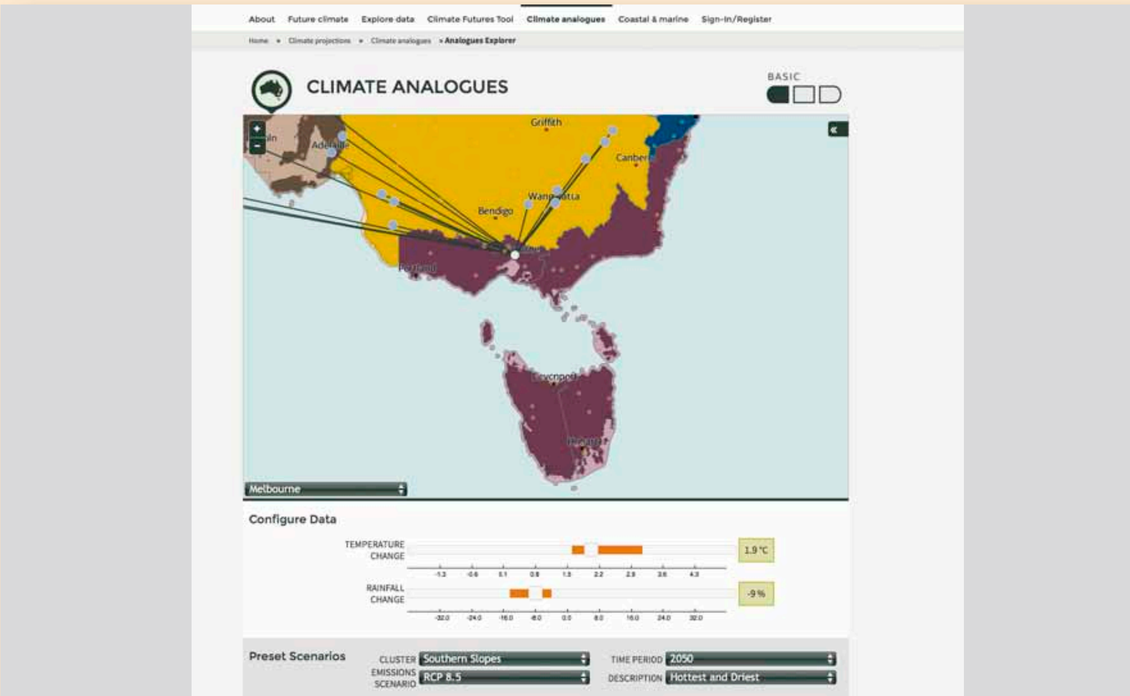


Figure 6. Comparable towns where the current climate matches that projected for Melbourne in 2050, using various preset scenarios. Reproduced from http://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-analogues/analogues-explorer/.

Step 3. Which strategy for selecting provenances will increase the likelihood of the local population surviving in the future?

The strategy to select the provenance/s best suited to a particular revegetation project is context-specific and driven by variables such as the species' phenotypic plasticity (the ability to cope with change through physiological and/or morphological means rather than by genetic alteration), levels of *in-situ* genetic diversity[18], and the location of the revegetation site. Therefore, in this Guide, the selection of the appropriate provenance strategy and subsequent recommendations can only be general and not site-specific.

Even though a species distribution may indicate that the species is able to tolerate a broader range of climate conditions than those currently being experienced at the proposed revegetation site, the survival of local populations is not guaranteed. For example, local populations may not have sufficient genetic diversity to have the capacity to adapt to a rapidly changing climate. The traditional approach of using only locally collected germplasm is based on an assumption that local genotypes are best adapted to local conditions. Given the rapidity of observed and future climate change, this 'local provenance is best' approach is unlikely to provide the most effective basis for long-term sustainability of revegetation projects.

Provenance selection strategies

Including propagation material from locations currently experiencing climatic conditions similar to that projected for the revegetation site will reduce the risk that the revegetation project will fail as the climate changes. Several approaches to selecting germplasm for revegetation are shown in Figure 7 and are briefly explained here: (but see[18] and references therein for more detailed information **http://journal.frontiersin.org/article/10.3389/fevo.2015.00065/full**).

