GUIDELINES FOR EMBEDDED EXPERIMENTS IN ECOLOGICAL RESTORATION AND MANAGEMENT IN AUSTRALIA

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COVER PHOTO: Measuring plant traits in the provenance trial at the Clarendon site (South Australia) of Nick Gellie. *(Photo credit Nick Gellie)*

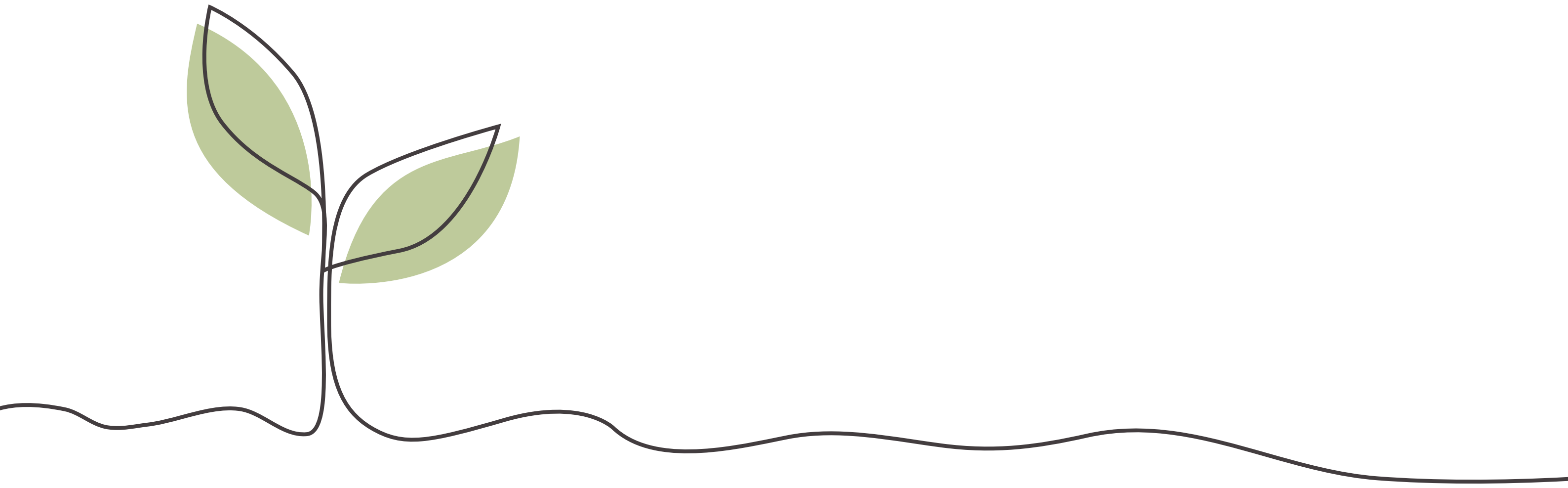
EXECUTIVE SUMMARY

Restoration of Australian ecosystems is typically conducted by a highly knowledgeable and experienced national network of practitioners. Growth in the restoration sector is expected to increase over the next few decades as we rebuild our environments devastated by drought, bushfires, flood, fragmentation, and ongoing vegetation decline. This growth presents a unique opportunity to capitalise on investment in restoration by embedding experiments within restoration projects so that we can:

- continue to expand the skills of practitioners who are now tasked with restoring vegetation communities under new and emerging environmental conditions with which they have limited experience; and
- build long-term, national experimental infrastructure (i.e. coordinated networks of physical experimental sites and associated data and meta-data), that helps tell the story of our restoration successes and will allow future generations to improve restoration and conservation practices, particularly in the context of a rapidly changing climate.

These guidelines provide a framework for planning and implementing standardised experiments within restoration projects to help build a national research network. They cover the value of science partnerships and how to enable them, planning, designing, and monitoring embedded experiments, and how to collate and manage data from these experiments. The guidelines conclude with real-world case studies that put these concepts into practice.

Practitioners from local and state government, consulting, industry, Landcare, and natural resource management (NRM) groups, and non-government organisations (NGOs), who are designing and implementing restoration projects, are encouraged to read these guidelines to integrate simple yet effective experiments into their restoration.



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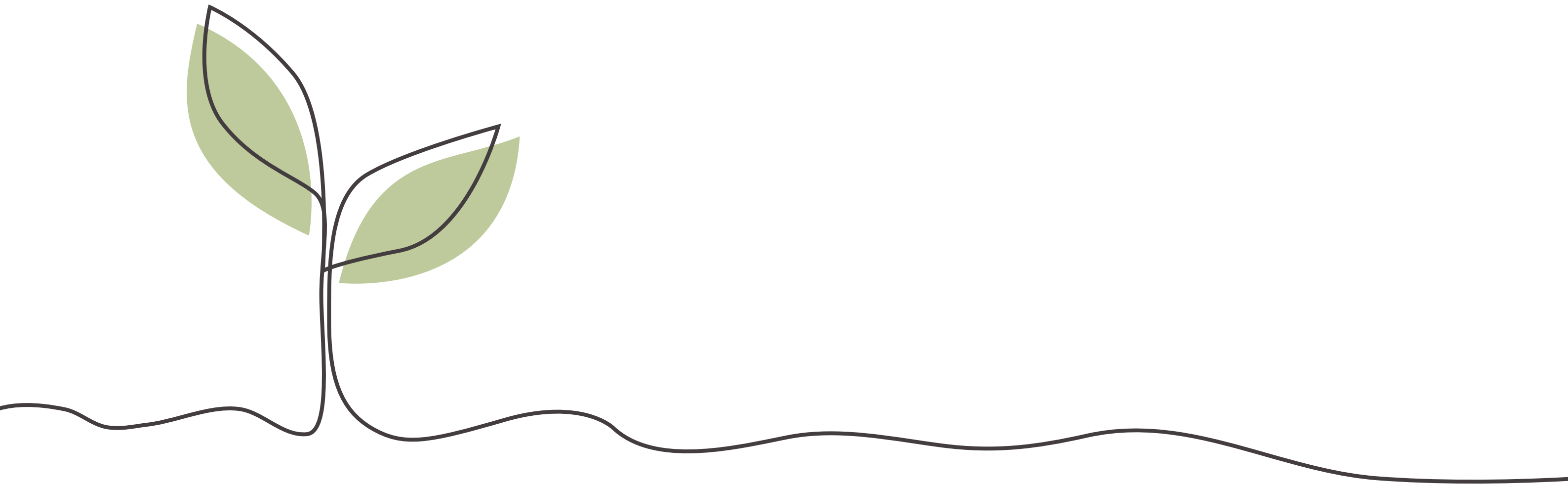

