Establishing Victoria's Ecological Infrastructure: A Guide to Creating Climate Future Plots

Greening Australia

VICTORIA State Government

Environment, Land, Water and Planning

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EXECUTIVE SUMMARY

What are Climate Future Plots?

Climate Future Plots are areas of revegetated and restored land which incorporate genetic and/or species diversity to enhance habitat resilience to the uncertain and unpredictable effects of climate change.

By including and monitoring the success of a mixture of local and climate pre-adapted plant genotypes (such as seed from hotter and drier climates) the plots aim to enhance the resilience of natural landscapes to the changing climate and to actively inform future restoration and biodiversity conservation management.

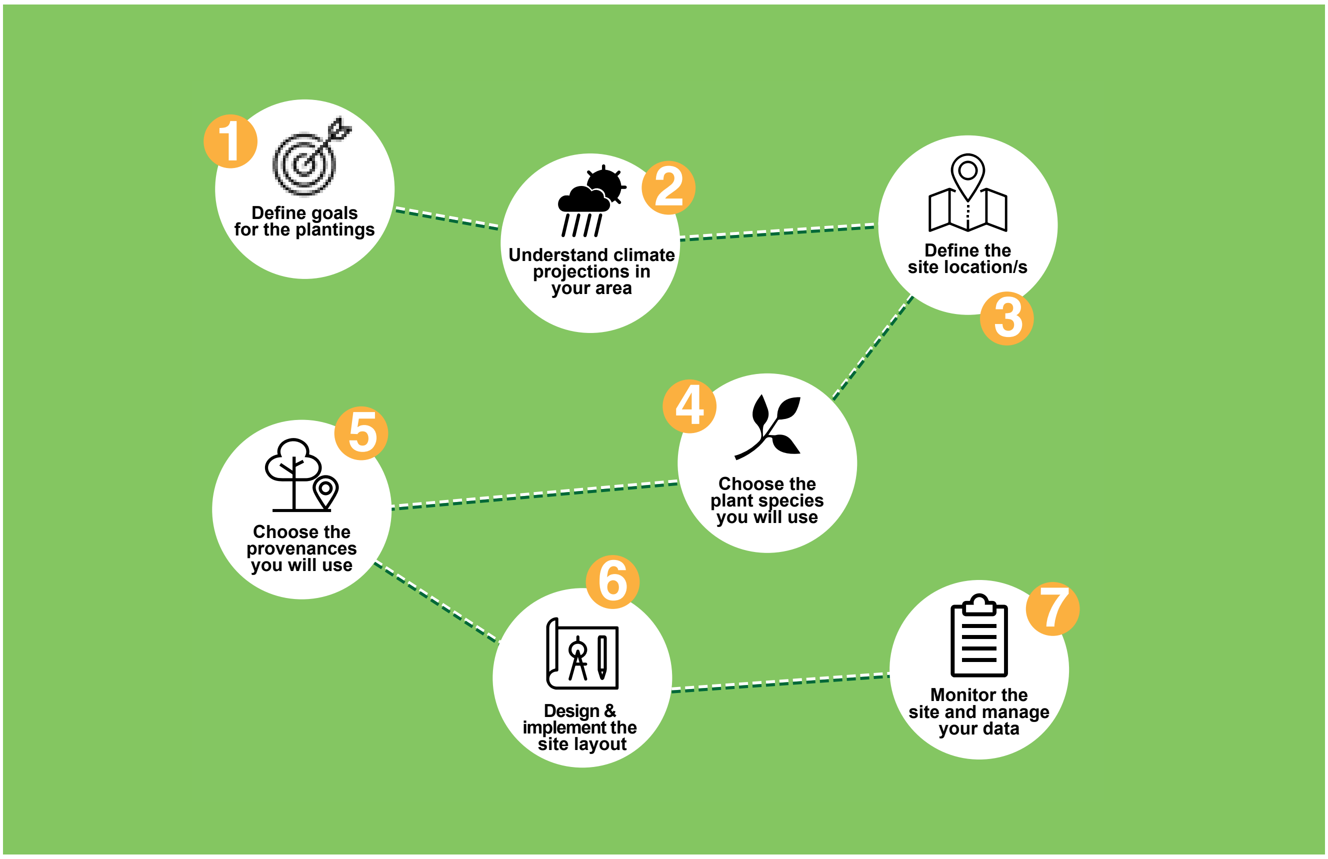
Purpose of this Guide

To provide a step-by-step process for organisations and community groups to plan, establish and monitor Climate Future Plots, and to establish a network of climate-resilient plant communities across Victoria and ideally nationally.

Benefits of Climate Future Plots

- Develop climate-resilient habitat by creating natural areas that maintain ecosystem function in uncertain climate scenarios.
- Act as nursery sites due to their high genetic diversity.
- Enable testing of predictions and proposed management strategies under a changing climate.
- Inform future adaptive management by showing how species respond to climate interventions.
- Enable community engagement and awareness by providing opportunities to work together.

Steps to Creating Climate Future Plots



How will Climate Change Impact Plants?

The most effective way to protect Victoria's biodiversity is to maintain native vegetation in a healthy condition.

Victoria's ability to achieve this will be impacted by climate change and the legacy of habitat clearing and fragmentation. We are already seeing a change in flora communities in Australia and globally as a result of climate change, resulting in forest, woodland, wetland and grassland declines at scale. This has a negative effect on ecosystem health and related socio-economic and cultural values.

The impact of climate change on plants requires an understanding of the plant's lifecycle, including the plant's requirements during different life stages, particularly during germination, early establishment and once fully grown. For most species this is currently poorly understood. Climate Future Plots will allow us to gain this knowledge across species and through time.

Factors to consider include:

- Climate change is expected to have a significant influence on flowering time and seed production, which will affect seed availability and viability, as well as pollination and seed dispersal.
- Climate change is likely to influence the ability of plants to germinate and recruit into the landscape.
- Climate extremes will play an important role in influencing plant survival. Furthermore, declines of one species may in turn influence the health of wider vegetation communities.

Tap into Existing Knowledge

In Victoria, there are many projects under way to identify and supply seed for priority plant species climatically matched to future conditions. Several projects combine genetic research and climate modelling for key species to locate 'climate-ready' seed sources for supplementing regional seed mixes. We provide examples of organisations you may wish to consult when planning your plots.

FOREWORD

We absolutely need to reduce our carbon emissions. But no matter what anyone – or everyone – does, big changes are ahead for nature in Victoria. The climate is already altering, and the bush as we know it is already being impacted. And those impacts will grow.

More severe droughts, extreme floods, frequent severe fires, as well as generally higher temperatures, new pest invasions and coastal erosion are all anticipated for the state. Future land managers will likely deal with challenges rarely faced before; ecosystems transforming or even crashing before their eyes.

Why plant Climate Future Plots?

During historic climate changes, ecosystems were interconnected across the landscape, and temperature changes were relatively slow. This allowed adaptive processes, such as cross-pollination with genetic variants of each particular plant species, and survival of the best climate-adapted types. Now, however, many of our native ecosystems are fragmented, leaving reduced genetic variation in an isolated area of bush. Even in larger, well-connected places like north-eastern Victoria, the rapid pace of climate change may not allow enough time for species with poor dispersal abilities to become resilient.

So, the idea driving this guide is to set up a series of 'Climate Future Plots' across Victoria. Plots may be located adjacent to or within vulnerable ecosystems, or in areas requiring restoration. Genetic variants of the plant species within these ecosystems, brought from further afield, can be deliberately and systematically introduced into the plots. We can record their seed provenance and monitor their success. This way, if some plant species fail in the future, we will be able to make informed decisions about how to introduce climate-suited variants into the ecosystem.

Is it okay to intervene?

Intervention in an ecosystem by introducing species or different provenances isn't simple. Any intervention must be done carefully, especially in high-value conservation areas. Some might say we should leave nature to fight its own battles, as it has done for millennia. But there has been considerable human intervention over the last 200 years – for example, we routinely manage pest plants and animals, and forest managers have introduced Eucalypt species not normally found in the state.

Natural selection, Darwin's well-accepted theory, allows for the strengthening of old species and the evolution of new species. But it depends on the evolution of – and ready exchange of – genetic material. We can help our fragmented and otherwise imperilled native ecosystems by exposing plants to their own genetic variants, to allow them access to this natural evolutionary process and help them survive the changing climate.

Knowledge for the future

In a few parts of the world, including Tasmania, climate-ready vegetation plots have already been trialled. However, we rarely see the systematic setting-up and monitoring of plots across a broad range of ecosystems.

With the right design protocols in place, Climate Future Plots can help to guide the planting activities of natural resource managers, National Parks staff, private landholders and community groups. Done well, Climate Future Plots will give us the knowledge and tools we need to help our remarkable natural heritage to adapt to whatever the future brings.

This project was initially driven by the Victorian National Parks Association, Melbourne University, CSIRO and Greening Australia.

Philip Ingamells, Victorian National Parks Association

WHAT ARE CLIMATE FUTURE PLOTS?

Climate change is already occurring and will continue to progress in Victoria [1,2]. Along with climate change come changes to biodiversity. We urgently need to assist nature to adapt to new climatic conditions [3]. Globally, habitat restoration remains the best mitigation strategy under climate change (after reducing carbon emissions), especially as forest loss is likely to increase as the climate continues to change [4].

Climate Future Plots (which we'll often simply call 'plots' in this document) are areas of revegetated and restored land which incorporate genetic and/or species diversity to enhance habitat resilience to the uncertain and unpredictable effects of climate change. Through the use of carefully selected species and provenances, genetic diversity is maximised and the adaptive potential of species and vegetation can be maintained [3]. By including a mixture of local and climate pre-adapted plant genotypes (such as seed from hotter and drier climates) the plots can enhance the resilience of natural landscapes [2]. As the climate changes, these plantings have a greater potential to change with it. Climate Future Plots are active learning tools which can help address uncertainties for future restoration and management activities.

Climate Future Plots can:

- **Enhance conservation** at the landscape scale by creating climate-resilient habitat elements within the landscape.
- **Incorporate diversity** into habitats to enhance their resilience in a time of climate uncertainty.
- **Use the best available science** to identify provenances from a species already adapted to climates similar to projected future climates of the area to be restored.
- **Create seed production areas** of climate-resilient pollen and seed for the surrounding landscape and other restoration projects.
- **Inform future adaptive management** regarding species resilience to climate change and provenance selection for restoration.

While the focus in this guide is on restoring native plants, animals also play a key role in terms of pollination, seed dispersal and habitat use.

Climate context

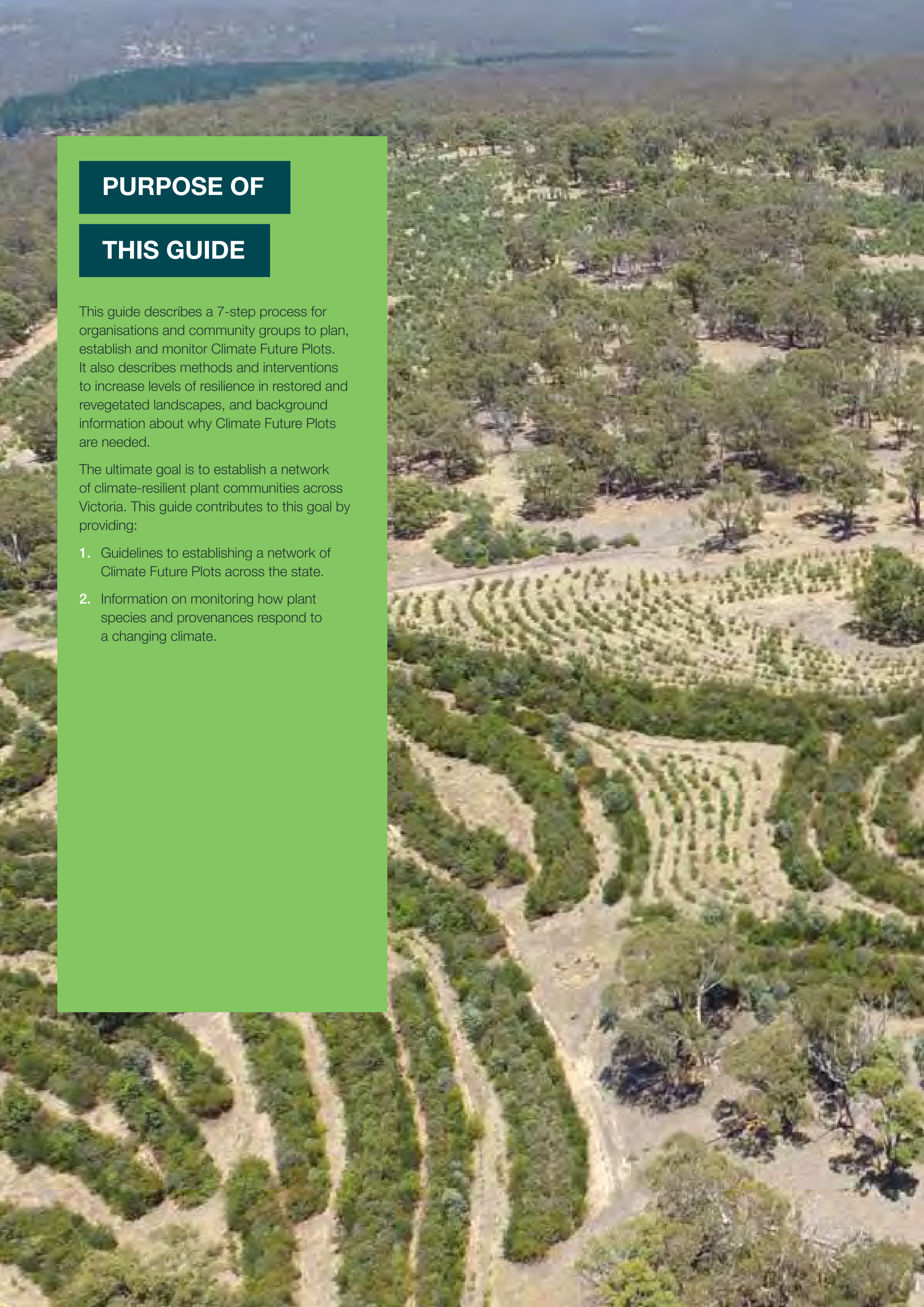
For the purposes of this document:

- The climate change point used to model and design Climate Future Plots are the years 2050 and 2070/2090.
- A representative concentration pathway (RCP) of 8.5 (high emissions scenario) is assumed.

It is widely accepted in climate science that human induced climate change may run for centuries if we don't change our behaviour now. But even if we dramatically reduce carbon emissions today, it will take 40+ years for the climate to stabilise, due to the delay in air-temperature increase as the atmosphere catches up with the heat the Earth has accumulated. While the majority of climate models show similar projections to 2050, projections differ past this point, especially for rainfall [2].

Provenance

The original place from where seed or other plant materials come from.



PURPOSE OF THIS GUIDE

This guide describes a 7-step process for organisations and community groups to plan, establish and monitor Climate Future Plots. It also describes methods and interventions to increase levels of resilience in restored and revegetated landscapes, and background information about why Climate Future Plots are needed.

The ultimate goal is to establish a network of climate-resilient plant communities across Victoria. This guide contributes to this goal by providing:

1. Guidelines to establishing a network of Climate Future Plots across the state.
2. Information on monitoring how plant species and provenances respond to a changing climate.

BENEFITS OF CLIMATE FUTURE PLOTS

In Victoria, the benefits of Climate Future Plots were first articulated at the VicNature2050 workshop and summarised by Jordan and Hoffmann (2017) [5].

Climate-ready habitat

The plots create habitat that maintains ecosystem function in uncertain climate scenarios by capturing a range of climate-adaptation within and among species. This is done by planting a mixture of genotypes from local and different locations (provenances), and a diversity of local species. The plots provide benefits for the surrounding landscapes by:

- Increasing habitat area, especially when other systems in the landscape are failing.
- Increasing genetic and species diversity upon which natural selection can act.
- Enhancing carbon sequestration and biodiversity values by providing stable, sustainable habitat.