- The '**Climate-adjusted**' approach[18] (Figure 7a) builds on previous research that recommends including non-local provenance with local provenance material to increase genetic diversity and adaptive potential[19,20]. Germplasm is sourced from locations in the direction of predicted climate change.
- A '**Local provenance**' approach (Figure 7b) uses germplasm that is only found within a certain geographic distance to the revegetation site.
- A '**Composite**' provenance approach (Figure 7c) recommends mixing a small proportion of genotypes from non-local high quality and genetically diverse populations with local sources to reinstate historical gene flow and address inbreeding and adaptive potential issues[19].
- Where changes to the local environment are expected but uncertainty about the scale and rate of this change is high, the '**Admixture**' approach may be appropriate (Figure 7d). This approach incorporates a wide variety of provenances with no spatial relationship to the revegetation site and is predicted to build evolutionary resilience[20].
- A '**Predictive**' provenance approach (Figure 7e) uses genotypes solely from a source population that has been experimentally determined to be the best match for the revegetation site[21].

The following points should be considered when selecting non-local provenances:

3.1 Where should non-local provenance material be sourced?

Use the process in Step 2 to select potential provenances. In the *E. melliodora* example, to use the 'Climate-adjusted' provenance method, select points on the scatterplot that represent a gradient towards and/or those that represent climatic conditions that are projected for the region where the revegetation site is located. These selections will then appear as red circles on the distribution/occurrences map. Click on the red circle on the map to get location details. Figure 7 illustrates how to determine which locations are chosen, depending on the provenance strategy. Always strive to collect genetic material from large populations, with consideration of other factors such as soil type.

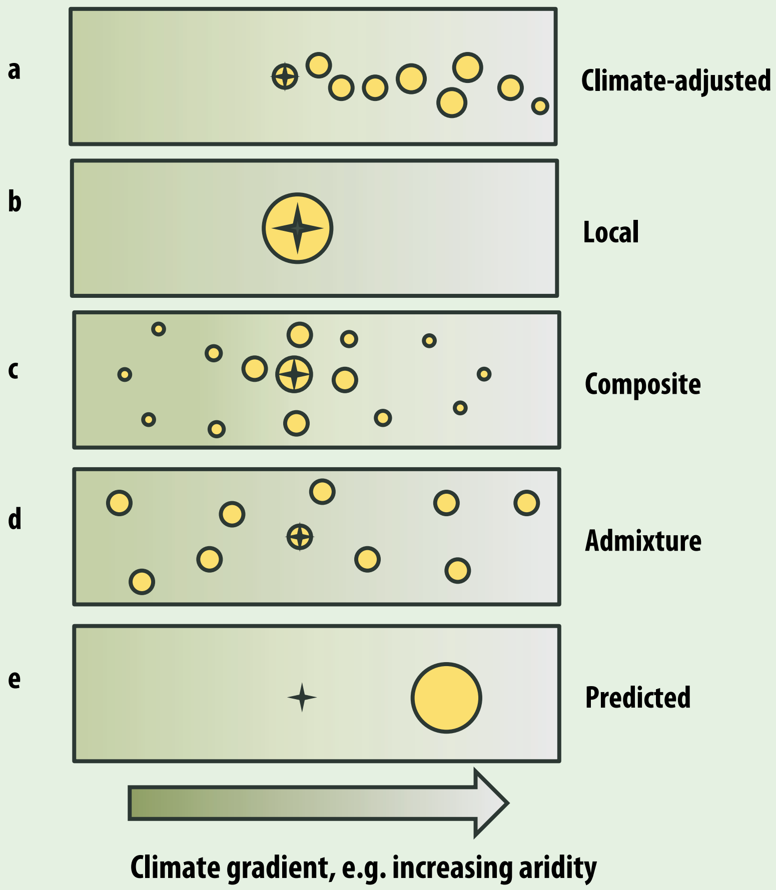
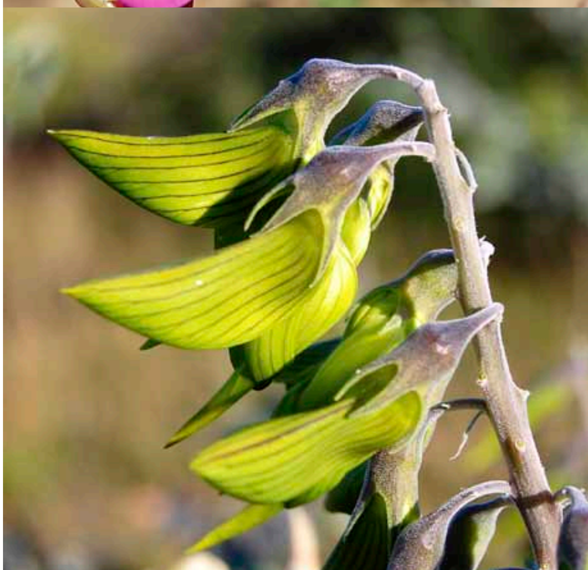