ABBREVIATIONS

ABIS	Australian Biodiversity Information Standard
ALA	Atlas of Living Australia
ARC	Australian Research Council
BDR	Biodiversity Data Repository
BGPA	Botanic Gardens and Parks Authority
BOM	Bureau of Meteorology
CBD	Convention on Biological Diversity
CMA	Catchment Management Authority
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DBCA	Department of Biodiversity, Conservation and Attractions
DBH	Diameter at Breast Height
DIPA	Data Integration Partnership for Australia
GBIF	Global Biodiversity Information Facility
IBSA	Index of Biodiversity Surveys for Assessments
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
MER Network	Monitoring, Evaluation and Research Network
MERIT	Monitoring, Evaluation, Reporting and Improvement Tool
MODIS	Moderate Resolution Imaging Spectroradiometer
NGO	Non Government Organisations
NLP	National Landcare Program
NRM	Natural Resource Management
OGC	Open Geospatial Consortium
PCA	Principle Components Analysis
PUCA	Provenancing Using Climate Analogues
SERA	Society for Ecological Restoration Australasia
SLA	Specific Leaf Area
TBA	Tree Breeding Australia
TERN	Terrestrial Ecosystem Research Network
UN	United Nations
UWA	University of Western Australia
WCC	Warren Catchments Council

FOREWORD

Delivering effective ecological restoration at scale is a critical tool in tackling the twin environmental challenges of climate change and biodiversity loss. Global goals embedded in the Paris Agreement, the UN Decade on Ecosystem Restoration, the Global Biodiversity Framework, the Taskforce on Nature-related Financial Disclosures, among many others, are driving major national and international policy initiatives and investment opportunities which will enable large scale application of nature-based solutions.

To scale up efforts and restore lands at the rate needed to combat the climate and biodiversity crises, we must rapidly advance our knowledgebase on best practice restoration across the broad range of Australian ecosystems. It is only through a collective and collegial approach that we will be able to achieve this. We need to maximise learnings at as many sites as possible and share data with one another for greater environmental impact.

The Guidelines for embedded experiments in ecological restoration and management in Australia provides the background and framework needed for these learnings and data sharing to occur. It is a valuable resource for everyone engaged in ecological restoration who want to ensure that the testing and application of methodologies or new techniques is scientifically robust, providing confidence in results.

These guidelines dedicate sections to outline the, often overlooked, importance of establishing appropriate governance and setting meaningful objectives aligned with the size and complexity of the restoration project. They clearly explain the foundations of experimental design, monitoring and data management and demonstrates key principles in the showcasing of real, on-ground case studies.

I look forward to seeing these guidelines becoming a central resource for scientists, practitioners, and industry alike and supporting impactful restoration practice throughout Australia.

Prof. Owen T Nevin

CHIEF EXECUTIVE OFFICER

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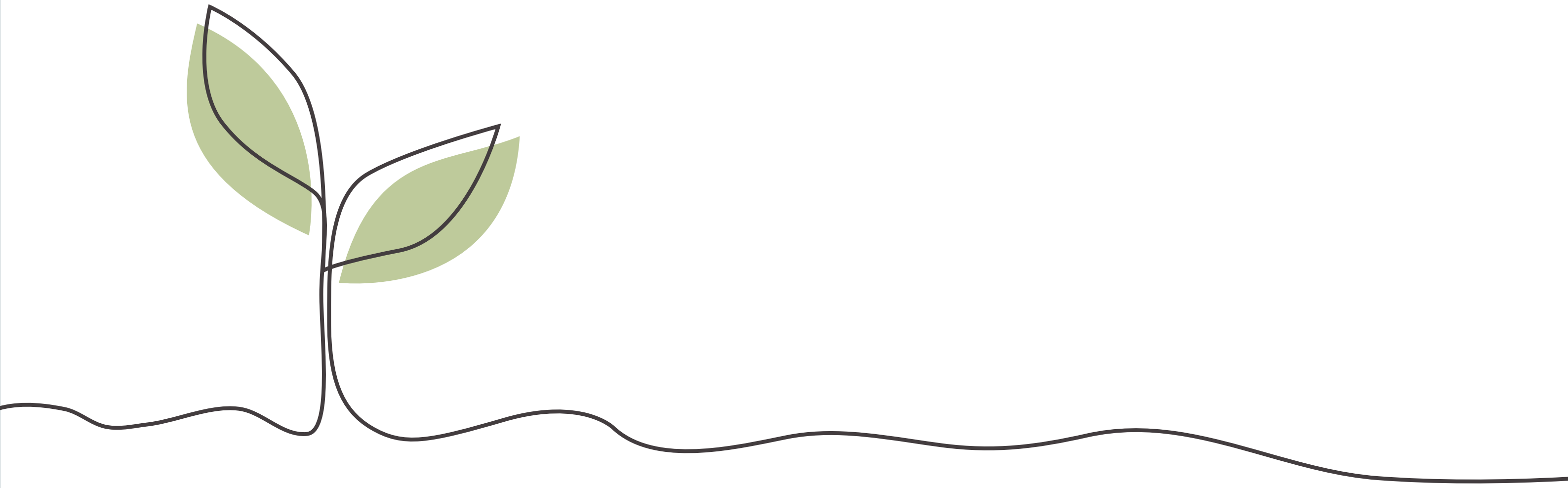

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Chapter 1.
INTRODUCTION

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SETTING THE SCENE

Globally, there are many pressures on native ecosystems including vegetation clearing, invasive species, changing disturbance regimes, nutrient and pollutant deposition, and climate change. The most visible impacts of these pressures are changes in species composition and distribution along with lost ecosystem functions and services (e.g. soil erosion, salinisation, eutrophication, loss of pollinators). The net result has been widespread ecosystem degradation worldwide, extinction of local populations and species, and the development of novel ecosystems.

Ecological restoration is one approach to help address widespread environmental degradation. This is reflected in the setting of global targets for ecological restoration such as through the Convention on Biological Diversity (e.g. the 30% by 2030 restoration targets of the Kunming-Montreal Global Biodiversity Framework), United Nations (UN) Sustainable Development Goals (Goal 15, **https://www.un.org/sustainabledevelopment/biodiversity/**), 2014 UN Climate Summit (United Nations 2014), and 2012 Rio+20 conference (UN General Assembly 2012). The importance of increased ecological restoration effort was further underlined in the thematic assessment on degradation and restoration of land and freshwater ecosystems by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), and the United Nations Decade on Restoration (**https://www.decadeonrestoration.org/**). The IPBES assessment estimated that 75% of the Earth's land surface and the wellbeing of 3.2 billion people has been adversely impacted by ecosystem degradation (IPBES 2018). Consequently, ecological restoration practitioners have a significant challenge to restore degraded ecosystems and return their functionality in a cost-effective manner.