Nursery sites

The high genetic diversity captured in plots enables them to act as nursery sites for native vegetation. Over time, as natural selection acts on the diversity within the plots, the surviving species and provenances become the best adapted sources of seed for future revegetation projects. Seeds can be collected from the sites for restoration and renovation projects. Also, pollen and seed can be passively dispersed to the surrounding landscape.

Knowledge building for management

Knowledge is limited about how climate change will impact plant and animal communities. Climate Future Plots help us understand the impacts, test our predictions and assess the effectiveness of management over long-time scales (30+ years). They can provide answers to questions like:

- Where and how widely does seed need to be sourced to create climate-resilient restoration?
- How much environmental and climatic variation can plant species tolerate beyond their current climate distribution?
- What is the capacity of species and ecosystems to adapt to changing conditions?

Adaptive management

Plots can provide long-term adaptive conservation management. They show how species respond to interventions such as mixed plant provenancing over time. Long-term studies are vital, as they help us distinguish between short-term events and long-term trends. Plots support the adaptive management strategies in the Victorian Biodiversity 2037 Plan by:

- Providing continual, long-term data on species and system responses as conditions change, especially in response to extreme events.
- Enabling improved practices in response to new data and knowledge.
- Facilitating transitions from current to future practices.

Community engagement and awareness

Many people want to help nature adapt to a changing climate. A Climate Future Plot network will provide opportunities for communities, agencies and researchers to work together to achieve this. Groups already engaged in restoration can provide advice to improve biodiversity outcomes and planting successes. Over time, plots will increase awareness of the impacts of climate change on native vegetation.

STEPS TO CREATING CLIMATE FUTURE PLOTS

Climate Future Plots need to be well planned to survive and even thrive for years to come [5]. Below, we take you through a step-by-step process to plan, establish and monitor your plots.

1. Define goals for the plantings

Why do you want to create Climate Future Plots? Choose one or more of these four broad goals - if you're unsure, pick the closest one:

a) Revegetate using new plant genetics to restore a cleared or fragmented landscape.

The goal here is to increase the area of climate-resilient habitat by planting a variety of species from local areas plus a range of locations that are currently similar to predicted future climates at the site (i.e. climate adjusted provenances).

b) Introduce new plant genetics into remnant vegetation to future proof it from the changing climate.

If your site is near or within existing vegetation, such as a national park or reserve, the goal is to make the existing vegetation more resilient to climate change by enhancing gene flow into these areas.

c) Produce 'climate ready' seeds from an area designed to be a seed production area (SPA).

Pick this one if you want to establish nursery sites where climate-adapted seed can be grown and collected.

d) Research how plant survival, growth, reproduction and genetics change over time and between provenances and species.

The goal here is to undertake research activities in an experimental setting.

Once you have selected one or more goals, prepare a statement of the outcomes you expect to achieve. All Climate Future Plots are important in helping us to learn how best to help restored or remnant habitat adapt to a changing climate, and to increase future survival outcomes.

Factors to consider

- Identify a budget for your plot or plots. Different plot types require different levels of investment and expertise, with SPAs and research plots generally being more costly.
- Determine how much time and effort will be required for your project. SPAs and research plots require a higher level of monitoring and management expertise than plots for ecological renovation.
- Consider any legislative issues. For example, plots in national or state parks, which have a high level of legislated protection, must be fully assessed before they can be approved, and carefully monitored once established. Cultural heritage assessments may be required for some areas.

2. Understand climate projections in your area

When aiming to establish plant communities resilient to climate change, it is important to understand the climate projections in your planting area [3].

Victoria is forecast to become hotter and drier under climate change [1] (see Figure 1). But the climate projections vary depending on location, seasonal variations and many other factors. Different types of climate models may also give different predictions for your area, particularly when it comes to rainfall [2].

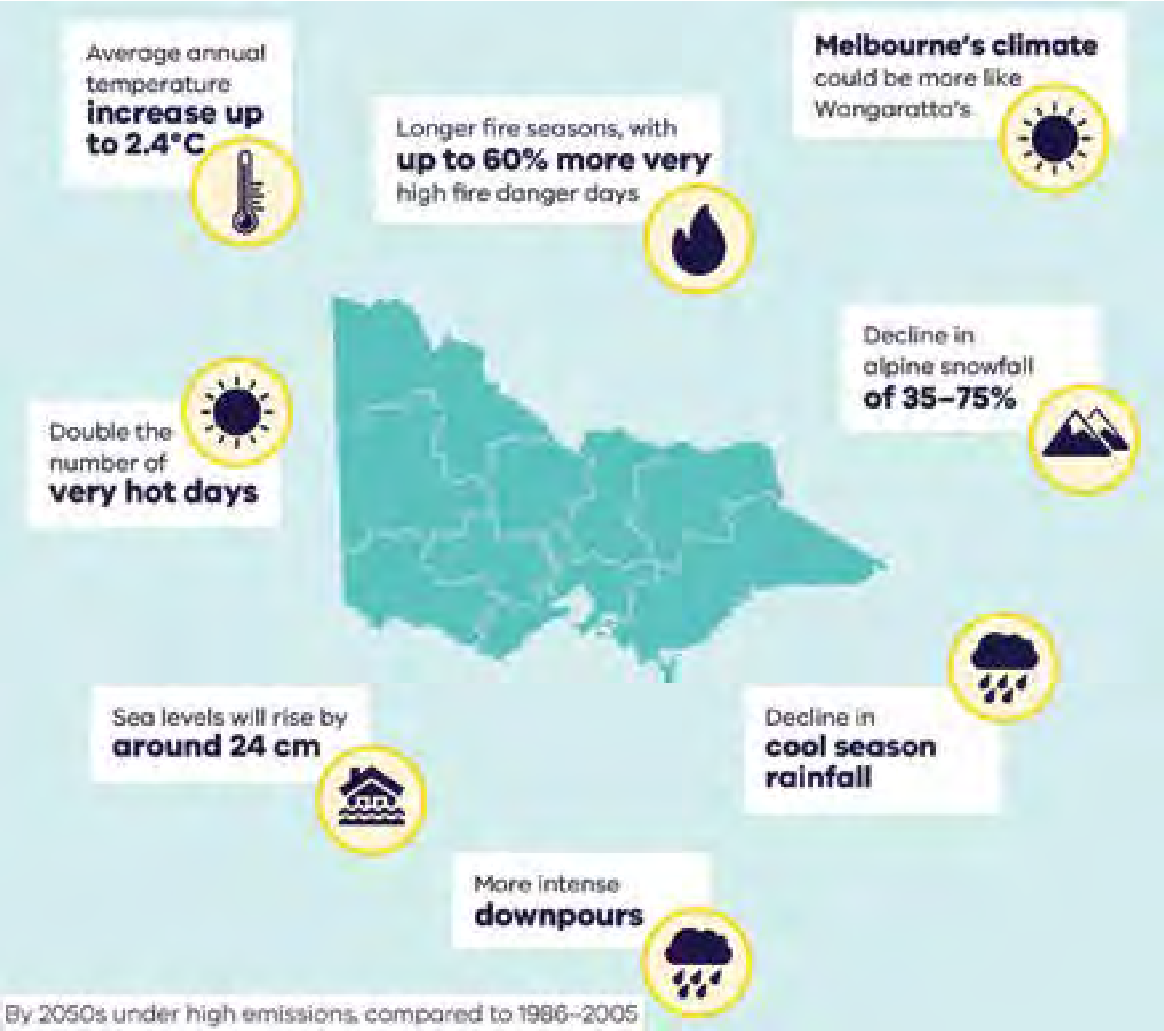


Figure 1. *How Victorias climate is expected to change by 2050.*

Figure 2. *How Victoria is expected to become hotter (top image) and drier (bottom image) by 2050* [1]

Remnant and revegetated areas are likely to be greatly influenced by climate variables such as the degree of aridity (degree of dryness in a given location), extreme weather events (such as extreme temperatures or rainfall events [1, 6]*), declines in frosts, or changes to seasonal temperature and rainfall averages* [6] *(see Figure 2). In Victoria, aridity changes from 'wetter' areas in the east and south, to 'drier' areas across the centre, to 'very dry' areas in the north-west of the state.*

Climate analogues

Climate analogues are "areas that experience similar climatic conditions, but which may be separated in space or time (that is, with past or future climates)" [7]. To define climate analogues, you need to locate areas in Australia where the current climate is similar to the projected future climate at your site. If you know how the climate will change, you will be able to choose locations that have similar climate variables now in order to source appropriate plant genetics.

CSIRO provides a tool called 'Analogues Explorer' on its website Climate Change in Australia: *www.climatechangeinaustralia.gov.au/en/climate-projections/climate-analogues/analogues-explorer*. In Box 1, we provide a guide to using this tool.

As an example, if your site is in or near Albury/Wodonga, you will want to know what the temperature and rainfall changes for that area will be in the next 30 to 50 years, so you can prepare for those climatic conditions. By using the CSIRO tool, we learn that temperatures are likely to increase by 2 - 3 °C, and rainfall to decrease by 5 - 10 % by 2050 under high emissions scenarios (RCP 8.5). This makes the projected climate for 2050 in Albury/Wodonga similar to the current climate in Dubbo and Parkes (NSW). These are the areas from which you need to source climate adjusted seed, if the species you are interested in are available (see Figure 3).

Box 1 - Steps to identify climate analogues for your project

I. Go to *Climate Change in Australia* website – 'Projections and Data' tab and select the 'Climate Analogues' tool (www.climatechangeinaustralia.gov.au/en/climate-projections/climate-analogues/analogues-explorer).

II. Open the 'Select Locality' tab and choose your location (or the nearest town to your location).

III. In the 'Preset Scenarios' section, under 'Emissions Scenario' choose RCP 8.5. Under 'Description' choose *Maximum Consensus*.

IV. To determine what your Intermediate seed provenances will be, in 'Time Period' choose 2050. For Long Distance provenances, choose 2090.

V. Look at the 'Configure Data' to see what the temperature and rainfall change will be.

VI. Look in the 'Analogue Towns' box to identify your analogue town/s.

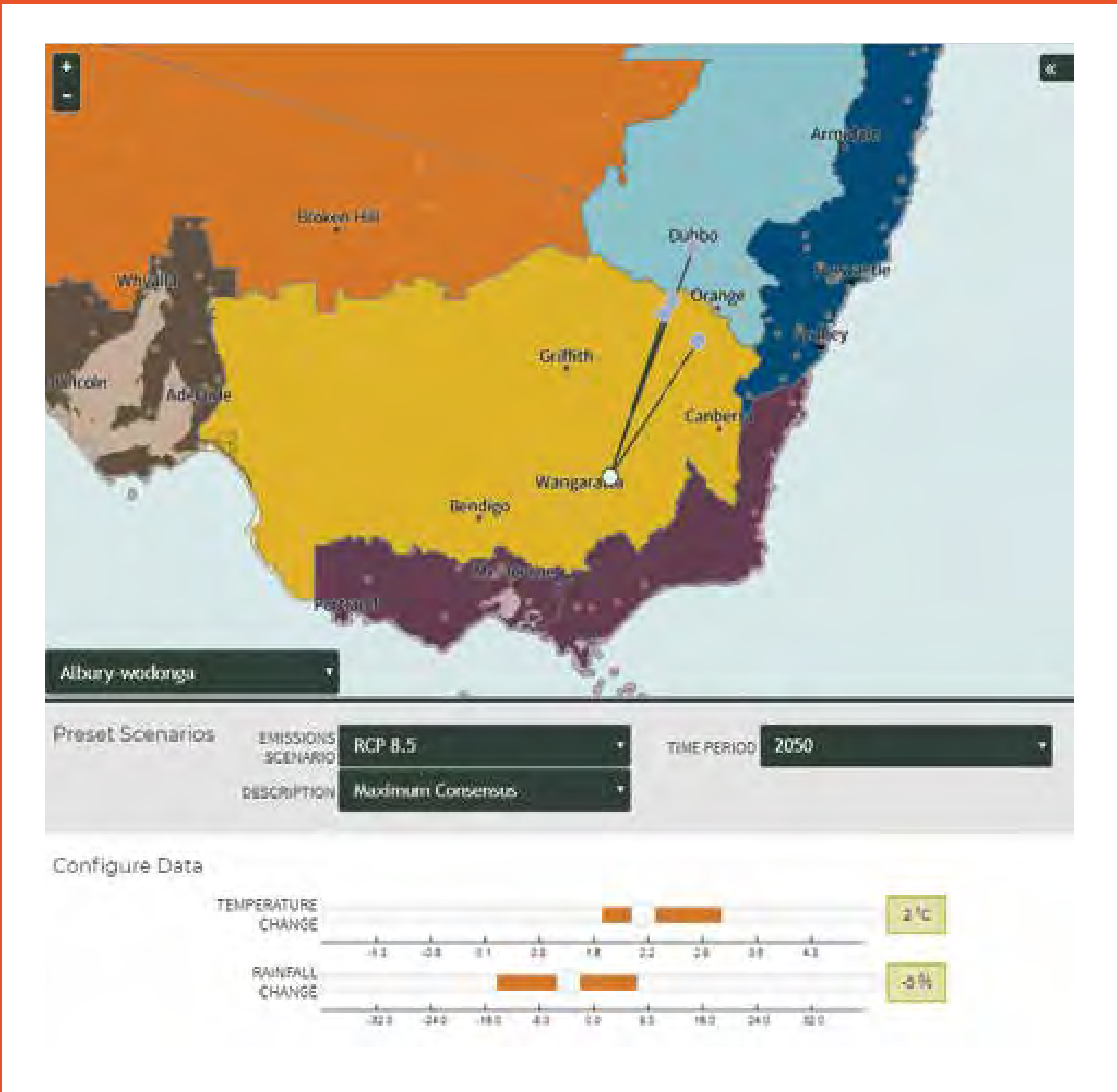


Figure 3. *Output from the CSIRO Climate Change In Australia website, showing climate analogues in 2050 for Albury/Wodonga based on a high emissions scenario [7].*

3. Define the site location/s

Exactly where you put your Climate Future Plot in the landscape depends on the goals you chose in Step 1.

For example, if you want to test how a species survives along an environmental gradient, the possible locations for your site may be limited (such as planting the same species along an alpine gradient). However, the possible area may be extremely large if the aim is to monitor how provenancing and species diversity is influenced in different landscapes. In this case, you should set up a state-wide array of plots to test the impact of aridity or temperature extremes (see *An example of a research plot and seed production area* on Page 37).

Legend – Goals for your plantings (from Step 1)

a) Revegetate to restore a landscape

b) Future proof remnant vegetation

c) Produce a seed production area (SPA)

d) Carry out research

If you wish to facilitate gene flow (pollination and seed dispersal) between your plot and nearby remnant vegetation, position your plot within 100 m to 1 km of remnant vegetation and ensure you are planting some of the same species as those in the remnant area. The ideal distance will depend on the species you are planting. Consider the seed dispersal distance of the plants you are likely to choose in Step 4 (Page 18), and the pollinators you hope to attract. If you plan to rely on wind for seed and pollen dispersal, the plot site will need to be upwind of remnant habitats. If you are planning for water dispersal, the plot will need to be located upstream. In general, we recommend revegetating as close as possible to or within patches of remnant vegetation (see the section on *How will climate change impact plants* on Page 43).

If you want to study how different species or provenances survive and grow, and how plant genetics change over time, position your plot at least 1 to 2 km away from remnant habitats (if your plots are likely to include the same plant species as the nearby remnants). This is to reduce the effect existing plants will have on your research area. Also consider if the local species are likely to cross with the species in your research plot.

Land protection and management

Consider how long the site/s will be used for the purposes of a plot, and seek written, ideally legally binding documentation to ensure that the site lasts at least 20 to 30 years, preferably 50 or more years, especially if it will be used as a research plot or an SPA.