Figure 7. Provenance strategies for revegetation. The star indicates the proposed revegetation site, and the yellow circles represent populations of the species. The size of the circles indicates the relative quantities of germplasm included from each population for use at the revegetation site. Climate change is represented as increasing aridity but other dimensions (e.g. increasing temperature) could be used[18]. Figure modified from[18,23].







3.2 What should the proportion of non-local provenance to local provenance be?

Figure 7 illustrates how to determine the proportions of different provenances to satisfy the different strategies. The star represents the proposed revegetation site and the green circles represent different populations of the target species. The size of the circles indicates the relative quantities of genetic material included from each population for use at the revegetation site[18]. For example, to adopt a Climate-adjusted provenance strategy where the revegetation site is projected to become warmer and drier, provenances should be selected along a gradient of warmer and drier locations[18]. The proportion of local germplasm that is combined with proportions of non-local germplasm along the gradient reflects the confidence in climate change projections and the likely genetic compatibility of the different provenances[18].

This Guide cannot be prescriptive about the best provenance strategy for individual sites. However, the provenance strategies shown in Figure 7 (a), (c) and (d) will increase genetic diversity and adaptive potential, compared to the sole use of local provenance. Further information regarding the different provenance strategies is available from[18] **http://journal.frontiersin.org/article/10.3389/fevo.2015.00065/full**.

3.3 Is there a risk of outbreeding depression when mixing local and non-local provenances?

Historically, there has been a reluctance to incorporate non-local provenance material into revegetation programs because of concerns that outbreeding depression (OD) will occur if two or more populations are mixed. Whilst OD has been experimentally shown to occur at some sites, (e.g. in old, naturally fragmented, landscapes such as those in WA), a recent review of the evidence for this concern concluded that the risk of OD is overstated and can be minimized[22]. In summary, OD is predicted to be low for crossing populations where[22]:

a) The populations are the same species (the species is not currently under taxonomic review and appears to be taxonomically stable);

b) The karyotype is the same (there are no differences in the number and structure of chromosomes between breeding individuals (see **http://www.tropicos.org/Project/IPCN** as a guide);

c) There has been gene flow between the populations during the last 500 years (this is generally the case in Australia, where populations have not been fragmented for more than 500 years); and

d) There are no marked differences between the habitats of the different populations, e.g. wet areas vs dry areas, different soil types, different day lengths.

Information may not be available to assess all these points, especially with regard to chromosomal differences. However, to balance the urgency of planning for climate-readiness against waiting for perfect knowledge, Climate-adjusted, Composite and Admixture provenance approaches alleviate some of the uncertainties (Figure 7).

3.4 What other factors should be considered?

This Guide cannot provide answers for site-specific questions because there are many factors other than provenance and species choices that need to be considered during revegetation projects. Which of these factors are relevant to a particular project will depend on the site and the species involved. We urge users of this Guide to read the papers and reports referenced here, relevant planning documents (e.g. the SERA Standards for the Practice of Ecological Restoration in Australia) and to fully explore the capabilities of the on-line tools and their associated caveats.

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This Guide is also downloadable as a PDF and can be viewed electronically at:
http://anpc.asn.au/resources/climate_ready_revegetation

The information provided in this Guide is based on the best available science at the time of publication. It is acknowledged that there are still many uncertainties surrounding the preparation of climate-ready revegetation. It is acknowledged that it is not understood whether species are currently occupying all suitable habitat (available niche space vs realized or actual niche space), and tools such as Species Distribution Modelling (see Step 2.6) are still being developed and improved. If and when projections and further research and tools become available, users of this Guide should update their strategies accordingly.

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