Over the last 30 years, Australia has directed more than AU$7.4 billion towards improving our degraded ecosystems. This includes ecological restoration activities to secure the long-term prospects of our unique species and ecosystems (Broadhurst and Coates 2017; Hajkowicz 2009). A further $61.8 million has been spent on restoration under the 20 Million Trees Program (**http://www.nrm.gov.au/national/20-million-trees**; **https://www.dcceew.gov.au/environment/land/landcare/past-programs/phase-one/20-million-trees**; **https://www.dcceew.gov.au/environment/land/national-landcare-program-phase2-review**). There has been significant growth in the practice and science of ecological restoration including the development of approaches for assisted regeneration (Standards Reference Group SERA 2021) and reintroductions, including the use of planting into remnant vegetation, and direct seeding into old fields. Other common activities towards restoration goals include fencing to manage livestock grazing, controlling invasive species, and managing fire regimes and water flows. These activities are undertaken or supported by a range of people and organisations including land managers, community groups, non-government organisations (NGOs), industry and government agencies at a range of scales.

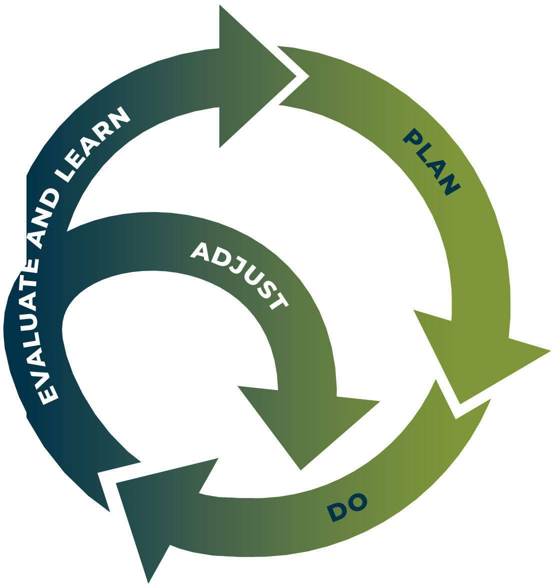

Figure 1.1 Diagram of an adaptive management pathway.

Despite substantial investments in ecological restoration, there remains a surprising lack of information about the effectiveness of ecological management actions in Australia (Doerr et al. 2017, Doerr et al. 2018). Projects have been initiated for a variety of purposes with differing stakeholder expectations and reporting requirements, while research has tended to be localised, has not addressed longer term ecological outcomes, or has not been adequately synthesised (Doerr et al. 2018). Consequently, the benefits of past ecological restoration practices are at best idiosyncratic and diffusely known, making it difficult for others to learn from successful or unsuccessful activities to improve future outcomes. In turn, there are few opportunities to close the adaptive management loop (Fig. 1.1) or for regional and national stakeholders to draw on learnings from local projects.

To equip ourselves to manage our environment optimally in a changing climate, and to successfully protect and build an enduring environmental legacy for future Australians, there have been increasing calls to think innovatively and carefully about how we can mature Australian ecological restoration science and practice (Broadhurst et al. 2017; Gellie et al. 2018; Prober et al. 2018). In response to these calls, some progress has already been made, including development of the Victorian Climate Future Plots Guidelines and trialling of a national Monitoring, Evaluation and Research (MER) Network approach by the Australian Government (Carwardine et al. 2021). However, no national guidelines yet exist to help guide partners from differing sectors and backgrounds in the implementation of research embedded in on-ground restoration. Here, we provide guidelines to support efforts to embed restoration experiments into restoration activities to facilitate collaborative learning and development of best practice for ecological restoration.

WHAT DO WE MEAN BY ‘ECOLOGICAL RESTORATION’?

Restoration often means something different to each of us. Box 1.1 outlines how the National Standards for the Practice of Ecological Restoration in Australia differentiates among ecological restoration, revegetation, and rehabilitation and also includes a definition of the overlapping concept of ecological renovation. For simplicity, we use the term ‘restoration’ to collectively include all these activities (Gann et al. 2019; Society for Ecological Restoration 2004; Standards Reference Group SERA 2021).

BOX 1.1

RESTORATION, REVEGETATION, OR REHABILITATION?

ECOLOGICAL RESTORATION – ‘the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed’.

ECOLOGICAL RENOVATION – ecological management and nature conservation actions that actively allow for environmental change, whilst where feasible supporting aspirations to conserve many historical values of ecosystems as expected for ecological restoration (Prober et al. 2019)

REHABILITATION – ‘the process of reinstating a level of ecosystem functionality on degraded sites where ecological restoration is not the aspiration, as a means of enabling ongoing provision of ecosystem goods and services’.

REVEGETATION – ‘establishment, by any means, of plants on sites (including terrestrial, freshwater and marine areas) that may or may not involve local or indigenous species’.

WHY DO WE NEED THESE GUIDELINES?

A close relationship exists between the scientific discipline of restoration ecology and the practical implementation of restoration leading to successful ecological outcomes. In Australia, this relationship has been recognised through the publication of the National Standards for Ecological Restoration in Australia (Standards Reference Group SERA 2021) and the recent development of a framework of practical restoration science questions that can assist with improved effectiveness of restoration efforts (Miller et al. 2017). Integrating experiments into restoration provides a practical mechanism for achieving several goals presented in these publications.

Australian restoration faces numerous challenges including:

- the absence of national restoration research priorities which has led to a fragmented and idiosyncratic research portfolio, much of which has an unclear path to impact and limited evidence of adoption;
- a limited understanding of the capacity and capability of practitioners to deliver restoration programs; and,
- limited data to contribute to and learn from assessments of restoration outcomes (e.g. Crouzeilles et al. 2016; Godefroid et al. 2011).