It is important to document:

- Who the agreement is with, such as the landowner and managing organisation
- Who has access to the site and who manages site access
- Who will be responsible for restoration and maintenance activities, including:
    - Site setup, preparation and planting
    - Monitoring of planted vegetation
    - Land inspections and their frequency (for example, weekly or monthly)
    - Ongoing maintenance, such as fence repairs, and weed and pest animal control.

4. Choose the plant species you will use

To achieve the best possible outcomes, choose plant species likely to survive, grow and reproduce in your plot by considering their traits and how they are likely to cope under the changing climate [3].

Factors to consider

Plant species in Victoria are classified into Ecological Vegetation Classes (EVCs), which groups plants based on floristic, structural and ecological features. Species from the local EVC are more likely to grow, survive, and achieve the best outcomes for ecosystem function and local animals. However, under a changing climate we should not assume that plant species and geographical areas will remain in the same EVC categories into the future. See Box 2 on how to determine current species distributions.

When selecting a plant species, consider how likely that species is to survive under future climatic conditions. For example, Appendix 1 shows how Sweet Bursaria (*Bursaria spinosa*) may be impacted by climate change, such as with fewer frost events.

In some cases, a local species may not survive under future climate scenarios, so introducing new species may be necessary. The new species may thrive and provide similar ecological services to the species that are no longer suitable in the landscape. However, introducing a new species should be done with caution; the new species may not provide the same function or habitat as locally adapted species, or they may become over abundant if they survive well.

There are also genetic risks associated with the use of native species for large-scale revegetation, even within their natural range. Broadhurst et al. (2017) provides a discussion about seed collection and genetics [8] and tools are available, such as the genetic risk protocol [9], which evaluate the factors that influence the likelihood and consequences of adverse genetic change from revegetation as a result of pollen dispersal. These risks should be considered when planting within or near native vegetation. See Byrne et al. (2011) [9] for more information.

Box 2 - Identifying the distribution of plant species

I. Go to the Victorian Government website:
www.environment.vic.gov.au/biodiversity/bioregions-and-evc-benchmarks

II. Determine the Bioregion of your site and define the Ecological Vegetation Classes (EVCs) that occur within your Bioregion. This will give you a list of the dominant plant species in each EVC.

III. Go to the *DELWP NatureKit* website (maps.biodiversity.vic.gov.au/viewer/?viewer=NatureKit) to identify the EVCs located within your area:

a. Zoom into the area of interest and click on the 'Ecological Vegetation Classes' tab.

b. Click on the shaded EVC areas you are interested in to identify what the vegetation is likely to be.

c. Use the list from Step II to identify the species you are likely to plant based on your EVC.

IV. Cross reference the species identified in Step IIIc with the species list in Appendix 2 of this guide. This will give you an idea of the likelihood of the species being available from nearby seed banks and nurseries. Note that this is not an exhaustive list, and that different nurseries will grow a variety of species.

V. Based on your above list of species, choose five to ten species to search for to see if they are located in your analogue areas (see Box 1).

a. Using the *Atlas of Living Australia* (www.ala.org.au), type in the first species you are interested in (scientific name) and choose the correct species from the list provided.

b. On the 'Occurrence records map' that appears, click on the 'View Records' and then the 'Map' tab. You can use the tabs on the left-hand side panel to 'Narrow Your Results'.

c. Using the map, identify whether your species is in your climate analogue. If it is, see if there are suitable nurseries in that area. If it does not occur there, or in the nearby region, you may need to consider another species.

d. As an alternative, if you want a species list for a certain area, at the home screen go to the 'Search and analyse' dropdown menu and select 'Explore your area'. Type in your location in the box provided and select a 10 km radius. This will display all of the plants and animals recorded in your area.

e. See Hancock et al. (2018) [3] if you wish to define the climate limitations of your species.
https://www.landcarevic.org.au/assets/Uploads/Climate-Reveg-Guide.pdf

Top revegetation plant species

Greening Australia, together with organisations and nurseries across Victoria, has compiled a list of the 100 most commonly used revegetation plant species in Victoria (Appendix 2). The list can help you identify species likely to have a broad distribution, which will make it easier to obtain climate adjusted seed.

The top 10 plants used in revegetation activities is shown in Table 1. If there are species in your region that are not represented in the list, but provide a good habitat or resource for native animals, we suggest you try to use them and, if possible, plant a variety of provenances (see Step 5, Page 21). For example, work with nurseries, a Landcare group or other local groups to obtain suitable seed.

Table 1. *Ten of the most widely distributed plant species found in Victoria that are regularly used in revegetation projects.*

Species Name	Common Name	Form
Acacia pycnantha	Golden Wattle	Shrub
Allocasuarina luehmannii	Buloke	Tree
Allocasuarina verticillata	Drooping Sheoak	Tree
Banksia marginata	Silver Banksia	Shrub
Bursaria spinosa	Sweet Bursaria	Shrub
Dianella revoluta	Black-anther Flax-lily	Tussock
Dodonaea viscosa	Sticky Hop-bush	Shrub
Eucalyptus camaldulensis	River Red-gum	Tree
Eucalyptus viminalis	Manna Gum	Tree
Lomandra longifolia	Spiny-headed Mat-rush	Tussock

Create a shortlist of species

Select species based on the following criteria:

- Widely distributed across the state, and (if relevant) into New South Wales or South Australia (using the *Atlas of Living Australia* website - see Box 2).
- Commonly used in revegetation (see the top 100 species used in Victoria - see Appendix 2)
- Species used in other Climate Future Plots, so we can learn how the same species survives, grows and reproduces in different landscapes and climatic regions.
- Occurs in the target Ecological Vegetation Classes (EVCs) and is an important component of the natural environment (for example, provides food and/or habitat for native animals).
- Diverse species lifeforms (for example, trees, shrubs, grasses and herbs), which will depend on the structural diversity you are hoping to replicate. This will help ensure that your revegetation area is attractive for native animals to live in. Check your target *EVC benchmark* (www.environment.vic.gov.au/biodiversity/bioregions-and-evc-benchmarks) to determine the ideal structural attributes.

To access a wealth of existing knowledge in Victoria, including from highly experienced revegetation groups, see Page 45. For tips on how to collect the best quality seed, see Page 23.

5. Choose the provanances you will use

The provenances of the plants you use, and the availability of seed from those provenances, will contribute to how successful you are in developing climate resilient plant communities [3].

Provenancing

In the past, it was thought that seeds should only be sourced locally - 'local provenancing' - with the assumption that seed adapted to the local environment was the most appropriate for that area [10]. 'Local' means it is collected within the same geographic area as the revegetation site or matches an ecological criterion. However, this approach fails to consider the influence of disturbance, habitat fragmentation and climate change. For example, Eucalypt species from non-local provenances have been known to survive and perform better than local provenances [11]. Also, seed from 'local' provenances may not be able to keep-up with the rate of climate change [10]. Historically, the climate changed over much longer time periods, giving local species time to adapt [10].

Using plants from provenances other than the local area will help you meet the ultimate aims of Climate Future Plots: to increase climate-resilient vegetation in a landscape, or increase the resilience of remnant vegetation. However, climate change is only one driver of plant survival and growth, and other environmental factors, such as soil conditions, competition, and pest animals, need to be considered when restoring landscapes [12]. Where possible your project should also include a diverse mix of species and lifeforms (trees, shrubs and grasses).

Provenance

The original place from where seed or other plant materials come from.

Habitat Fragmentation

Occurs when native vegetation is removed from the landscape, leaving patches of remnant vegetation of various shapes and sizes. The greater the degree of habitat fragmentation, the more difficult it is for animals and plants to move and disperse across the landscape, which results in communities becoming isolated. This makes them more susceptible to disease, disturbance, and loss of genetic diversity.

In Figure 4, we describe some provenancing strategies to consider (see Appendix 3 for more detail on the different provenancing strategies). The role of plants from other provenances is to 'pre-adapt' habitats to future climates and enhance the genetic diversity of revegetation. We recommend a combination of 'composite' and 'climate adjusted' provenancing when selecting seed-sources.

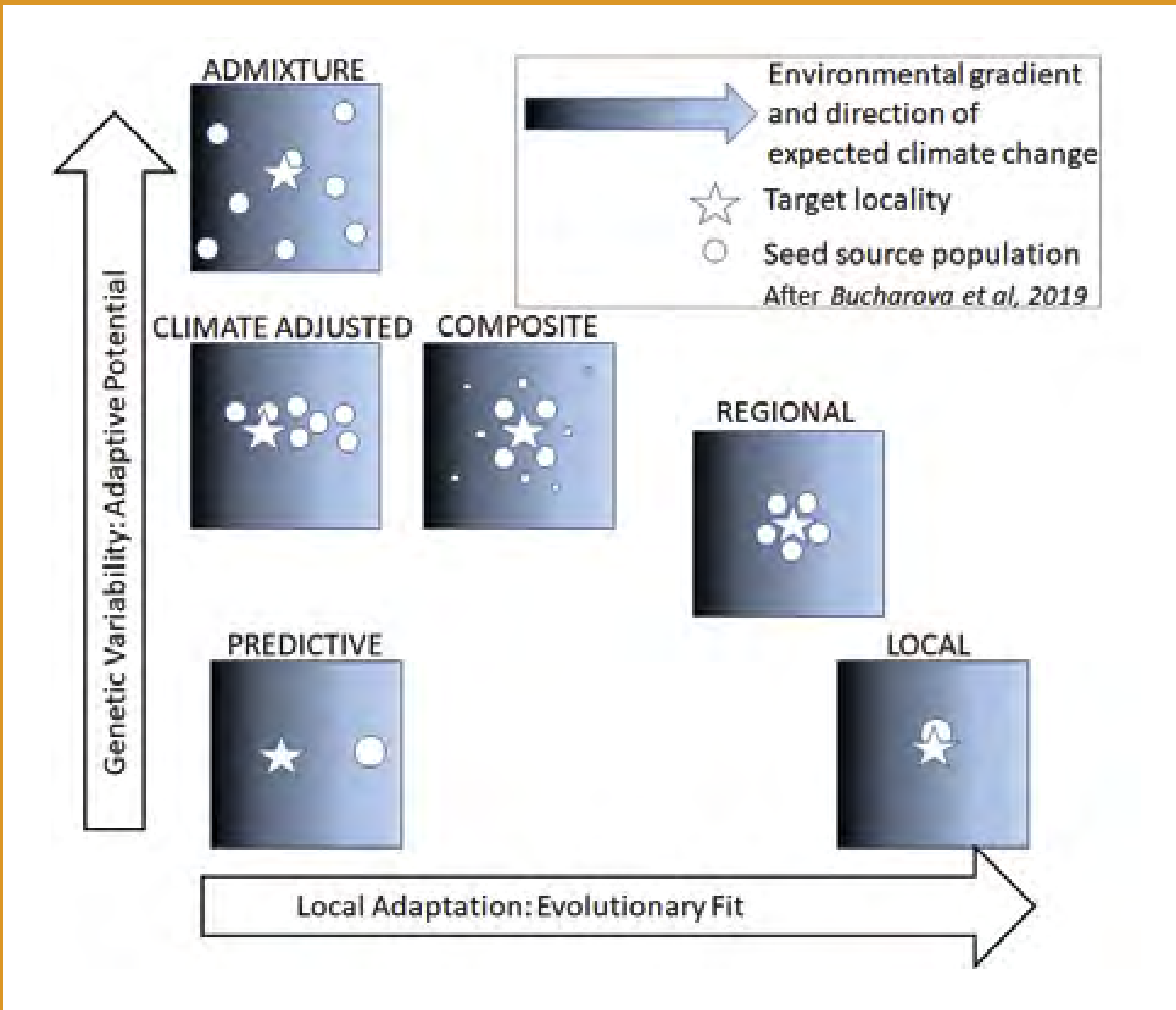


Figure 4. *Provenancing strategies based on Bucharova et al.* [12] *and Prober et al.* [13]*. We recommend a combination of 'composite' and 'climate adjusted' provenancing. Note - the different sizes of the seed-source populations reflect their relative contributions. See Appendix 3 for more detail.*

We suggest planting four or five provenances per species in case some fail to thrive, using:

- One local provenance (aim for about 60 to 70 % of the seed you use to comprise this).
- One provenance being from a wetter, cooler climate (10 %).
- Two or three provenances from hotter and drier climates (10 to 15 % from 2030 analogues, 10 to 15 % from 2050 analogues and 10 to 15 % from 2070/2090 analogues) [14, 15].

This will help to maintain locally adapted genetic material, while bringing in new genetics to make the local populations more robust to a changing climate [15]. If you have strong concerns about the viability or genetic diversity of local provenance seed, you can increase the proportions of climate adjusted seed.

How to collect high quality seed

Where seeds come from and how they are collected is very important. For example, overharvesting from individual plants or collecting from plants with poor genetic health can hinder your revegetation project [10].

1. Collect from a wide range of plants (at least 10 plants from each provenance).
2. Avoid collecting from dead or diseased plants but include seed from plants that are not perfect specimens.
3. Collect widely from within the source patch. For plants of the same species within a patch, try to collect from plants separated by at least twice the plants' height (for example, if a plant grows 10 m tall, collect from plants at least 20 m apart).
4. Avoid collecting from isolated patches or combine it with seed from other plants in the area.
5. Keep a record of where the seed was collected from, how many and from which parent (mother) plants were sampled at that location, and when it was collected.

6. Design and implement the site layout

Designing Climate Future Plots can be complex. Don't embark on a project without careful planning. The design will depend on the number of species you are planting, the number of provenances, and the level of replication you will need to make the results statistically powerful, especially if the chance of plant mortality is high.

Property

The area of land, which may be owned by one or more people or organisations.

Site

The area within a property to be planted.
A property can contain multiple sites, and a site can contain multiple plots.

Plot

A planting area containing one or more species with multiple provenances.

Factors to consider - Planning

- The goal/s of the plot that you identified in Step 1.
- A list of the key people involved in the plot and their roles.
- A timeline of actions to be performed, including when plants need to be ordered and by whom.
- The attributes of the site:
  - Access to water (during plant establishment or times of low rainfall).
  - Topography (for example, is the site on the flats, or on upper or mid slopes?).
  - Soil type and depth.
  - Hydrology and the hydrological regimes of the site.
  - Characteristic wind directions and speeds (if pollination or seed dispersal is important - see the *Bureau of Meteorology* website).
- If you are planting tubestock or direct seeding, this will influence the way in which you will prepare the site, how you will incorporate plant provenances, how much seed you need, and from where the seed comes from.
- There will be seasonal variability in rainfall and temperature at the site or sites that you plant in. If the rainfall projections for your site suggest that rainfall will be very low over the planting period, you may decide not to plant that year. Similarly, as rainfall is projected to decline over the winter months [1], you may choose to plant earlier or later in the year than you normally would [16]. For more detail on planting timelines and risk evaluation see Broadhurst et al. (2016) [16] and also Broadhurst et al (2017) [8].

Legend – Goals for your plantings (from Step 1)

a) Revegetate to restore a landscape

b) Future proof remnant vegetation

c) Produce a seed production area (SPA)

d) Carry out research

Factors to consider - Site preparation

- **Will the site need to be fenced?**

  We suggest fencing to keep livestock out at a minimum, but it depends on the site being restored.

  Fencing is highly desirable, as these areas require a lot of time, effort and resources to set up, maintain and monitor. Disturbances will affect the results of research plots.

- **What preparation is required?**
  - Determine whether pest animals or plants could be a problem, and how you will control them (for example, ripping for rabbits and spraying or burning to control weeds).
  - Consider whether machinery is needed, for example if ripping or mounding is planned.
  - Decide whether plants need to be guarded and what type of guard is most appropriate.

- **What will the layout of the plot look like?**

  See the plot layout examples provided in the Step 7.