NATIONALLY COORDINATED LEARNING, INFRASTRUCTURE AND DATA

There have been growing calls to create ‘research infrastructure’ in Australia by embedding long-term, on-ground research into existing ecological restoration programs (Bailey et al. 2013; Bailey et al. 2021; Breed et al. 2013; Broadhurst et al. 2017; Gellie et al. 2018; McDonald et al. 2021; Prober et al. 2018). Some of the anticipated benefits of embedding experiments in restoration programs include:

- providing long-term sites for experimental assessment directly linked to restoration practice;
- linking community groups, practitioners, policy makers, funders and researchers to co-develop restoration experiments, programs and key research questions, and to learn together from outcomes;
- generating local information that also contributes to a national network allowing aggregation of data to track responses at regional and national scales;

- creating a mechanism for broader dissemination of learnings across land managers, governments, non-government organisations, funders and researchers;
- providing a reference for jurisdictions and organisations to develop their own guidelines for more specific purposes and goals;
- creating awareness of good practice in stakeholder engagement;
- embedding a transdisciplinary approach that facilitates shared goal development and engages partners throughout all phases of a project;
- supporting more strategic investment decision making in restoration and building opportunities for private-public partnerships;
- providing a way to quantify and assess the effectiveness of restoration program achievements; and,
- in the case of plantings, generating a new source of local plant material for future restoration efforts.

The Platform for Ecological Restoration Research Infrastructure (PERRI), as proposed by Prober et al. (2018) and being trialled through the MER Network project (Carwardine et al. 2021), seeks to broaden these benefits by embedding integrated, networked research infrastructure (small, well-designed experiments across a range of sites) to address a range of nationally-relevant ecological restoration questions. These guidelines will support PERRI objectives by:

- capitalising on existing and emerging on-ground restoration investments to enable rigorous evaluation and development of restoration methods;
- promoting and coordinating national-scale experimental infrastructure through distributed network experiments and/or sentinel sites embedded in restoration investments;
- ensuring data comparability at local to national scales, including the use of emerging standard indicators in monitoring programs;
- enabling long-term data and information management;
- delivering generalised (‘question-free’) ecosystem surveillance through long-term control plots, broadening the potential uses of the data; and,
- stimulating capability-building in science by providing infrastructure that can be used for a wide range of short- and longer-term projects, and guidance on experimental design principles to practitioners.

Under the PERRI framework, restoration-related questions could include:

Planting for a different future

- From where should we source seed so that plants can establish under current conditions and persist under future conditions?
- What species and provenances (i.e. seed sources) should we be planting to establish ecological communities that are resilient in future environments?
- Are there alternative native species which offer similar services and functions to species predicted to decline under climate change?
- What factors help enhance resilience to disturbance and environmental stress in ecological restoration (e.g. the diversity of species or functional types planted)?

Species relationships

- Does improving the habitat and resource requirements of fauna species deliver enhanced biodiversity values and ecosystem function beyond that anticipated?
- Does augmenting native mycorrhizas stimulate native plant growth and survival in restoration?
- What landscape configurations should revegetation activities target to optimise landscape-scale native faunal abundance and diversity?
- What are the ‘assembly rules’ for restoring different ecosystems – which species need to be established before others can colonise or be successfully introduced?
- In what circumstances is management of exotic species worthwhile?

Practice

- What plant species, how many seeds, tube stock, and so on of each are required to meet final revegetation targets?
- What is more cost effective for each species we need to return: direct seeding or tube stock planting?
- What factors contribute to (or inhibit) effectiveness of assisted colonisation of species outside their known contemporary range?
- In what situations is management of total grazing pressure valuable for enhancing recovery of degraded vegetation?
- In what contexts are other management activities (e.g. prescribed burning, ecological water releases) effective for achieving ecological goals?

ADVICE FOR POLICY, SCIENCE AND PRACTICE

The development of these national guidelines provides practical advice for policy makers, ecological restoration practitioners and scientists when embedding simple research experiments into their restoration programs. In doing so, the guidelines aim to facilitate efforts to enhance the effectiveness of ecological restoration, address major barriers to recovery, and improve the cost-effectiveness and scalability of restoration projects. In particular, the guidelines will support the design and implementation of simple ecological experiments within on-ground ecological restoration projects to enhance evidence-based decision making in ecological restoration programs and inform more effective targeting of investment. Further, the guidelines provide advice on how to coordinate and disseminate scientific learning across these programs. While much progress has been made by practitioners on improving the effectiveness of restoration approaches in recent decades (e.g. restoration plantings, fire management, introduction of predators), practitioners have often worked in isolation, with limited support and interaction nationally. These guidelines aim to facilitate a coordinated, networked approach to restoration research, offering a more powerful way to learn from and improve restoration outcomes (Broadhurst et al. 2017; Gellie et al. 2018; Harrison et al. 2021; Prober et al. 2018).

FACILITATING COLLABORATION

Work to increase the success of restoration efforts under current and future environments is likely to be most effective with close collaboration among on-ground practitioners, scientists, and policy makers, both at local and larger scales, to enhance overarching planning and coordination. Consistent with this, the UN General Assembly (2012) also recommended the sharing and dissemination of evidence-based environmental information to raise public awareness on critical and emerging environmental issues.

In Australia, collaborations between governments, NGOs and research institutions do already exist. For example, a number of collaborative initiatives between scientists and practitioners have been established to investigate provenance planting under climate change (see Chapter 7: Case Studies). Nevertheless, there is still much to be gained by increasing the number, scale and cross-comparability of such collaborations. Indeed, collaborating across all levels from community groups and landholders to policy makers and research institutions was identified as the key factor underlying the success of a decade-long project that is restoring the grasslands and woodlands of Tasmania (Harrison et al. 2021).

Towards this initiative, these guidelines promote a broad and long-term view to support the ecological restoration sector to co-develop a secure, long-term network of experimental sites that will inform future Australian ecological restoration policy, programs, and practice. This outcome can be achieved by coming together as a community to agree on principles, approaches, and processes to provide a basis for the integration of science, policy and practice.

WHO SHOULD READ THESE GUIDELINES?

These guidelines are intended for those in the ecological restoration sector wishing to participate in a long-term experimental project designed to assess the effects or outcomes of a management action and to answer key ecological questions faced by the restoration sector (Fig. 1.2). They are also designed to support the development of regional to national networks of experimental sites. Developing networks of experimental sites should provide a more efficient approach that best uses available resources to deliver high quality science and support continual improvement in restoration practice. The guidelines are presented in a way that the restoration sector can use to support the inclusion of an experiment within a restoration project if desired. While the guidelines target those directly involved in active restoration, it is important to note that they are relevant to the restoration sector more broadly, including all people involved in science, management, planning, policy, and practice who enable the delivery of ecological restoration projects.

WHAT IS IN THESE GUIDELINES?

The guidelines are structured as chapters that reflect broad processes that are undertaken during ecological restoration projects, including:

- science partnerships;
- planning;
- experimental design and implementation;
- monitoring; and,
- data management.

We present key case studies that demonstrate the typical establishment of experiments embedded within broader restoration projects. It is anticipated that these guidelines will be regularly reviewed and updated.

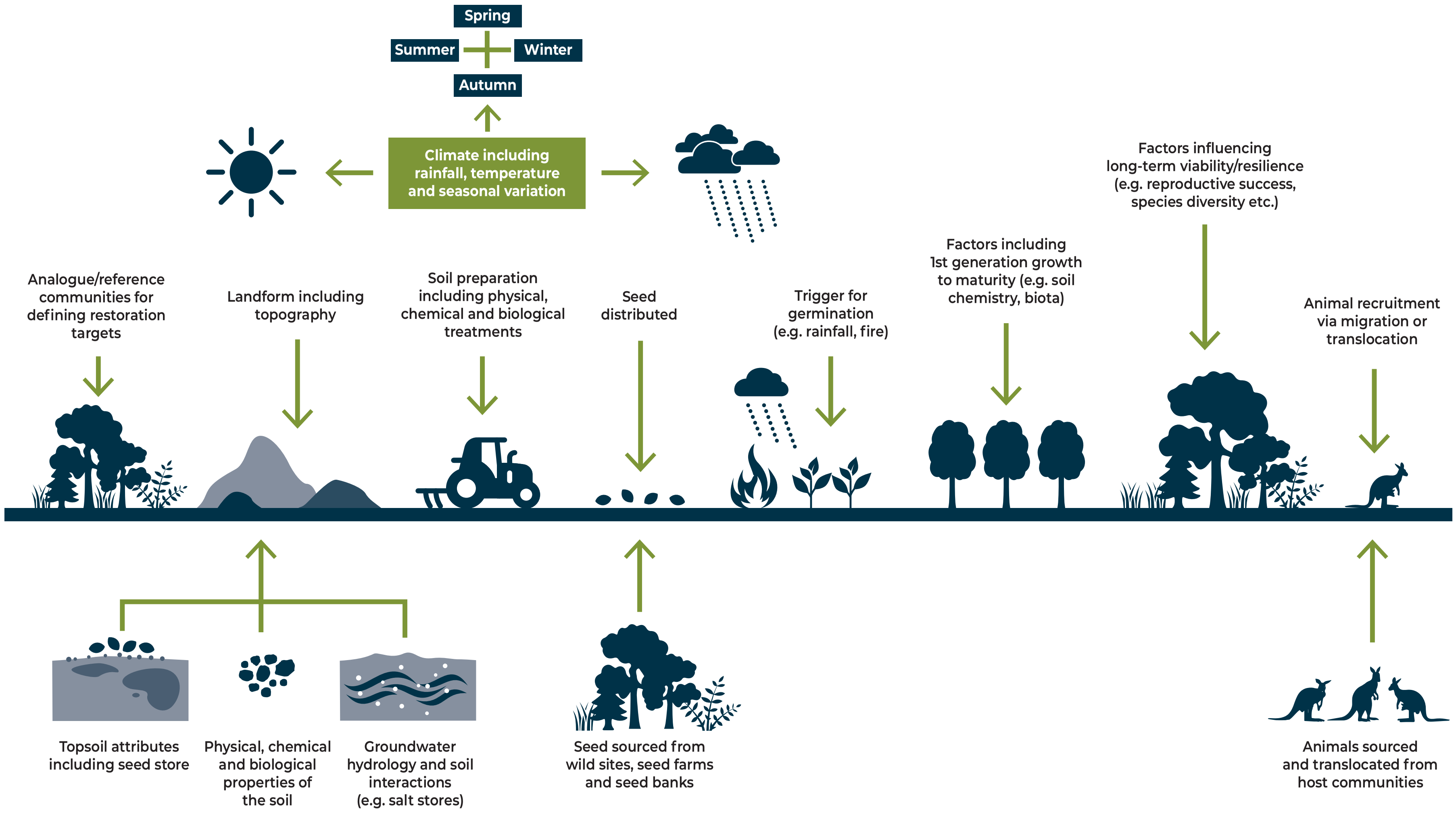

Figure 1.2 Key elements required for restoration of biodiverse ecosystems, each step may benefit from an experimental approach to improve success (taken from Western Australian Biodiversity Science Institute Research Plan, 2014).

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Chapter 2.

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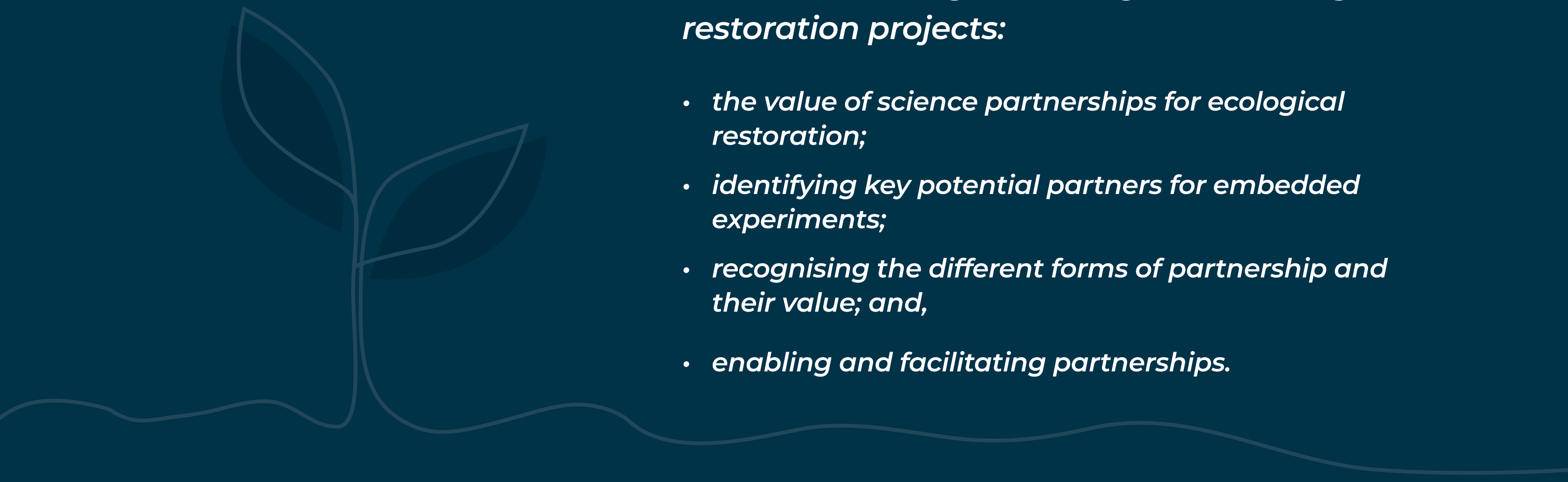
SUMMARY