  The layout can be similar to the examples provided in Step 7, or see the example of a research plot and seed production area on Page 37.

Factors to consider - Plantings

- **How many species and lifeforms with mixed provenances are you going to plant?**

  Plant diversity should be quite high, depending on your EVC benchmark. A proportion of these - 30 to 40 % - should be of mixed provenance (see the DELWP Revegetation Planting Standards). The number of lifeforms and the density of the plantings will depend on the EVC you are restoring. Note that mortality may be up to 30 to 40 % or higher after the first summer.

  We suggest mixed provenance plantings of three to five species, though research plots could consist of just one species with mixed provenancing. Note that the use of other locally sourced species in provenancing plots may cause a competitive effect on the mixed provenance species.

- The number of provenances and the proportion of provenance seed from outside of the local range you are using for each species.

  We recommend 60 to 70 % local, 10 % wetter/cooler, 20 to 30 % hotter/drier analogues.

  We recommend the same proportion of local provenance seed to other provenances (i.e. 20% local, 20% wetter/cooler analogues, 20% 2030 analogues, 20% 2050 analogues, 20% 2090 analogues).

- The distance between plants and plots, as this can be important for site maintenance. We suggest leaving 2.5 to 3 m between trees, 1 to 2 m between shrubs and 0.5 m between grasses and herbs, and 6 m between plots.

Recording site characteristics

Once you have designed and laid-out your plots, draw a map of the site and record some site and plot information (also relevant for monitoring the site) that includes [17]:

- Name and location of the trial, including GPS coordinates, scale of map and a North arrow.
- Description of the landscape being planted (for example, topography).
- Past land-use history, such as what the land was used for or issues with compaction.
- Total area of the planting site and number and size of the plots planted.
- Planting date and total number of plants planted.
- Plot layout, including the number of species and provenances used in each plot, the spacing between plants and plots, and the replicate, plot and treatment numbers (if relevant).
- Site preparation undertaken, planting techniques, whether guards were used and guard type, if the site was fenced and fence type and the presence of grazing animals.
- Information gathered online (for example, from the *Bureau of Meteorology* website) on the mean annual rainfall and temperature at the site, including likely weather extremes (such as mean maximum temperature in the hottest month).
- Information about whether long-lived chemicals have been used in the soil in the past, and if soil and pasture improvement was undertaken.
- Any other relevant details.

7. Monitor the site and manage your data

Collectively, we have never before known so much about techniques for good quality, lasting revegetation, and we continue to learn about the value of revegetation for native fauna, aesthetics and ecosystem services (which are the benefits that humans gain from properly functioning natural environments).

It is vital to monitor your revegetation and restoration activities. The information you collect will enable restoration practitioners to get a better understanding of the long-term outcomes for plantings, particularly in relation to plant survival, growth and reproduction, and how these vary between seasons and years and across species, provenances and locations. Ideally it would provide information on how animals are using these areas as well.

Legend – Goals for your plantings (from Step 1)

a) Revegetate to restore a landscape

c) Produce a seed production area (SPA)

b) Future proof remnant vegetation

d) Carry out research

Establishing a monitoring strategy

Examples of different ways that your group could set up and monitor climate future plots are presented in the diagrams below. These range from simpler designs for either tubestock plantings (see Figure 5) or direct seeding (see Figure 8a) that allow comparisons between climate adjusted plantings and local provenance plantings, to more complex designs (see Figure 6, Figure 7 and Figure 8b) that allow testing of which climate adjusted and local provenances do better. Other species that are locally sourced can be planted within these plots and monitored alongside the mixed provenance species (see Figure 5 and 6). Where possible, you should monitor each species and provenance combination at a minimum of five times within a site (5 replicates).

For all the examples below 60% of the plants are from local provenances and 40% are from climate adjusted provenances (10% wetter and cooler, 10% 2030 climate analogues, 10% 2050 climate analogues and 10% 2090 climate analogues). Monitoring areas will differ in size, depending on the lifeforms being planted (trees, shrubs and grasses) and the ecosystem and/or region you are planting in. For example, grassy woodland ecosystems will be less densely planted than forest areas.

In tubestock plantings, all monitoring plots are set-up to have a 'buffer' of sixteen plants around them to reduce the effects of wind, insect attack or other factors (also known as 'edge effects') on the nine inside plants being monitored (see Figures 5 to 7). The buffer plants do not need to be monitored. If trees are spaced 3 m apart the monitoring area will be approximately 9 m^2. Table 2 outlines the different goals and implementation steps required for tubestock plantings.

For direct seeded areas (Figure 8), the monitoring area will similarly differ depending on the region and habitat being restored, but monitoring should be undertaken using transect lines (see Figure 9). Here we suggest multiples of 20 m transect lines to ideally monitor 9 plants in each provenancing line, but this transect length will likely differ depending on the density of planting and the length of the direct seeding line (see Table 3 for a guide on monitoring numbers). These transect lines should be undertaken in all climate adjusted provenance planting lines and adjacent local provenance planting lines (Figure 8). Table 3 outlines some of the goals and implementation steps required for direct seeding.

If you are interested in generally seeing how climate adjusted provenances survive and grow in comparison to local provenances, then the climate adjusted provenances can be mixed together and planted in monitoring blocks within local provenance plantings (see Figure 5), or direct seeded adjacent to local provenance direct seeding lines (see Figure 8a). This design is relatively simple to set-up, as you don't need to worry about keeping different climate adjusted plants separate during propagation and planting (although they will still need to be kept separate from the local provenances). However, it will not allow you to compare survival and growth between the different climate adjusted provenances.

If you are interested in knowing which climate adjusted provenances survive and grow in comparison to other climate adjusted and local provenances, then separating the individual climate adjusted provenances is necessary (see Figure 6 and Figure 7 for tubestock plantings and Figure 8b for direct seeding). For direct seeding lines, the individual climate adjusted provenances would be seeded in separate lines but could contain multiple different species from that same climate adjusted provenance. These would be seeded adjacent to local provenance lines containing the same species mix (Figure 8b).

For tubestock areas, individual provenance blocks can be planted and monitored within areas with a mix of local and climate adjusted provenances, where the majority (60%) of the plantings outside the monitoring plots are local provenances (Figure 6). Alternatively, the whole planting could be made up of provenance plots with more local plants needing to be included in these plots to ensure the same proportion of local to climate adjusted provenances (Figure 7). It should be noted that for both these planting types the climate adjusted provenances will need to be separated during seed-collection, propagation and planting, so it may be necessary to work with seed collectors and/or seed banks and your local nurseries to ensure this occurs.

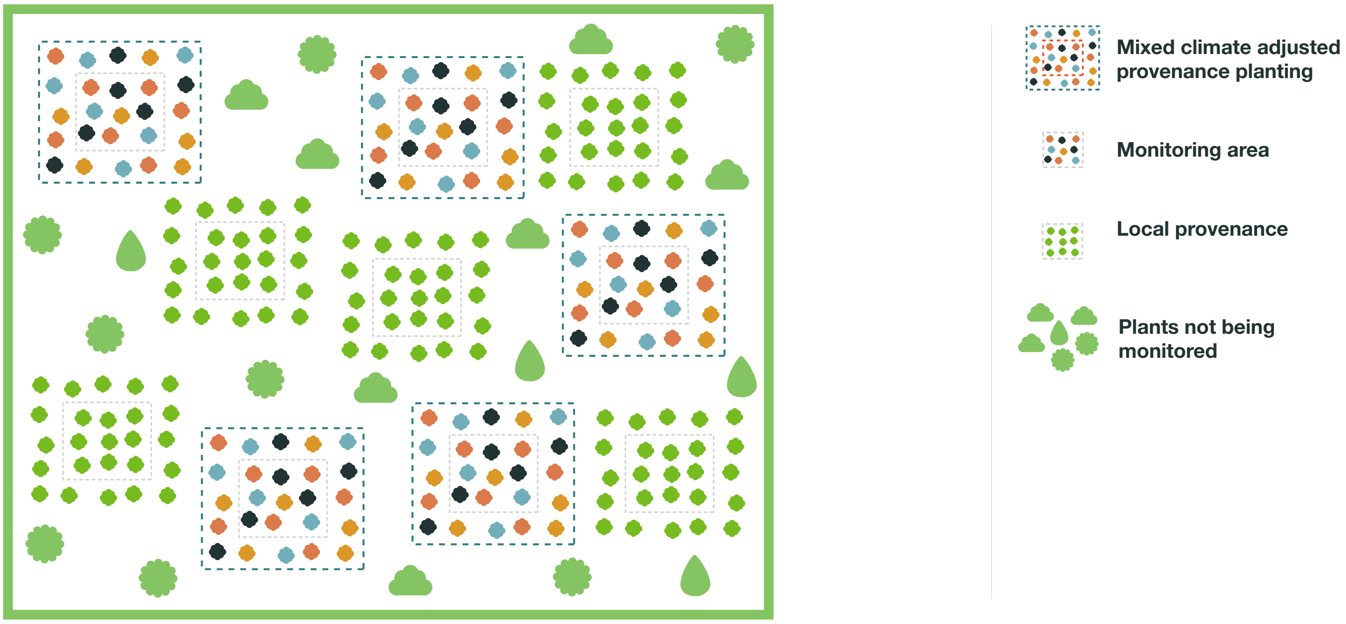


__Figure 5.__ Layout for mixed climate adjusted provenance blocks within local provenance plantings that have a mix of species. This would allow you to see how climate adjusted provenances survive and grow in comparison to local provenances. Dots that are blue, orange, red and black represent different climate adjusted provenances, while green dots represent a local provenance of the same species. Note that these provenance plantings could be done using one species or multiple species.

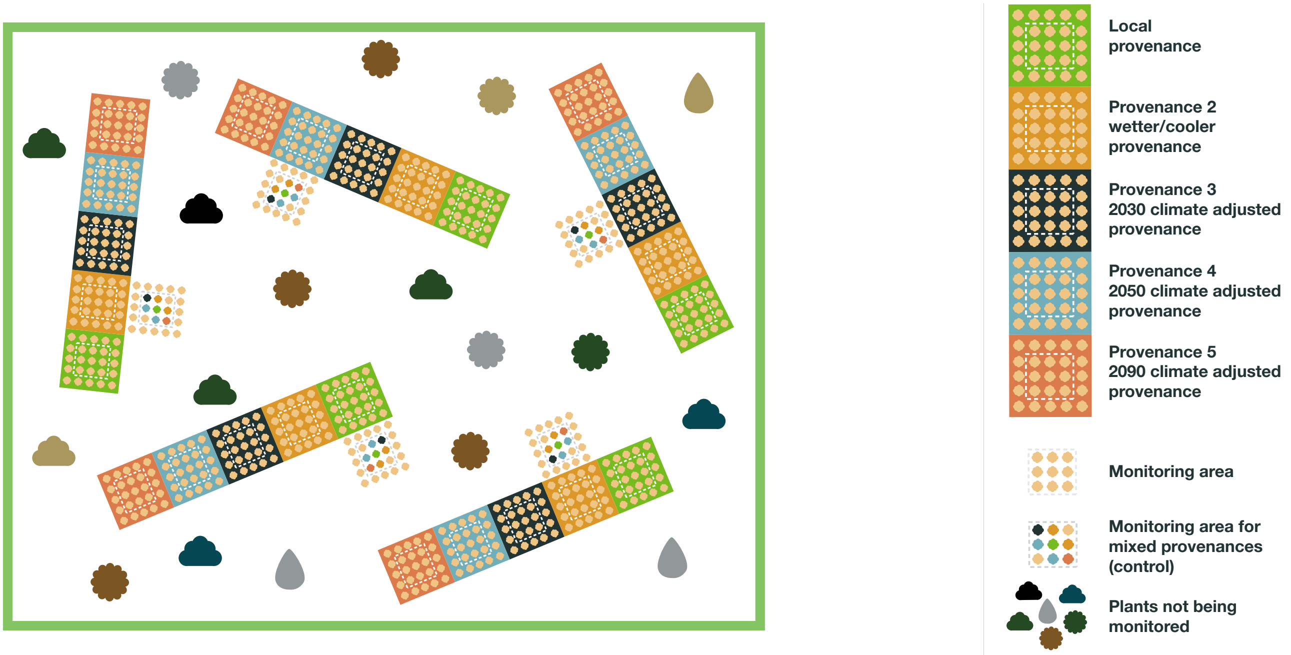


__Figure 6.__ Layout for individual climate adjusted & local provenance blocks within climate adjusted provenance plantings. A group of 'blocks' represents a 'plot'. This would allow you to compare how individual climate adjusted provenances and local provenances survive and grow. The mixed provenance monitoring areas measure how the general plantings are performing and act as a control for the individual provenance blocks being monitored. Note that 60% of the plants not inside the plots are expected to be local provenances. These plantings can be interspersed with different species from local provenances.

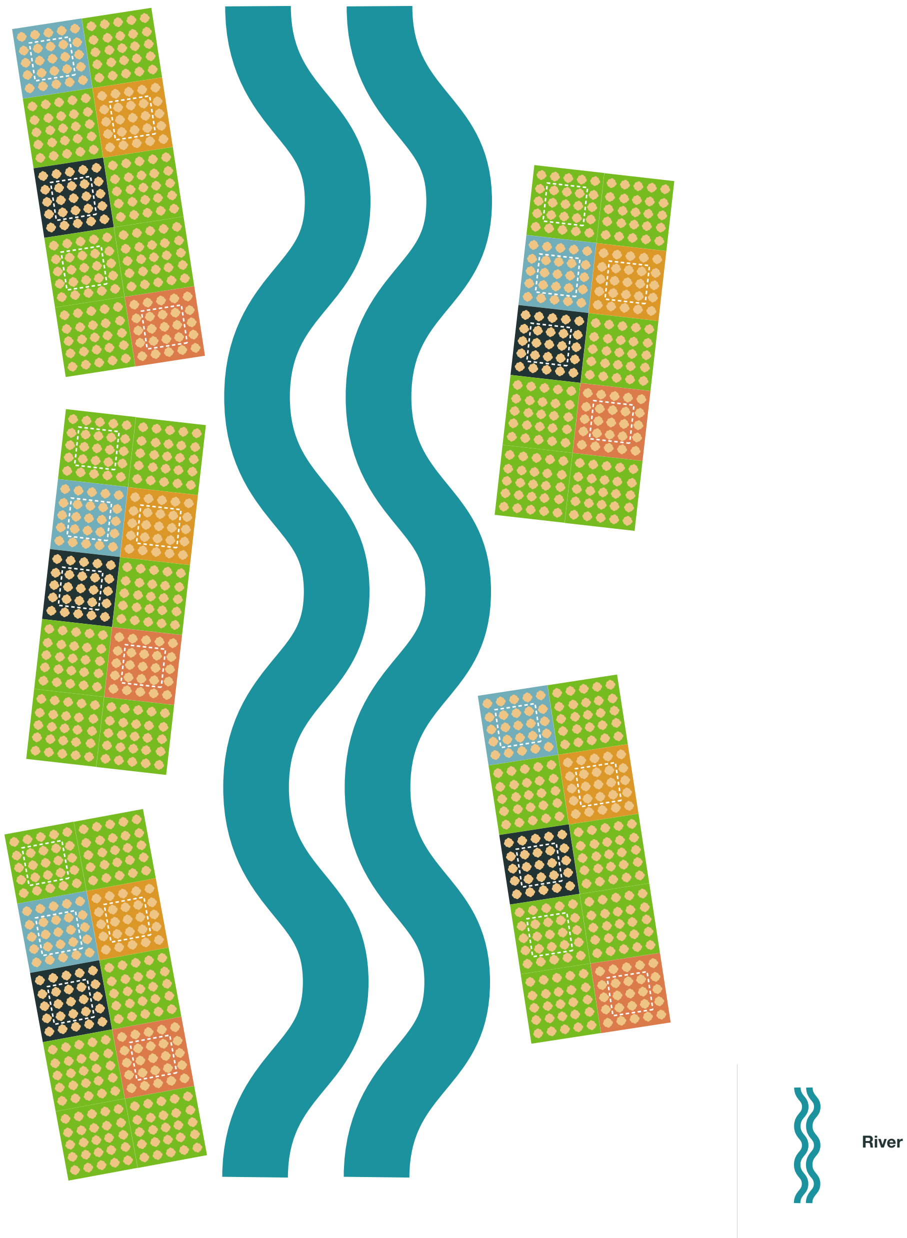


Figure 7. *Layout for individual climate adjusted & local provenance blocks as a whole climate adjusted planting. As in Figure 6, this layout would allow you to compare how individual climate adjusted provenances and local provenances survive and grow. There are more local provenance blocks within this design to maintain the 60% local provenance plantings in comparison to the climate adjusted provenances (40%), but only one of these local provenance blocks is monitored within a plot. The blue lines represent a stream or river, but these plantings could be along a roadside or existing vegetation. Provenances as per the legend in Figure 6.*