This chapter of the guidelines focuses on science partnerships in recognition of the importance of establishing partnerships early in any collaborative project. The chapter is structured around four major themes that are important in building science partnerships to facilitate learning from on-ground ecological restoration projects:

- *the value of science partnerships for ecological restoration;*
- *identifying key potential partners for embedded experiments;*
- *recognising the different forms of partnership and their value; and,*
- *enabling and facilitating partnerships.*



THE VALUE OF SCIENCE PARTNERSHIPS FOR ECOLOGICAL RESTORATION

Ecological restoration that is undertaken in partnership among practitioners, scientific researchers, decision makers, Traditional Owners and other parties can greatly increase the value of a restoration project (for example, see Harrison et al. 2021). Partnerships can bring together complementary skills, experience, resources and networks of wider contacts, providing opportunities to identify and address restoration knowledge gaps, test innovative new approaches, build on past experience and answer new questions. They enable evaluation of restoration approaches in real-world environments rather than narrow experiments, and the co-creation and sharing of knowledge to benefit future projects and improve our understanding of ecology and restoration science (see Case Studies 1, 2 and 3 for examples of partnerships between restoration practitioners, researchers, government and community groups to conduct embedded restoration experiments).

Principle 5 in the National Standards for the Practice of Ecological Restoration in Australia recognises that restoration science and practice are synergistic (Standards Reference Group SERA 2021). This recognition reflects the rapidly evolving nature of restoration practice and the integral role that 'trial and error' processes have played in driving continual improvement in restoration. However, while a culture of continual improvement exists in ecological restoration, a lack of scientific process and *ad hoc* practice may limit progress. Developing science-based partnerships to implement embedded experiments brings scientific rigour to support evidence-based decision making in restoration project delivery.

A range of different approaches to forming partnerships can be taken. To maximise the value of partnerships, potential partner organisations need to consider the different possible options for working together and to identify the most appropriate form of partnership for the intended experiment (Jellinek et al. 2019). This will better enable practitioners to capitalise on what specific forms of partnership can offer in support of the realisation of restoration goals and contracted outputs and outcomes required by the funder. Similarly, potential research partners can consider what sort of partnership arrangements will best support their research goals.

IDENTIFYING KEY PARTNERS FOR AN EMBEDDED EXPERIMENT

As outlined in Chapter 1, ecological restoration has a long life-cycle. From the early stages of choosing restoration interventions, to the ultimate goal of a structurally diverse, functional and resilient natural ecosystem, is a long journey influenced by many factors (Fig. 2.1). As with adaptive management and learning, there are opportunities and value in incorporating research throughout the multiple stages and progression of restoration.

Designing the embedded experiment should be a process that involves all partners, and identifies knowledge gaps and priority questions. Embedded experiments will therefore benefit from including partners early in the restoration process, fostering engagement of partners with a science and research focus alongside the many other actors that can be involved in planning, providing plant material and machinery, landscaping, planting or managing sites.

The first stage in identifying project partners is therefore to establish the questions or topic to be examined through the embedded experiment. Prober et al. (2018) discuss the development of 'big ecological questions' that could guide embedded experiments designed to address core questions targeting evaluation and improvement of current methods for the sector as a whole. Experiments could focus on optimising site-level restoration activities. More regionally significant questions can also be valuable, such as those around seed provenance, delivery techniques, pollinator networks or landscape connectivity (Breed et al. 2018, Miller et al. 2017). Often, careful planning can make it possible to develop experimental methods that can answer questions at multiple spatial scales.

Development of the focus questions for an embedded experiment can involve two distinct pathways that influence the choice of partners.

1. Questions may be developed through a regional or national prioritisation of research. In this pathway, organisations representing natural resource management practitioners, the research sector or policy makers develop 'big ecological' or natural resource management questions that identify and prioritise large-scale strategic knowledge gaps for the restoration sector. Partners involved in the identification of questions may or may not go on to be involved

Figure 2.1 Examples of stakeholder groups that could be considered when identifying partnerships while implementing an embedded experiment.

in the resulting experiments, and new partners may subsequently join as experiments are developed.

2. Questions may be developed directly by the partners involved in the embedded experiments. In this case, embedded experiments are developed through a co-design model which involves the partners in both the question development and the implementation process.

There are five major groups of people ('stakeholder groups') that could be considered when identifying partnerships while implementing an embedded experiment (Fig. 2.1):

- **Funders** – who is funding the ecological restoration intervention, what are their goals and expectations for the intervention and does the experiment help deliver the outcomes they are seeking? Will the funding agent be expected to provide extra resources to support the experiment? Will separate research funding need to be sourced from a different funding provider? Funding agents may either be active or passive partners in the embedded experiment.
- **Indigenous and non-Indigenous land managers and communities** – who of these have a long-term interest in the site? Land managers and local communities will provide an important contribution to the identification and prioritisation of questions. They also provide a critical role as long-term custodians of a site.
- **Practitioners** – who is involved in the on-ground implementation of the embedded experiment? Given the various implementation stages involved in a restoration project, consideration should be given to who is managing the project implementation as a whole, who may be able to make a valuable contribution to ensuring the experiment is well executed, and any key sub-contractor groups that are directly relevant to the proposed experiment.
- **Researchers** – who are the researchers involved in the embedded experiment? Does the experiment form part of an externally funded project or involve students that may have study commitments to be considered? Are the most appropriate researchers for the experiments from universities, government departments or the private sector? Are they local, interstate or international? Who are the key project leads or contacts for the experiment and who has oversight of the data? Could the site include multiple research partners and experiments? Is there a need for additional statistical advice?
- **Knowledge brokers and science communicators** – who is likely to help communicate the findings from an embedded experiment? It is important to consider and engage early those groups or individuals that will be important in ensuring that key aspects and findings of embedded experiments are communicated to those who will use and apply this knowledge.

Identifying the key partners — the groups and individuals that are crucial to the delivery of the project — will depend on the project and questions being addressed (see Table 2.1 for examples), but is likely to require consideration of all five groups above. It is important also to identify other partners that may enhance the project's likelihood of success and impact. This may include a hierarchy of partnerships such as where local land managers consult with their wider local community. Checklist 1 for Stakeholders shown in Chapter 3 provides a useful starting point for identifying those stakeholders who could be directly involved in setting up a restoration experiment.

The value of existing networks for helping to identify partners for embedded experiments cannot be underestimated. The Landcare sector is well connected through Landcare networks and natural resource management (NRM) and catchment management authorities (CMAs). Many industry bodies, such as the Nursery and Garden Industry Association, may also be able to assist with identification of practitioners relevant to embedded experiments. For building the research component of partnerships, professional bodies, such as the Society for Ecological Restoration

Table 2.1 Possible research topics and stakeholders at various stages of restoration projects that could be considered when identifying partners for embedding an experiment within a restoration project focused on revegetation plantings. Restoration project stages and topics are taken from Miller et al. (2017).