Figure 8. *Direct seeding lines showing how mixed provenance plantings could be undertaken when the question relates to: (a) the difference in plant survival and growth between mixed climate adjusted provenances and local provenances, or (b) the difference in plant survival and growth among individual climate adjusted provenances and local provenances. Rectangles represent monitoring transects. The length of the transect may vary with planting density (see Figure 9).*

Table 2. *The monitoring goals, implementation steps and minimum plant numbers needed for the different tubestock plantings.*

Identify outcomes between different provenances (including local)
Identify outcomes between local and climate adjusted provenances
Identify species and climate analogues
Choose the number of climate adjusted provenances to use
Collect/purchase local and climate-adjusted seed
Nurseries to propagate local and climate adjusted provenance seed, labelling & separating climate adjusted provenances
Maintain plants/seeds in local and mixed climate-adjusted provenances from propagation to planting
Maintain plants/seeds in local and individual climate-adjusted provenances from propagation to planting
Mark out local and climate adjusted blocks/plots on-ground prior to planting (minimum of 5 replicates per site)
Randomly allocate provenance blocks within each replicate plot
Plant separate local and climate adjusted blocks and mark and map areas to be monitored within these blocks (internal 3x3 plants)
Check plants and measure heights directly after planting
Monitor plant survival and height after the first summer (March-April), and then subsequent summers and/or after extreme events
Plants per block per replicate
Plants monitored per block per replicate
Number of blocks in a plot
Plants per plot per replicate
Plants monitored per plot per replicate
Overall plants in experimental planting areas per site (60% local:40% climate adjusted provenance plots replicated 5 times)
Overall plants in monitoring areas per site (60% local:40% climate adjusted provenance plots replicated 5 times)

Table 3. *The monitoring goals and implementation steps needed for the different direct seeding plantings.*

Identify outcomes between different provenances (including local)
Identify outcomes between local and climate adjusted provenances
Identify species and climate analogues
Choose the number of climate adjusted provenances to use
Collect/purchase local and climate-adjusted seed
Maintain plants/seeds in local and mixed climate-adjusted provenances from propagation to planting
Maintain plants/seeds in local and individual climate-adjusted provenances from propagation to planting
Seed local and climate adjusted lines and mark and map areas to be monitored within these lines (minimum of 5 replicates across site), designating a 20 m transect line to monitor at least 9 plants in each line (transect length may differ depending on planting density).
Monitor plant survival and height after the first summer (March-April), and then subsequent summers and/or after extreme events

Mixed climate adjusted provenance blocks (within local provenance plantings) – See Figure 5	**Individual climate adjusted & local provenance blocks (within climate adjusted provenance plantings)** – See Figure 6	**Individual climate adjusted & local provenance blocks –** See Figure 7
Monitoring goals		
X	√	√
√	√	√
Implementation steps		
√	√	√
√	√	√
√	√	√
X	√	√
√	X	X
X	√	√
√	√	√
n/a	√	√
n/a	√	√
√	√	√
√	√	√
Minimum Plant Numbers		
25 plants (5*5)	25 plants (5*5)	25 plants (5*5)
9 plants (3*3)	9 plants (3*3)	9 plants (3*3)
2 (1 local + 1 mixed)	5 + 1 adjacent	10
25	125 (25*5) + 25	250 (25*10)
9	45 + 9	45
250 (125 mixed climate adjusted provenance, 125 local provenance)	750 (500 climate adjusted provenance, 125 local provenance, 125 random provenance)	1250 (500 climate adjusted provenance, 750 local provenance)
90 (45 mixed climate adjusted provenance, 45 local provenance)	270 (180 climate adjusted provenance, 45 local provenance, 45 random provenance)	225 (180 climate adjusted provenance, 45 local provenance)

Mixed climate adjusted provenance lines adjacent to local provenance lines – See Figure 8a	**Individual climate adjusted & local provenance lines** – See Figure 8b
Monitoring goals	
X	√
√	√
Implementation steps	
√	√
√	√
√	√
√	X
X	√
√	√
√	√

Steps for monitoring

During planting:

Thorough mapping and marking of plots are essential for ease of ongoing monitoring and data collection, especially if assessments are likely to be undertaken by different people to those that set them up. Once plants start to grow plot configurations can also become confusing (even to those who set them up) so accurate maps are extremely helpful.

We recommend using, at a minimum, a robust weatherproof marker (e.g., a metal post with a metal tag) to indicate the position of the first plant in each plot. Ideally all four corners of a plot should be marked with robust markers, with the first plant being given a consistent position (e.g., south-eastern corner of each plot).

You should record GPS coordinates of the four corners of each plot. Ideally all provenance blocks within a plot should also have GPS coordinates recorded. If possible, map where each plant is (including species and provenance) relative to the first marked plant.

- Mark out five or more monitoring areas for each species and provenance combination within a planting site (see Figure 6).
- Record all the species and the number (abundance) of each planted species in the plot directly after planting. You will need to be able to identify the plants to species level to do this effectively.

We recommend the labelling/barcoding of each individual plant (including family/provenance information) prior to planting, and then mapping where each plant is located immediately after planting. Sorting labelled plants in the nursery into their respective plots can speed-up the planting process and improve accuracy.

After planting:

- Revisit the site during flowering or after summer (March/April) and record plants that are alive and their approximate height. Record flowering time and if seeds are being produced.
- Revisit the site after extreme events such as heatwaves or flash floods, to record its impact and variation in survival and growth between provenances and species.

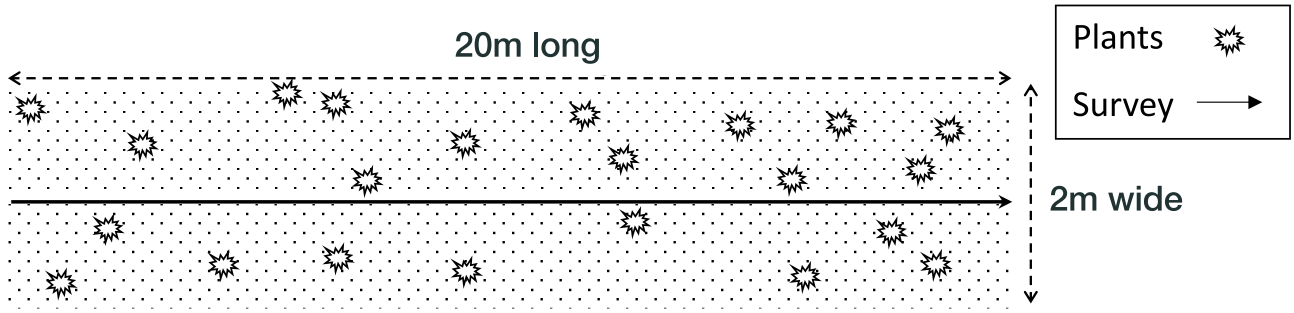


Figure 9. *The suggested setup for monitoring different plant provenances within a direct seeding line. The transect length may vary depending on planting density, but try and monitor at least 9 plants in each provenancing line.*

Monitoring methods for these areas should be designed in consultation with research institutions.

Consider monitoring native animals such as invertebrates in the plot area and birds using the site. Also consider recording disease spread in the planted plants. While these methods are not described here, if they are relevant to your management objectives you should incorporate them into your monitoring plan.

Define the resources required to monitor into the future

Sites should be monitored at least annually for the first three to five years, and then every five years after that, or as appropriate for the species being monitored. Consider the resources you need to achieve this, such as the number of people needed, time required to monitor the plots and enter the data, and where the data will be stored (i.e., monitoring database).

Long-term datasets extending to 30 years or more generate invaluable data about how revegetated areas change. They provide information on performance differences between provenances, between environments and over time. This improves our understanding of the influence of plant provenances on short and long-term revegetation outcomes.

How to manage planting and monitoring data

It is best to enter planting information and monitoring data into a centralised database, such as *Atlas of Living Australia BioCollect* or *ArcGIS Collector*, to ensure this information is kept for future use and analysis. This information can show how ecological systems are changing in the face of environmental and anthropogenic pressures, and what management actions help mitigate those changes.

To date, only small amounts of data have been properly recorded and stored, so only a fraction of the data collected in the past is discoverable, accessible or even usable. This is why it is important to collate and store data in a robust and accessible format, with up-to-date metadata, especially for long-term, large-scale and interdisciplinary projects [18]. Metadata is the information about one or more aspects of the data and summarises basic information about the data. It ensures the longevity of the database beyond a single researcher or practitioner and allows new people to understand how the database has evolved and which versions to revert to in case of errors. The most commonly used metadata for conservation projects is Darwin Core [19]. We strongly suggest using the database fields in Appendix 4 to record your data to ensure other programs are consistent and comparable.

A well-designed database allows users to store and update data and quantify how their on-ground activities are achieving biodiversity and potentially social benefits over time [20]. If you are not able to create and maintain a database or use someone else's, start with a spreadsheet with consistent column headings.

Whether you make your data publicly available is up to you or your funding agency, but it is increasingly common. If you do make your data publicly available, you need to provide statements regarding the contribution of authors and data providers, and whether you allow the data to be accessed, used or disseminated by others. The *Atlas of Living Australia* has five data sharing options that may be useful to consider [21].

Always ensure that the data is available to the manager responsible for the land (now and in the future). Also provide information about intellectual property and access agreements to ensure data is correctly cited.

AN EXAMPLE OF A RESEARCH PLOT AND SEED PRODUCTION AREA (SPA)

Designed by Dr Rebecca Jordan – CSIRO, Dr Peter Harrison, Dr Tanya Bailey and Professor Brad Potts – niversity of Tasmania and Dr Sacha Jellinek – Greening Australia & LaTrobe University

Picture this, a group of organisations and universities join forces to set up a series of standardised Climate Future Plots across the state. While the below example follows the decision-making process for one site in Bendigo, it would be ideal to set-up a network of sites across the state that encompass a variety of environmental gradients. For example, to get an even set of replicates across the state 12 sites could be established; four replicates in areas of high aridity, moderate aridity and low aridity (see Figure 10). Each site would ideally have reciprocal plantings, where the local provenance from one site is included in every other planting, along with the climate analogues for that site.

The following is a description of how one groups undertakes the process at their site using the 7 Steps.

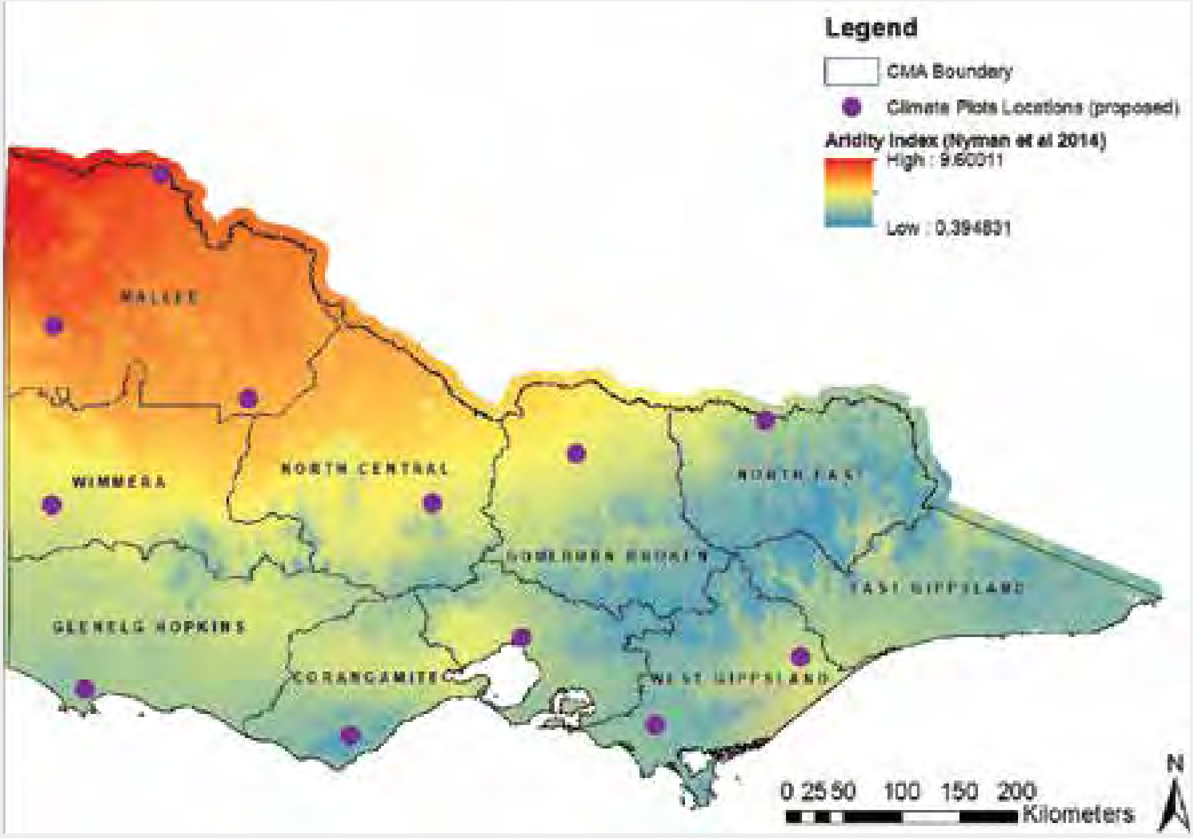


Figure 10. *Potential Climate Future Plot locations based on aridity gradients across the state* [22].

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1. Define goals for the plantings

The groups goal is to carry out research to monitor how plant species and provenances survive, grow and reproduce, and observe how these vary over time under changing conditions.

The group creates a list of broad research questions:

a. How does performance (such as plant survival, growth and reproduction) differ between provenances within a species and between species? Does this vary between planting sites in different climates, genetic contexts (mixed versus single provenance plots), and community contexts (mixed species versus single species)?

b. What is the genetic make-up of the restored species after the first and subsequent generations following mixed provenance plantings?

c. Can local provenances adapt to withstand climatic changes into the future (30 to 50 years) compared to different provenances of the same species (cooler and wetter or hotter and drier)?

d. How much environmental and climatic variation can a species tolerate?

e. Are abiotic factors (such as frosts and drought) and biotic factors (such as fungal interactions, animal occurrence, and co-occurring plants) important to determine differences in performance and planting success between provenances?

The group also makes a list of questions to consider in the future:

a. Does carbon sequestration differ between species and provenances?

b. How do plant diversity and plant provenance influence the way animals use the restored areas, and does this differ in other climatic regions?

c. What is the role of species diversity and plant provenance on ecosystem services?

d. Does land-use history, site preparation or site maintenance influence plant survival in different planting regions?

e. How does the surrounding matrix and plot size and shape influence species genetics and pollination or seed dispersal over time?

f. Where and how widely does seed need to be sourced to create climate-resilient restoration?

g. Do different provenances flower at the same time, allowing for crosses?