STAGES OF RESTORATION PROJECTS	RESEARCH TOPICS	POSSIBLE STAKEHOLDERS
Targets and planning	• Reference sites • Site attributes • Monitoring and evaluation • Development dynamics • Required seed species numbers	• Local, state/territory government • Regional NRM • Proponent • Indigenous groups • Landholders/land managers • Ecological consultants
Sourcing material	• Passive regeneration • Topsoil seedbanks • Provenance • Wild/farmed seed • Tube stock propagation • Tissue culture	• Bush regenerators • Seed collectors • Seed banks • Plant geneticists • Nurseries
Optimising establishment	• Seed dormancy • Germination • Seed delivery • Tubestock treatment • Scheduling/site treatment	• Seed providers • Seed ecologists • Nurseries • Machinery suppliers • Community groups • Landscape contractors • Hydrologists • Agronomists
Facilitating growth and survival	• Threat management • Biotic interactions • Aboveground and below ground environment • Surfaces and landforms	• Community groups • Landholders • Pest/weed management contractors • Indigenous groups • Landscape contractors
Sustainability, resilience and landscape integration	• Resilience • Regeneration • Fauna • Ecosystem processes • Landscape integration	• Consultants • Proponents • Regulators • Indigenous groups

or the Ecological Society of Australia, can be important networks from which partnerships may develop. Formal mechanisms are being developed to support research-practitioner partnerships, such as knowledge brokers within the National Environmental Science Program, or organisations such as the Western Australian Biodiversity Science Institute, and South Australia NRM Research and Innovation Network.

Identifying individuals within an organisation who will enable and support the partnership is a key final step. Many organisations will have people, or are linked to organisations, who can take on a 'knowledge brokering' role. Knowledge brokers can straddle the divide between information producers and users (e.g. researchers and non-researchers, respectively) and actively seek to facilitate two-way communication across organisations and individuals. When seeking to develop a new partnership, identification of people who occupy a liaison or communication facilitation role can be a good starting point. These people can help identify researcher and practitioner partners who are most appropriate or best positioned to support and engage in an embedded experiment.

RECOGNISING THE DIFFERENT FORMS OF PARTNERSHIP AND THEIR VALUE

Embedded experiments provide a fantastic opportunity for researchers and practitioners to come together and explore innovative, evidence-based approaches to ecological restoration. They enable practitioners delivering restoration projects to work with researchers to directly improve outcomes from restoration activities and advance ecological restoration practice. They also enable researchers to benefit from the knowledge of practitioners and the on-ground infrastructure that restoration sites provide for advancing understanding of restoration ecology. Ideally, what we are seeking in restoration partnerships is a collaboration where all parties are actively involved and produce knowledge, and all parties gain benefits. This partnership provides a focal point for shared learning (Box 2.1).

Partnerships often develop where there are shared goals and there is clear value in bringing diverse skills together that are complementary to a project. Recognising what each partner is hoping to achieve by participating in the embedded experiment is important when considering how the partnership may develop. The potential strengths or constraints of each partner also need to be considered. Internal factors, such as staff or volunteer availability, management expectations, skills, or resource allocations, are important. Meanwhile, external considerations such as funding rules or political considerations may influence the direction a partnership will take.

It is important to recognise that there is no 'one size fits all' rule when it comes to developing and maintaining partnerships, with different partners able to have different roles and levels of involvement depending on the nature of the project and the research being conducted. However, it is clear that communication is critical to ensuring any form of partnership is successful. The 'type' of partner and how they are involved in the project will influence the communication expectations and methods that may be used. The public participation spectrum suggests five categories that influence appropriate communication (www.iap2.org.au/):

- **Inform** – this is the least active partnership, and partners that fall into this category are provided with information. Communication may be through newsletters, websites or seminars. For example, this may include the members of a Landcare group hosting an experimental site or broader members of a research network.
- **Consult** – partners to consult are those whose input will improve understanding of the topic and may influence decisions about research or practice. Broad communication methods that allow feedback, such as surveys or public meetings, may be useful; for example, consulting a scientist to help inform experimental design.
- **Involve** – where a shared understanding is being developed, the partner should be actively involved through workshops, face-to-face meetings or advisory committees. This may include groups with a vested interest in the experiment, but who are 'one step removed' from a site, such as a landowner, scientific advisory group or funding agency.
- **Collaborate** – collaborative partnerships involve all partners in decision-making processes. This can occur through joint planning, steering committee membership or forms of consensus-based decision making. This is likely to involve the key researchers and practitioners responsible for implementing and managing the experiment.
- **Empower** – where the decision making and responsibility for implementing the activity rests with the partner/s. Where the first four categories imply a leading role in the experiment, this final category is to inform and support others involved in the partnership.

BOX 2.1
SHARED LEARNING

Embedded experiments bring researchers, land managers, practitioners, and funders together with unique experience, perspectives and knowledge to advance our understanding and practice of ecological restoration. Embracing a shared learning approach can help develop lasting, effective solutions. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has developed ten principles of shared learning that are worth considering when thinking about the partnerships to develop and how the project will contribute to share learning across the partners involved https://adaptnrm.csiro.au/):

DEMOCRATISATION OF KNOWLEDGE

1. **Culture of equal value**
   Create a culture where different forms of knowledge are valued, thus encouraging a sense of ownership and equality.
2. **Real relationships**
   Build relationships with individuals, not just ‘links’ with organisations, to better improve communication and deepen understanding.
3. **Co-produce knowledge**
   Go beyond consultation and generate co-ownership. Knowledge co-production involves finding ways to work in deeper collaboration with stakeholders from start to finish.
4. **Audience context and style**
   Adapt to the audiences’ language, style and culture of communication to ensure that messages are heard and understood.
5. **Flexible and responsive**
   Plan activities and projects to allow for flexibility to varying needs – opportunities for shared learning can occur at any time.
6. **User-friendly resources**
   Develop communication resources for cognitive impression, not just visual impact, so they are interesting and easy to engage with.

PEER LEARNING

7. **Opportunities to learn**
   Bring people together – facilitate multiple social learning experiences to encourage peers to share.
8. **Shadow spaces**
   Encourage individuals to self-organise beyond the boundaries of organisational structures to facilitate learning and growth free from specific deadlines and requirements.
9. **Build credibility**
   Help others view their peers as credible experts to facilitate collaboration rather than competition.
10. **Peer collaboration**
   Encourage peers to build on foundational information by collaborating to produce new, contextualised knowledge.