2. Understand climate projections in your area

The group looks at environmental factors such as aridity gradients and the predicted mean maximum monthly temperatures in 2050 and 2090 for their site. Using the CSIRO Climate Change in Australia website the group is able to see that the climate around Bendigo will be similar to Wagga Wagga or Echuca in 2050 and Forbes in 2090.

3. Define the site location/s

To determine where to put the plots, the group thinks about where in the landscape it would be most appropriate to undertake the planting. They want to ensure that they will be able to access the site for the next 30 years, and that it is at least 2 km away from remnant stands of native vegetation that contain similar species to those they wish to plant. They locate cleared land owned by the local council that is easy to access and ensures the longevity of their plantings.

4. Choose the plant species you will use

The group chooses several species common across Victoria that are regularly used in revegetation projects, using the list in Appendix 2. They also choose species that are local to the area or are likely to move to the region in the future.

As they want to include species from a Low Rises Grassy Woodland system, they decide to plant three species in the first year for a provenancing trial: Grey Box (*Eucalyptus macrocarpa*), Yellow Box (*Eucalyptus leucoxylon*) and Golden Wattle (*Acacia pycnantha*). They select 10 other mid and understorey species, using local provenance stock, to ensure that the planting is biodiverse.

The site will be fenced to protect it from grazing and vandalism and located in an area that ensures its viability for the next 30 or more years.

5. Choose the provenances you will use

The group decides on using five provenances, as they know each of the three species (Grey Box, Yellow Box and Golden Wattle) are located in their respective climate analogues. As they are creating a research plot, they will use the same proportion of seed for each provenance:

- A wetter region - Ballarat
- The local provenance - Bendigo
- A warmer region (2030 analogue) - Wangaratta
- An intermediate hot region (2050 analogue) - Wagga Wagga
- A hot region (2090 analogue) - Forbes.

6. Design and implement the site layout

Each species is to be planted at the optimal spacing, so the group settles on these spacing rules:

- 3 m x 3 m for eucalypts and other large tree and shrub species.
- 2 m x 2 m for shrubs.
- 0.5 m x 0.5 m for understory grasses and herbs.

As they have a relatively large, rectangular block of land, they propose a number of different layouts for the planting of their three species with mixed provenances.

Firstly, focussing on the layout of just one species, each plot consists of five provenances, with each provenance comprising twenty five plants (a 'block'), where nine plants within each block will be monitored (see Figure 11a). Each plot is replicated five times in an area (25 blocks - five provenances x five replicate plots, see Figure 11b, c). This means that each experimental planting contains 625 plants, of which 225 plants are monitored (nine plants per provenance x five provenances x five replicate plots). For Figure 11b, with twenty five plants per provenance (5 x 5 plants) they work out the layout would be 25 plants along each side (with 3 m spacings this requires an area of 75 m x 75 m = 5,625 m^2).

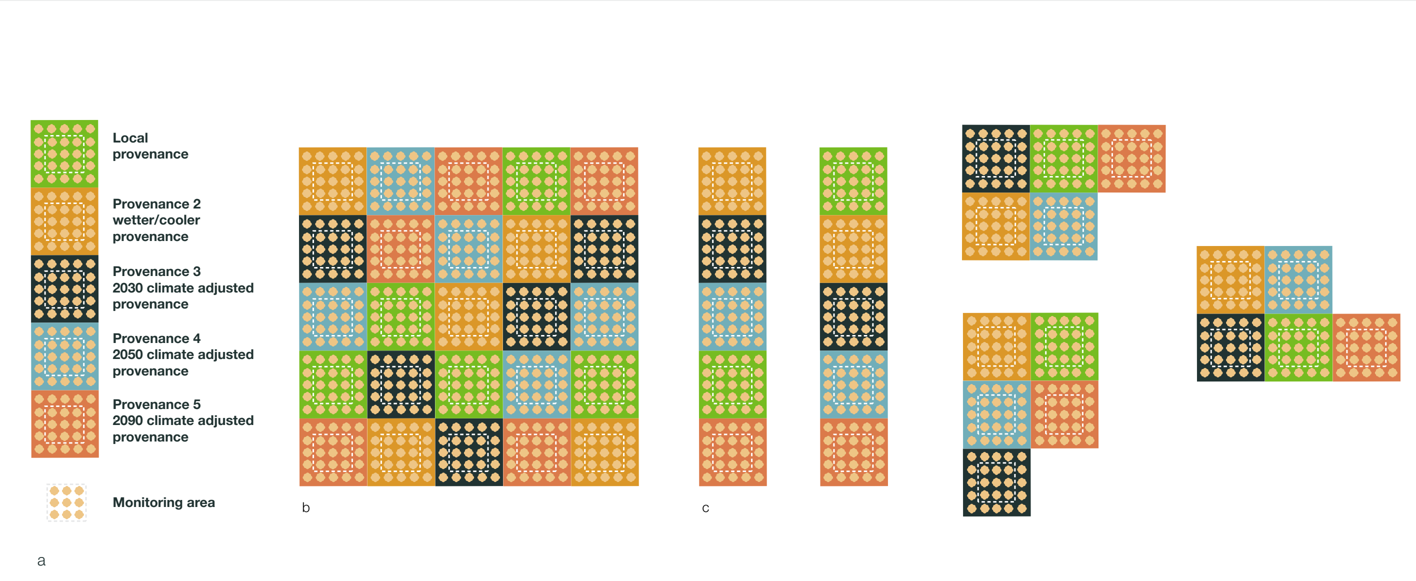

Figure 11. *Example layouts to compare performance between provenances of a single species (orange circles): (a) one plot comprises five provenances, twenty five plants per provenance with nine plants being monitored (a 'block'). A full experimental planting contains five plots (five replicates of each of the five provenances). The replicates may be arranged continuously (b - where columns represent a plot in this example) or planted separately (c). In both (b) and (c), blocks are randomly arranged within each plot so that the order and location of provenances is not the same.*

For greater accuracy and/or if plant mortality is likely to be high, they consider that they could increase the number of plants to be monitored to 16 plants per provenance (4 x 4 plants), which would be 36 plants along each side in a continuous design (for trees, 108 m x 108 m = 1.16 ha area, 1,296 plants).

They then look at the potential layout of the three species, using a similar design as Figure 11b.

They decide they can ask two or more separate questions, depending on their layout:

- If their question is related to a multiple species design in which the focus is on differences within a species, but to observe three species in the same planting area, the planting layout will look like Figure 11b or c, simply repeated three times (once for each of the three species). The layout could be either three separate plantings (see Figure 12a) or a large, single continuous planting (see Figure 12b).

This planting would contain 75 blocks – 25 blocks as per Figure 11 (one plot per provenance x five provenances x five replicates) x three species. If each block contains twenty five plants (nine of which would be monitored), the total number of plants required would be 1,875 (625 of each species = 25 x 25 blocks). For species planted at 3 m spacings, this would cover an area of at least 225 m x 75 m (1.7 ha).

- If their question is to understand how stable provenance differences are within a species when planted in different community contexts, the design would need to alternate species within each plot.

The group decides to go for the option outlined in Figure 12a, with rows between each of the plantings to make maintenance and monitoring simpler. This design could be scaled-up for more species, with the design and space required increasing by the number of species.

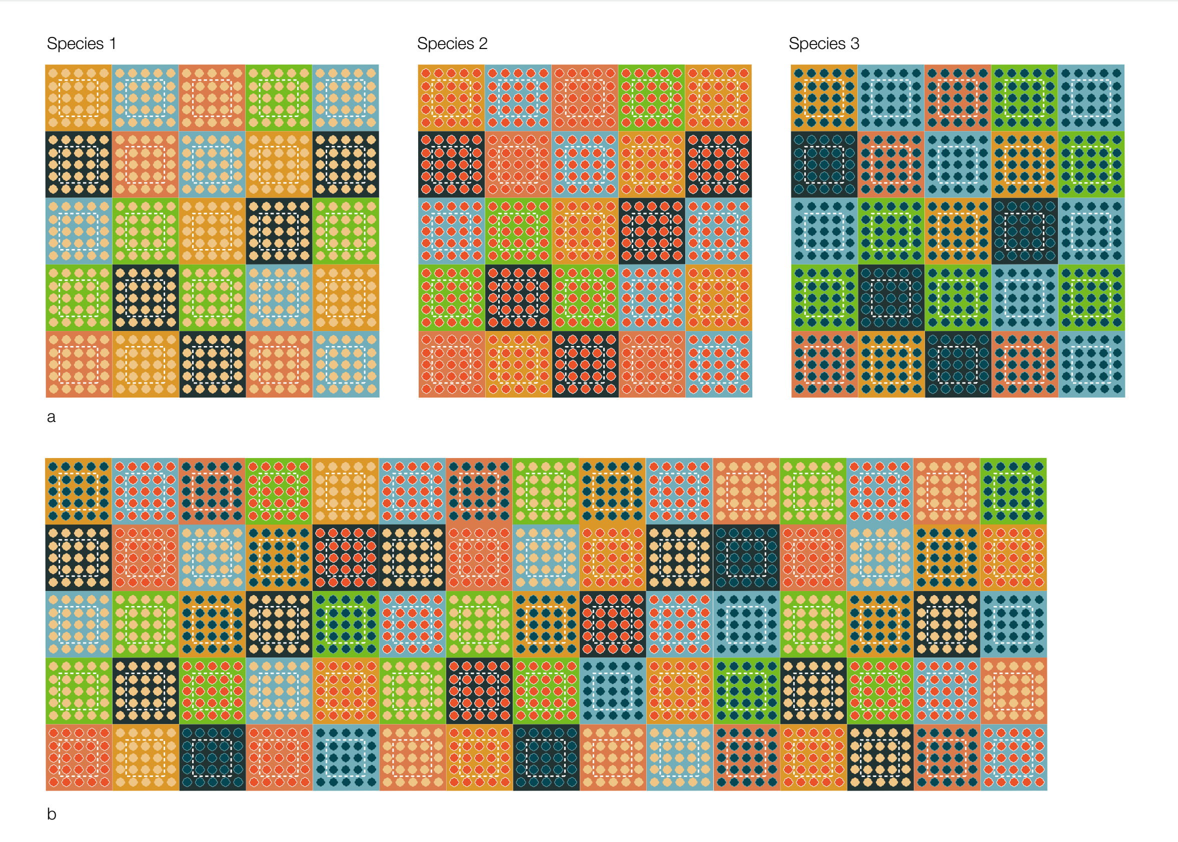

Figure 12. *An example layout for an experimental planting for three species (orange circles represent species 1, red circles represent species 2 and blue circles represent species 3) containing five provenances. This could be (a) three separate plantings or (b) a large continuous planting.*

7. Monitor the site and manage your data

Detailed information will be recorded about the site (see the monitoring section on Page 28) and site preparation. Each plant is to be individually tagged by the group, and data collected at least annually on their survival and growth (for example, during flowering, which may be at different times of the year for different species). Once the plants have matured, reproduction will also be monitored (for example, flowering, seed productivity and viability). Together, this information will guide seed sourcing efforts for future restoration investments by the group and help determine which provenances perform best, now and into the future.

HOW WILL CLIMATE CHANGE IMPACT PLANTS?

The most effective way to protect Victoria's biodiversity is to maintain native vegetation in a healthy condition [23].

Victoria's ability to achieve this will be impacted by climate change and the legacy of habitat clearing and fragmentation [24]. We are already seeing a change in flora communities in Australia and globally as a result of climate change, resulting in forest, woodland and grassland declines at scale [25]. This has a negative effect on ecosystem health and related socio-economic and cultural values [26].

Some plant communities will need to move more than 1 km a year to stay within zones of suitable conditions as the climate changes [27]. Up to 29 % of plant populations are unlikely to migrate fast enough, or are limited in their movement due to natural or human created barriers to species dispersal (such as habitat fragmentation or hydrological barriers from dams or altered hydrological regimes through extraction), or a disconnect between dispersal pathways (for example, wind-dispersed species moving from west to east, while climate impacts are north to south) [5, 27].

Climate change acts as an environmental filter that selects for species or individuals within a species best suited to the changing conditions. Plants need to be able to pass through this environmental filter at different life history stages in order to be able to complete their lifecycle and survive. Knowledge of plant lifecycles, climate futures and the tolerance of plants to these changes can help us predict which species may be suitable in a given location. In some cases, it may be necessary to introduce new species (translocations) or help local species adapt by introducing genetic diversity. Translocation is a good option if a species is likely to go extinct in its current location but may survive elsewhere and can fulfil a missing ecosystem function in that new location [28].

The impact of climate change on plants requires an understanding of the plant's lifecycle, including the plant's requirements during different life stages, particularly during germination, early establishment and once fully grown. For most species, this is currently poorly understood.

Hydrological changes due to climate change will also have an impact on plant communities. For example, declines in river flows due to decreasing rainfall and less runoff [29] will likely result in shifts in riparian and floodplain vegetation. Studies suggest that runoff in south-eastern Australia may decline by as much as 17 % under climate change [30], which is likely to have a major effect on riparian plant communities and aquatic dispersal pathways. However, groundwater may buffer this decline, at least temporarily, and plant species or communities may shift downslope to match their water requirements.

Climate change may also impact wetlands via altered water regimes that increase wetland salinity or decrease the frequency of freshwater flows and inundation, decrease wetland connectivity, damage vegetation through more frequent storms, and alter salinity and water levels via sea level rise [31]. For example, a study in the Gippsland Lakes found that declines in runoff linked to climate change over the next 30 years will likely increase wetland salinity and decrease the availability of freshwater habitats [31].

Flowering, pollination, seed dispersal and seed production

Climate change is expected to have a significant influence on plant reproduction, which will affect seed availability and viability, and ultimately the timing and scale of revegetation activities [32]. Ensuring we have enough viable seed for restoration projects in the future will be critical. This is especially true in Australia, as over 90 % of our seed comes from wild populations, and this seed may already be compromised due to the fragmented nature of many landscapes, reducing seed quantity and quality through inbreeding depression [32]. SPAs that contain climate-adapted plant genetics are one way to give more certainty to the restoration industry into the future.

Some of the recommendations for managing seed resources are provided in Appendix 5.

Plant lifecycles, floral abundance, and timing of flowering and seeding also alter as a result of increasing temperatures, whereas drought stress is predicted to lead to declines in seed number and size and increases in unviable seed rates [32]. The size and number of seeds produced by a species will impact how far those seeds disperse, influencing the distance we should undertake revegetation from remnant habitats if we aim to boost resilience in these areas.

As stated above, revegetated areas need to be less than 1 km away from remnant habitats [33, 34], and upwind, if we want seed and pollen to reach those areas. Insects and birds are most effective at pollinating plants that are up to 100 to 200 m apart, although birds may still be effective at distances of 1 to 2 km (see Figure 13).

Depending on the landscape, pollination effectiveness may be influenced by habitat fragmentation, altering pollinator behaviour, abundance of pollinators, and pollen transfer. Climate change may exacerbate changes in pollination rates, especially if there is a time-lag between plant movement and pollinator colonisation [32]. Understanding what animal species are likely to assist in pollination and choosing plant species that can attract pollinators may be beneficial for your project.

Germination and recruitment

Climate change is likely to influence the ability of plants to germinate and recruit into the landscape. For example, some seeds require cold, moist conditions to break seed dormancy (for example, Alpine Ash - *Eucalyptus delegatensis* and Snow Gum - *E. pauciflora*), and with warming temperatures and fewer frosts and snow cover, these chilling requirements may not be met.

Seeds are dependent on factors such as temperature, soil moisture and light in order to germinate. In open, sparsely vegetated habitats, such as grassy woodlands and grassland, increased air temperatures are likely to increase soil temperatures, which could accelerate the decline of seed viability [35]. In floodplain species, river flow modifications and reduced frequency, duration and flood timing are compounded by climate change and deteriorating groundwater conditions (in depth and salinity), causing a dieback in species reliant on these hydrological regimes [36]. This can result in a change in plant community composition in riparian systems [36].

Increased temperatures are also likely to result in higher frequencies of fire in some habitats, meaning that species with long-lived seed banks can be compromised. However, higher temperatures and lower rainfall may also reduce plant density and the rates of leaf litter and fallen timber accumulation, possibly reducing the likelihood that some habitats will carry hot, frequent fires. Similarly, as rainfall declines, recruitment could be reduced and fewer plants could grow and set seed, resulting in a net-loss of seed-bank longevity. However, temperature increases will likely benefit some species. For example, Grey Box (*E. microcarpa*) may benefit from warming temperatures [37], outcompeting species with which they currently co-exist [37].

Adult plant survival

Climate extremes play an important role in influencing plant survival [6, 11]. Adult plant survival has been shown to be affected by changes in climate in Tasmania, where the Miena Cider Gum (*E. gunnii ssp. divaricata*) has shown severe declines due to rising temperatures and 25 % lower rainfall over the last 50 years [38]. Manna Gum (*E. viminalis*) has also declined as a result of the interaction of multiple stressors such as temperature, rainfall and invertebrate infestations [39]. Declines of one species in turn influences the health of the wider vegetation communities [39].

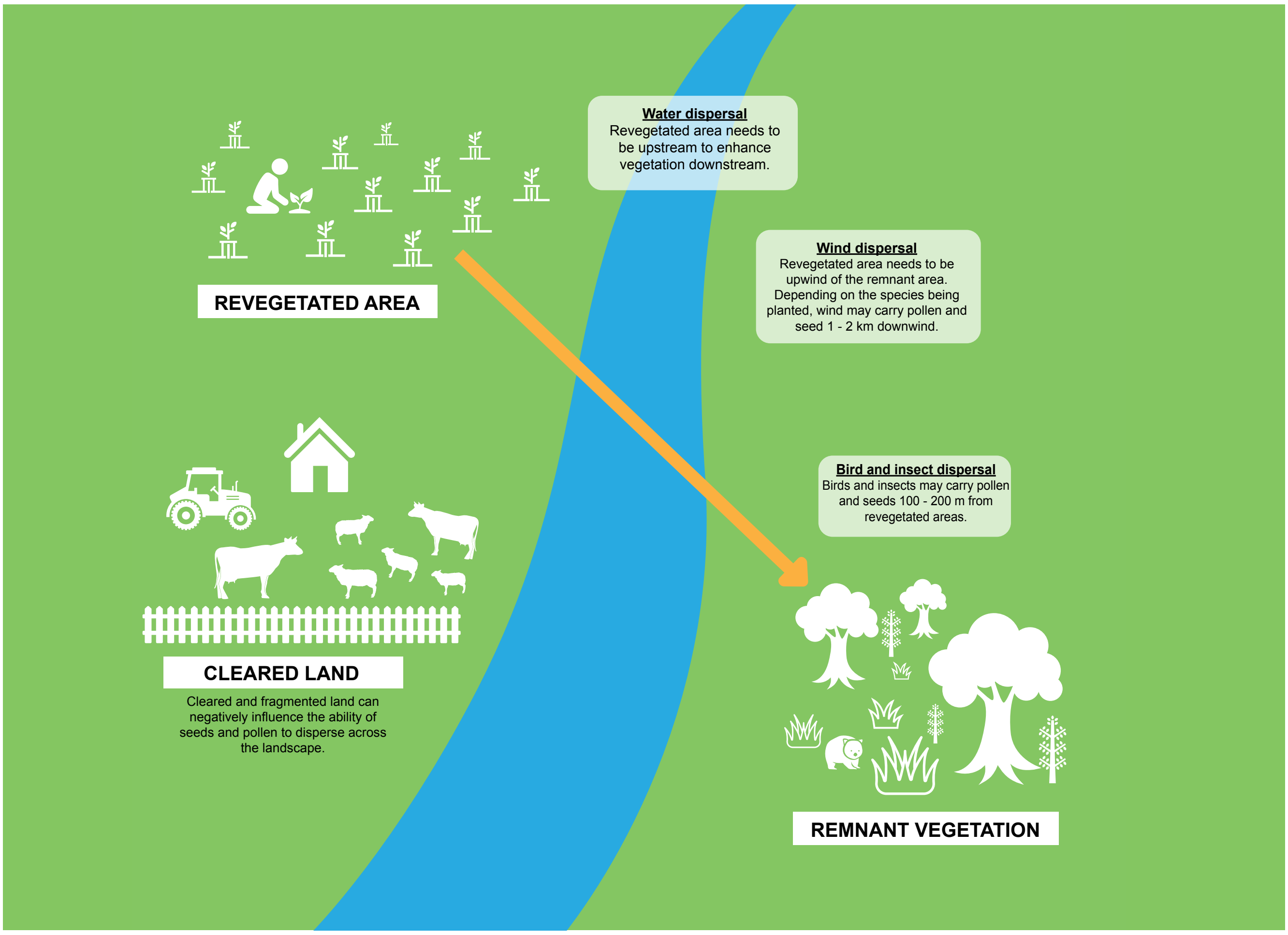

Figure 13. *Factors influencing plant pollination and seed dispersal.*

TAP INTO EXISTING KNOWLEDGE

People and nature will greatly benefit from the Climate Future Plots network in Victoria, and the network can be expanded if we link with other projects occurring nationally. One such network that links with a wider set of plots around Australia is called the 'Provenancing strategy' network of the proposed Platform for Ecological Restoration Research Infrastructure (PERRI) [40].

In Victoria, there are many projects underway to identify and supply seed for priority plant species climatically matched to future conditions. Several projects combine genetic research and climate modelling for key species to locate 'climate ready' seed sources for supplementing regional seed mixes. Here is a selection of projects that you could potentially contact for assistance:

- Bush Heritage Australia – Climate Impacts on Grey Box (*Eucalyptus microcarpa*) and Yellow Box (*E. melliodora*). This project provides long-term guidance on viable, climate-ready Eucalypt revegetation options for central Victoria using climate adjusted provenancing. It began in 2018 and a large field trial in the Nardoo Hills reserve was established in mid-2019 to help restore threatened woodland bird communities.
- The Friends of Forgotten Woodlands, Deakin University, La Trobe University, Glenelg Hopkins and Corangamite CMAs – This project identifies climate ready seed mixes and develops climate adjusted SPAs for Silver Banksia (*Banksia marginata*), Drooping Sheoak (*Allocasuarina verticillata*), and Sweet Bursaria (*Bursaria spinosa*) on the Victorian Volcanic Plains.
- Forest and Landscape Dynamics Research Group, University of Melbourne – This project quantifies the impacts of climate change and altered fire regimes on alpine plant communities, and develops strategies to help these communities become more resilient in the future.
- Goulburn Broken Catchment Management Authority and CSIRO – Revegetation activities using climate adjusted provenancing and the Silver Banksia Rescue Project. This project is testing the genetic viability of Silver Banksia populations and has developed a SPA at Euroa Arboretum to improve the genetic resilience of Silver Banksia into the future.

GLOSSARY

Climate adjusted provenancing – A planting method in which local seed collections are supplemented with non-local seed collected along an environmental gradient of change, such as in the direction of climate change projections for the site being restored.

Climate analogues – Geographic regions that experience similar climatic conditions, but which may be separated in space or time (that is, with past or future climates).

Climate change – Anthropogenic-induced changes in the pattern of weather, and related changes in oceans, land surfaces and ice sheets, occurring over time scales of decades or longer.

Climate change adaptation – Natural or assisted adaptation that allow natural systems to deal with the consequences of climate change.

Ecological renovation – Conservation activities that actively allow for environmental change [41].

Environmental gradient – Changes in factors such as rainfall, temperature, soil type and altitude that influence plant and animal species.

Genetics – The study of genes, genetic variation and heredity in organisms.

Germoplasm – Living genetic resources such as seeds or tissues that are maintained for the purpose of plant breeding and preservation.

Genotype – The genetic makeup of a cell and therefore an individual, which can be passed onto the next generation.

Provenance – A geographic location of a species usually thought to represent genetic adaptation to local environmental conditions.

Population – The individuals within a geographic location and their offspring.

Replication – The number of times a test or an experiment is repeated; the more replication, the more accurate the results are likely to be.

Representative concentration pathway (RCP) – The long-term concentration and trajectory of emissions from greenhouse gases, aerosols and chemically active gases adopted by the Intergovernmental Panel on Climate Change.

Revegetation – The establishment, by any means, of plants on sites (including terrestrial, freshwater and marine areas).

Restoration – The process of assisting the recovery of ecosystem function and services that have been degraded, damaged or destroyed.

Seed production area (SPA) – An area that provides larger quantities of high-quality seed of known origin, quality and genetic diversity for replanting onto restoration sites.

Species distribution model (SDM) – Numerical and statistical tools that combine observations of species occurrence or abundance with environmental estimates to predict the distribution of a species across geographic space and time.

Translocation – The intentional movement of plants out of their natural environment to other locations either to protect them from local extinction, or to fill a functional niche if no local species exist. This is also referred to as assisted migration.

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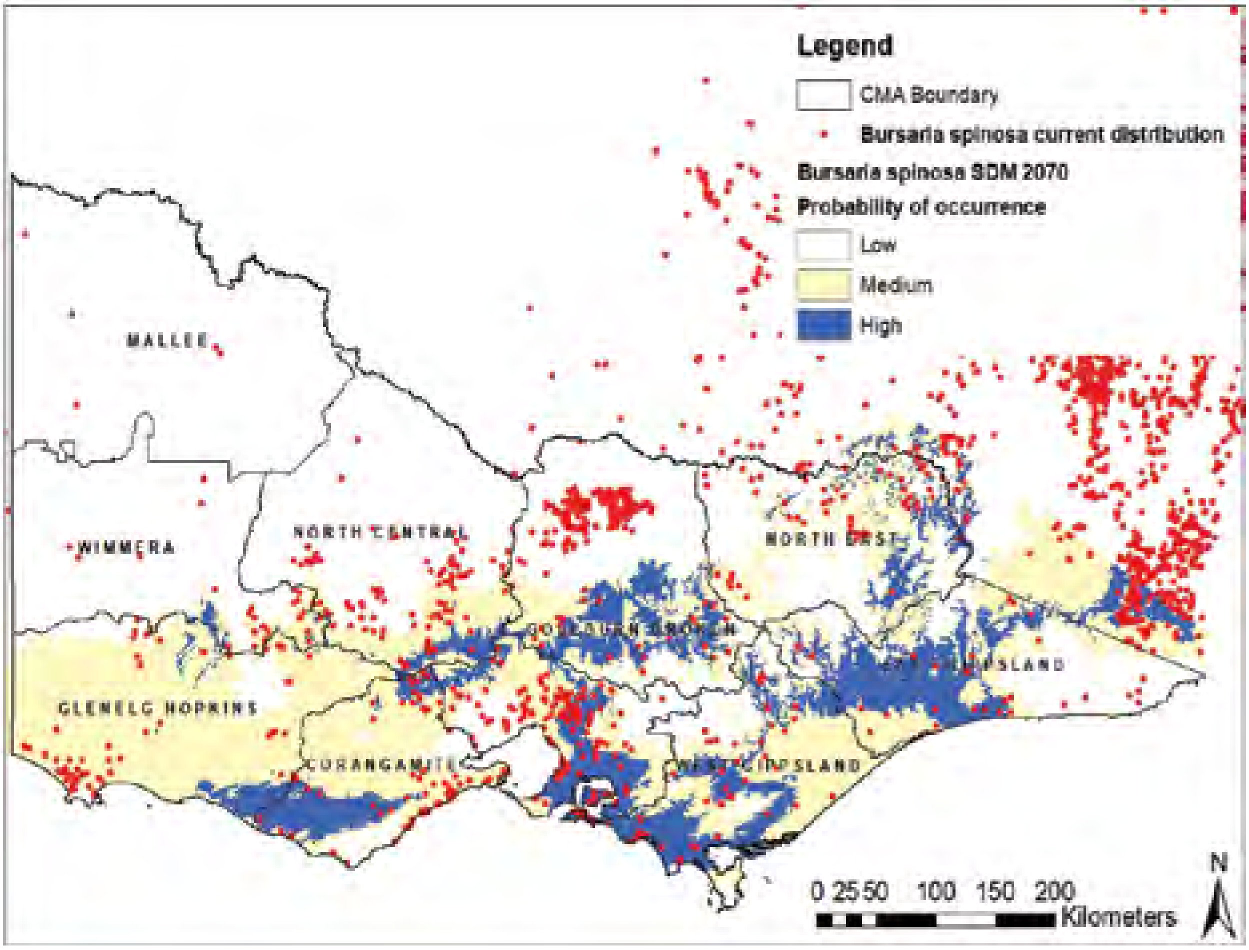
Appendix 1. The current distribution of Sweet Bursaria (*Bursaria spinosa*) and its projected distribution in 2070 (SDM – Species Distribution Model, high emissions scenario, ACCESS 1.0 model).

Sweet Bursaria is found in most parts of Victoria, although it is generally absent from the more arid parts of the state. As the state becomes hotter and drier, and potentially more arid, Sweet Bursaria may become more restricted to the southern half of the state by 2070. Incorporating genetics from hotter and drier parts of the state and from interstate may improve the likelihood of this species persisting in its current range.



Appendix 2. The top 100 plant species used for revegetation projects in Victoria

Number	Species Name	Common Name	Form
500025	*Acacia dealbata*	Silver Wattle	Tree
500045	*Acacia implexa*	Lightwood	Tree
500056	*Acacia mearnsii*	Black Wattle	Tree
500057	*Acacia melanoxylon*	Blackwood	Tree
500677	*Allocasuarina littoralis*	Black Sheoak	Tree
500678	*Allocasuarina luehmannii*	Buloke	Tree
500685	*Allocasuarina verticillata*	Drooping Sheoak	Tree
500362	*Banksia integrifolia subsp. integrifolia*	Coast Banksia	Tree
500576	*Callitris glaucophylla*	White Cypress-pine	Tree
503759	*Eucalyptus baxteri s.s.*	Brown Stringybark	Tree
501258	*Eucalyptus camaldulensis*	River Red-gum	Tree
501293	*Eucalyptus leucoxylon*	Yellow Gum	Tree
501294	*Eucalyptus macrorhyncha*	Red Stringybark	Tree
501297	*Eucalyptus melliodora*	Yellow Box	Tree
501298	*Eucalyptus microcarpa*	Grey Box	Tree
501304	*Eucalyptus obliqua*	Messmate Stringybark	Tree
501307	*Eucalyptus ovata*	Swamp Gum	Tree
501308	*Eucalyptus pauciflora*	Snow Gum	Tree
501313	*Eucalyptus radiata s.l.*	Narrow-leaf Peppermint	Tree
501323	*Eucalyptus viminalis*	Manna Gum	Tree
502150	*Melaleuca lanceolata*	Moonah	Tree
502239	*Myoporum insulare*	Common Boobialla	Tree
502299	*Olearia argophylla*	Musk Daisy-bush	Tree
502650	*Pomaderris aspera*	Hazel Pomaderris	Tree
500363	*Banksia marginata*	Silver Banksia	Tree
504778	*Acacia acinacea s.s.*	Gold-dust Wattle	Shrub
500038	*Acacia genistifolia*	Spreading Wattle	Shrub
500061	*Acacia montana*	Mallee Wattle	Shrub
500063	*Acacia myrtifolia*	Myrtle Wattle	Shrub
500072	*Acacia paradoxa*	Hedge Wattle	Shrub
500078	*Acacia pycnantha*	Golden Wattle	Shrub
500091	*Acacia stricta*	Hop Wattle	Shrub
528406	*Acacia verniciflua s.s.*	Varnish Wattle	Shrub
500100	*Acacia verticillata*	Prickly Moses	Shrub
500683	*Allocasuarina paludosa*	Scrub Sheoak	Shrub
505690	*Bursaria spinosa*	Sweet Bursaria	Shrub
500565	*Callistemon sieberi*	River Bottlebrush	Shrub

Number	Species Name	Common Name	Form
500609	*Calytrix tetragona*	Common Fringe-myrtle	Shrub
500666	*Cassinia aculeata subsp. aculeata*	Common Cassinia	Shrub
903436	*Cassinia arcuata s.s.*	Desert Cassinia	Shrub
500822	*Coprosma quadrifida*	Prickly Currant-bush	Shrub
500829	*Correa alba*	White Correa	Shrub
500832	*Correa reflexa*	Common Correa	Shrub
505931	*Dillwynia cinerascens s.s.*	Grey Parrot-pea	Shrub
501095	*Dodonaea viscosa*	Sticky Hop-bush	Shrub
501156	*Enchylaena tomentosa var. tomentosa*	Ruby Saltbush	Shrub
501507	*Goodenia ovata*	Hop Goodenia	Shrub
505076	*Goodia lotifolia s.s.*	Common Golden-tip	Shrub
503853	*Gynatrix pulchella s.s.*	Hemp Bush	Shrub
501761	*Indigofera australis subsp. australis*	Austral Indigo	Shrub
501956	*Leptospermum continentale*	Prickly Tea-tree	Shrub
501958	*Leptospermum lanigerum*	Woolly Tea-tree	Shrub
500581	*Leucophyta brownii*	Cushion Bush	Shrub
501987	*Leucopogon parviflorus*	Coast Beard-heath	Shrub
502146	*Melaleuca decussata*	Totem-poles	Shrub
502147	*Melaleuca ericifolia*	Swamp Paperbark	Shrub
502149	*Melaleuca halmaturorum*	Salt Paperbark	Shrub
502153	*Melaleuca squarrosa*	Scented Paperbark	Shrub
504933	*Melicytus dentatus s.s.*	Tree Violet	Shrub
502312	*Olearia lirata*	Snowy Daisy-bush	Shrub
502322	*Olearia ramulosa*	Twiggy Daisy-bush	Shrub
501616	*Ozothamnus ferrugineus*	Tree Everlasting	Shrub
502523	*Pimelea humilis*	Common Rice-flower	Shrub
502541	*Pittosporum angustifolium*	Weeping Pittosporum	Shrub
502743	*Prostanthera lasianthos*	Victorian Christmas-bush	Shrub
502927	*Rhagodia candolleana subsp. candolleana*	Seaberry Saltbush	Shrub
503179	*Solanum laciniatum*	Large Kangaroo Apple	Shrub
503523	*Viminaria juncea*	Golden Spray	Shrub
502844	*Pultenaea daphnoides*	Large-leaf Bush-pea	Shrub
500623	*Carex appressa*	Tall Sedge	Grass
505555	*Dianella admixta*	Black-anther Flax-lily	Grass
501029	*Dianella revoluta s.l.*	Black-anther Flax-lily	Grass
501395	*Gahnia sieberiana*	Red-fruit Saw-sedge	Grass
501830	*Juncus pallidus*	Pale Rush	Grass

Number	Species Name	Common Name	Form
502046	*Lomandra longifolia*	Spiny-headed Mat-rush	Grass
502437	*Patersonia occidentalis var. occidentalis*	Long Purple-flag	Grass
502600	*Poa labillardierei*	Common Tussock-grass	Grass
502608	Poa sieberiana	Grey Tussock-grass	Grass
500961	*Rytidosperma caespitosum*	Common Wallaby-grass	Grass
504971	*Stylidium graminifolium s.s.*	Grass Triggerplant	Grass
503387	*Themeda triandra*	Kangaroo Grass	Grass
503588	*Xanthorrhoea minor subsp. lutea*	Small Grass-tree	Grass
501782	*Ficinia nodosa*	Knobby Club-sedge	Grass
502179	*Microlaena stipoides var. stipoides*	Weeping Grass	Grass
505126	*Arthropodium strictum s.s.*	Chocolate Lily	Forb
500332	*Atriplex semibaccata*	Berry Saltbush	Forb
500510	*Bulbine bulbosa*	Bulbine Lily	Forb
500582	*Calocephalus citreus*	Lemon Beauty-heads	Forb
500583	*Calocephalus lacteus*	Milky Beauty-heads	Forb
500657	*Carpobrotus rossii*	Karkalla	Forb
504281	*Chrysocephalum apiculatum s.s.*	Common Everlasting	Forb
501628	*Chrysocephalum semipapposum*	Clustered Everlasting	Forb
501073	*Disphyma crassifolium subsp. clavellatum*	Rounded Noon-flower	Forb
501133	*Einadia nutans*	Nodding Saltbush	Forb
501847	*Kennedia prostrata*	Running Postman	Forb
503886	*Microseris lanceolata*	Alpine Yam-daisy	Forb
502442	*Pelargonium australe*	Austral Stork's-bill	Forb
507386	*Clematis microphylla s.s.*	Small-leaved Clematis	Vine
501596	*Hardenbergia violacea*	Purple Coral-pea	Vine
503343	*Tetragonia implexicoma*	Bower Spinach	Vine

Appendix 3. Alternative seed sourcing strategies

In order to maximise a population's performance under a future climate scenario, the following strategies are proposed to enhance natural patterns of gene flow by mixing seed from local provenances combined with seed from more distant sites:

- 'Predictive provenancing' [14], which involves gathering seed (genes) from areas that have a similar climate now to the predicted future climate for the planting location.
- 'Climate adjusted provenancing' [13], which involves gathering seed from multiple provenances along a climatic gradient, from local provenances toward future predicted climates. The goal is to increase genetic diversity and genotypes pre-adapted to future climates.
- 'Composite, admixture and regional admixture provenancing' does not take climate matching into consideration. Instead the aim is to capture genetic diversity generally.
- 'Admixture provenancing' builds evolutionary resilience into plantings by sourcing provenances across a species range and mixing them, without taking into consideration the location of the planting site [10].
- 'Regional admixture provenancing' is similar to admixture [12], however provenances are obtained from a region close to the planting site, rather than from a wide geographic range.
- 'Composite provenancing' mixes seed from local populations with progressively smaller amounts of seed from sites further away, replicating natural patterns of gene flow [42].

Appendix 4. Suggested database field names

Data Name	Description	Darwin Core Link	Data Type
Project ID	Unique identifier for each assessment or monitoring project	http://rs.tdwg.org/dwc/terms/datasetID	Long Integer
Project Name	A name to identify a project. Projects are structured data, with one or more surveys grouped together.	http://rs.tdwg.org/dwc/terms/datasetName	Text (Short)
Project Description	A description of the project. Example: "Revegetation data recorded from 50 x 6 m quadrats at the Coorong and Lower Lakes Landcare Restoration project 2018 - 2020"	http://rs.tdwg.org/dwc/terms/catalogNumber	Text (Short or Long)
Observer Name	The name of the person undertaking the monitoring.	http://rs.tdwg.org/dwc/terms/recordedBy	Text
Property ID	The identification number of the property		Long Integer
Landholder Name	The name of the property owner		Text
Site ID	A unique identifier for each site surveyed. A site could be a discreet restoration area.		Long Integer
Site Name	The name for the set of location information. If you are monitoring a series of sites then use the Site Name field, for example, Site 1a.	http://rs.tdwg.org/dwc/terms/verbatimLocality	Text
Site Location	Describes the locality using an accepted place name. Preferably give a distance and direction from a named point.	http://rs.tdwg.org/dwc/terms/verbatimLocality	Text
Coordinate System	From a defined list, indicates the type of coordinates used. Only complete one of the following type of coordinates: • latlong, to identify latitude/longitude DMS (degrees minutes seconds). • decdegrees, to identify latitude/longitude DD (decimal degrees). • eastnorth, to identify easting/northing (long – must include zone).	http://rs.tdwg.org/dwc/terms/verbatimCoordinateSystem	Text
Coordinate Datum	From a defined list, a value to indicate a standard position or reference system, for example GDA94, WGS84, AGD66.	http://rs.tdwg.org/dwc/terms/verbatimCoordinates	Text
X coordinate	A numeric representation of the precision of the coordinates given in the Easting or Longitude related with the type of coordinates used.	http://rs.tdwg.org/dwc/terms/verbatimCoordinates	Text or Integer
Y coordinate	A numeric representation of the precision of the coordinates given in the Northing or Latitude related with the type of coordinates used.	http://rs.tdwg.org/dwc/terms/verbatimCoordinates	Text or Integer

Site Details

Data Name	Description	Darwin Core Link	Data Type
Restoration Goal	Unique identifier for each assessment or What the restoration aims to achieve – e.g., biodiversity, windrow, land stabilisation, climate resilience, other		Text (dropdown)
Previous Landuse	Previous land use – e.g., grazing, cropping, remnant protection, other.		Text (dropdown)
Current Landuse	What the land is currently used for – e.g., grazing, cropping, remnant protection, other.		Text (dropdown)
Dominant Vegetation	Dominant vegetation at the site – e.g., pasture grass, scattered trees, remnant bush, other.		Text (dropdown)
Soil Type	What the dominant soil type is – e.g., clay, loam, sand, gravel, other.		Text (dropdown)
Topography	Topography of the monitoring site – e.g., floodplain, slope, ridge, dune, flats, other.		Text (dropdown)
Planting Area (ha)	The overall planting area being restored.		Integer (double)
Previously Planted	Has the land been previously revegetated?		Text (Y/N)
Date of Previous Planting	The single date or the start date when planting occurred, for example dd/mm/yyyy.	http://rs.tdwg.org/dwc/terms/verbatimEventDate	Text/Date

Site Preparation

Data Name	Description	Darwin Core Link	Data Type
Planting Date	The single date or the start date when planting occurred, for example dd/mm/yyyy.	http://rs.tdwg.org/dwc/terms/verbatimEventDate	Text/Date
Planted by	Who undertook the planting – e.g., contractors, volunteers, landholders, other.		Text (dropdown)
Planting Type	How the planting was done – e.g., using tubestock, direct seeding, other.		Text (dropdown)
Source of Plants	The name of the nursery or nurseries that supplied the plants.		Text
Provenance	The location where the seed came from (if possible, provide GPS coordinates and the mother plant ID). Provide a separate row for each provenance.		Text
Weed Control	Type of weed control undertaken – e.g., spot spray, strip spray, whole paddock, other.		Text (dropdown)
Weed Control Dates	When weed control was undertaken.		Text/Date
Other Site Preparation	Other site preparation undertaken – e.g., fencing to exclude animals, ripping, scalping, animal control, burning, other.		Text (dropdown)
Planting Agents	Planting agents used – e.g., fertiliser tablets, wetting agents, pest repellents, other.		Text (dropdown)
Guarded	Whether the plants were guarded or not.		Text (Y/N)
Guard Type	If they were guarded, the guard type used – e.g., cardboard, mesh, hard plastic, soft plastic, other.		Text (dropdown)
Plant Watering	Whether plants were watered during or after planting. Provide dates.		Text

Plot Monitoring

Data Name	Description	Darwin Core Link	Data Type
Plot ID	A unique identifier of the survey.	http://rs.tdwg.org/dwc/terms/eventID	TLong Integer
Plot Name	An identifier for the set of information associated with a survey. Can be built from sampling protocol and date.	http://rs.tdwg.org/dwc/terms/eventID	Text
Observer Name	The name of the person undertaking the monitoring.	http://rs.tdwg.org/dwc/terms/recordedBy	Text
Survey Date	The single date or the start date when a survey occurred for example dd/mm/yyyy.	http://rs.tdwg.org/dwc/terms/verbatimEventDate	Date
Survey Effort	A description of the time spent surveying or the area surveyed.	http://rs.tdwg.org/dwc/terms/samplingEffort	Text
Photopoint Number	If a photopoint was taken, what was the number and description of how it was taken.		Text
Survey Method	A description of the sampling methods, for example 50 x 6 m quadrat.	http://rs.tdwg.org/dwc/terms/samplingProtocol	Text
Plot Topography	Topography of the monitoring site – e.g., floodplain, slope, ridge, dune, flats, other.		Text (dropdown)
Plot Aspect	What aspect was the plot facing (use a compass).		Text
Grazing Animals	Were grazing animals present, and if so what type – e.g., livestock, rabbits, kangaroos, deer, hares, other.		Text (dropdown)
Grazing Animal Density	Is the grazing density high, medium or low?		Text (dropdown)
Species Name	The scientific name of the plant species surveyed.	http://rs.tdwg.org/dwc/terms/scientificName	Text
Common Name	The vernacular name of the plant species.	http://rs.tdwg.org/dwc/terms/vernacularName	Text
VBA code or Taxon ID	A unique identifier for that species. This may differ between states.	http://rs.tdwg.org/dwc/terms/taxonID	Long Integer
Count Alive	The number of that species recorded in a plot that are alive.	http://rs.tdwg.org/dwc/terms/individualCount	Long integer
Count Dead	The number of that species recorded in a plot that are dead.	http://rs.tdwg.org/dwc/terms/individualCount	Long integer
Height (mm)	The average height of the first five plants for each species in a plot.		Integer (double)
Reproduction	Presence or absence of buds or flowers; or intensity of flowering.		Text (binary) or integer
Recruitment	Presence of new plants within a planting; number of new plants.		Text
Estimated Weed Cover	The weed cover in the plot – e.g., <5 %, 6 - 25 %, 26 - 50 %, >50 %.		Text (dropdown)
Estimate Bare Ground	The cover of bare ground in the plot – e.g., <5 %, 6 – 25 %, 26 – 50 %, >50 %.		Text (dropdown)
Notes	A field to write notes about factors not covered in the above fields.		Text

Appendix 5. Potential changes to seed availability and viability associated with climate change and options or recommendations for managing seed resources (based on Broadhurst et al. [32]).

Climate Influence	Likely Effects	Outcome	Options or Recommendations
Rising temperatures	Phenological shifts	Smaller seed crops	Stockpile seed
	Reduced flowering and/or length of flowering	Smaller seed crops	Create SPAs; stockpile seed
	Changes to pollinator behaviour and abundance	Inbreeding produces poor quality seed or small seed crops	Create SPAs; stockpile seed
	Alteration of dormancy depth	Germination delay or failure	Seed pre-treatment; create SPAs; research
	Increased wild seed abortion	Smaller seed crops; low vigour	Create SPAs; stockpile seed; research
	Altered germination cues	Poor germination	Seed pre-treatment; research
	Increased weeds	Contamination of stocks and/or restoration sites	Seed cleaning; stockpile seed
	Altered seed longevity	Rapid decline in viability and/or vigour (except alpine species)	Stockpile seed under optimal conditions
Reduced water availability	Reduced flowering and/or length of flowering	Smaller seed crops	Create SPAs, stockpile seed
	Changes to pollinator behaviour and abundance	Inbreeding produces poor quality seed or small seed crops	Create SPAs; stockpile seed
	Reduced wild seed production	Smaller seed crops	Create SPAs; stockpile seed; research
	Increased wild seed abortion	Smaller seed crops; low vigour	Create SPAs; stockpile seed; research
	Smaller seed	Poor germination or low vigour	Create SPAs; stockpile seed; research
	Alteration of dormancy depth	Germination delay or failure	Seed pre-treatment; create SPAs; research
	Altered germination cues		Seed pre-treatments; research

Climate Influence	Likely Effects	Outcome	Options or Recommendations
Increased frequency of severe events	Damage to or loss of plants	Smaller seed crops	Stockpile seed, create SPAs
	Impacts on pollinators	Inbreeding produces poor quality seed or small seed crops	Stockpile seed, create SPAs
Poor seasonal outlook	High risk of planting failure	Poor restoration outcome	Stockpile seed for good planting years
Higher soil temperatures	Altered germination cues	Poor germination	Seed pre-treatments, research
	Reduced seed persistence	Rapid decline	Requires research
	Symbioses and mutualisms	Poor germination; failure to thrive	Requires research

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