ENABLING AND FACILITATING PARTNERSHIPS

There are many ways to enable and facilitate partnerships. This chapter is not designed to be prescriptive but rather suggests aspects of partnerships to consider when developing embedded experiments based on the experience derived from successful partnerships. These are aimed at all partners and are intentionally flexible in their application, while a formal framework for co-production science is shown in Box 2.2.

EACH PARTY

- Engage early and communicate regularly.
- Start with a shared vision and articulate what this means for each partner.
- Respect the contributions of each partner and recognise the complementarity of respective expertise.
- Understand and respect financial and resourcing contributions of each partner and recognise the requirements of any external funding.
- Organise joint meetings to develop the initiative and plan the project.
- Clearly articulate objectives of each partner, and identify where there are common goals and specific goals for each partner.
- Clearly articulate the expectations of each partner towards the others.
- Take the time to understand each other's languages and establish a common understanding of the languages being used.
- Agree on processes, deliverables, milestones, and responsibilities.

RESEARCHERS

- **Be proactive in making links with restoration practitioners** — physically and geographically demonstrate willingness to engage; this will make the science more relevant to restoration practice and may reveal opportunities.
- **Decentralise power** — recognise the value of the practitioner and the benefit of involving partners in planning and conducting research. Undertake background research about the partner organisations — know their stories and values.
- **Value the knowledge of the practitioners** — embedded experiments provide a perfect opportunity for two-way knowledge sharing.
- **Recognise partners' funding environments** — a major point of conflict is that researchers and practitioner organisations are similarly operating within competitive funding environments. How do objectives align with (or even better add to) funding arrangements?
- **Timing is fundamental** — it is best to establish partnerships over a project life-cycle so that partners work together from design to completion.
- **Provide a balanced view of success criteria** — integrate research performance indicators such as publications and research income with the partners' success criteria.
- **Recognise the intellectual contributions of partners and discuss these early in the relationship** — is co-authorship warranted or appropriate for any publications emerging from the project? What are the expectations of all partners?
- **Consider models of 'designing research for impact'** — be aware of models or approaches that can help research deliver real change in environmental outcomes.
- **Identify a facilitating person or organisation** — someone or an agency who can broker knowledge and communication between partners where needed.
- Make sure the knowledge gained by the experiment is presented in a way that assists in decision making by the partners.
- Work with the unique challenges of the location and region, within the broader experimental framework. Be flexible enough to account for this local context.
- **Be realistic about what can be achieved** — often the 'perfect' experiment cannot be implemented.
- Be clear on the fact that sometimes a clear answer cannot be obtained.

PRACTITIONERS

- Be clear about expectations for your organisation and ensure these are documented in a way that can be passed between staff members in response to organisational changes.
- Support the development of key questions that would assist in improving outcomes for your organisation to help ensure the proposed experiment aligns with your core priorities.
- Participate through a formal governance structure for the project to ensure communication is maintained.

- Recognise the importance of publications and research income as scientists' key performance indicators at an institutional level.
- Recognise that the research sector is largely driven by competitive funding and recognise the funding cycles that underpin this.
- Students are a valuable group to support partnership development, but recognise that students are not contract agents; there is a level of risk associated with project delivery and substantial input from supervising researchers is typically required.
- Value the knowledge of the researchers — embedded experiments provide a perfect opportunity for two-way knowledge sharing.
- Look for opportunities for staff to be involved in aspects of the research, including in publications.
- Be prepared for the fact that sometimes the expected answer cannot be obtained despite all the dedicated experimental work.

BOX 2.2

HOW-TO GUIDE FOR CO-PRODUCTION OF ACTIONABLE SCIENCE

Adapted from: Beier P, Hansen LJ, Helbrecht L, Behar D. 2016. A How-to Guide for Coproduction of Actionable Science. Conservation Letters, 10, 1-9.

The co-production of actionable science is an alternative model to what is sometimes referred to as the 'loading dock' approach to linking science and action. The loading dock involves the delivery of science resources to a manager through a direct contracting or external funding situation. This can lead to an incompatibility between the science and management decision making, particularly when addressing complex problems.

Beier et al. (2016) developed three guiding principles and recommended practices for the co-production of actionable science to support climate change adaptation. This framework can be used to support science that will inform the complex decision making involved in delivering ecological restoration programs. Three definitions are important within this context:

1. **Actionable science** includes data, analyses, projections, or tools that can support decisions in natural resource management; it includes not only information, but also guidance on the appropriate use of that information.
2. **Co-production** is the collaboration among managers, researchers, and other stakeholders, who, after identifying specific decisions to be informed by science, jointly define the scope and context of the problem, research questions, methods, and outputs, make scientific inferences, and develop strategies for the appropriate use of science.
3. **Partners** collectively refer to the co-producers involved.

GUIDING PRINCIPLE #1:

Co-production begins with decisions that need to be made

Recommended practice 1. Managers: Approach researchers with a management need, goal, or problem, rather than a request for a product.

Recommended practice 2. Researchers: Before suggesting specific products, make sure there is an understanding of the decision to be made, and the environment in which the decision will be made.

Recommended practice 3. Partners: Invest in at least one in-person meeting of all potential partners and stakeholders to specify the types of decisions to be made and the types of scientific information needed to support those decisions.

Box 2.2 continued following page....

GUIDING PRINCIPLE #2:

Partners should give priority to processes and outcomes over stand-alone products

Recommended practice 4. All partners: For a large, complex project, engage a subset of key people to serve on a technical advisory group which can adjust goals, review key methodological decisions, and co-produce inferences. Recruit a smaller steering committee to manage the project calendar, products, and workflows.

Recommended practice 5. All partners: Over the course of the project, discuss key assumptions, models, approaches, data sources, and criteria on an iterative basis.

Recommended practice 6. Decision makers: Explain to researchers how risk is evaluated and managed in the organisation. Help researchers to appreciate how to inform decisions (not perfect decisions) despite uncertainty about current or future conditions and the outcomes of interventions. Explain the context in which decisions are made, the limitations on your authority, and who is accountable. If multiple agencies are responsible for decisions, make sure that researchers provide the array of scientific information that each agency may need to act independently.

Recommended practice 7. Researchers: Honestly convey the meaning of uncertainty in results, but (respecting the fact that decisions must be made) clearly convey the main implications of the research. In addition to providing information, an equally important task is to provide clear guidance on appropriate use of that information. Expect managers to challenge the science and to have multiple drivers on their decision making. Be open about your policy preferences.

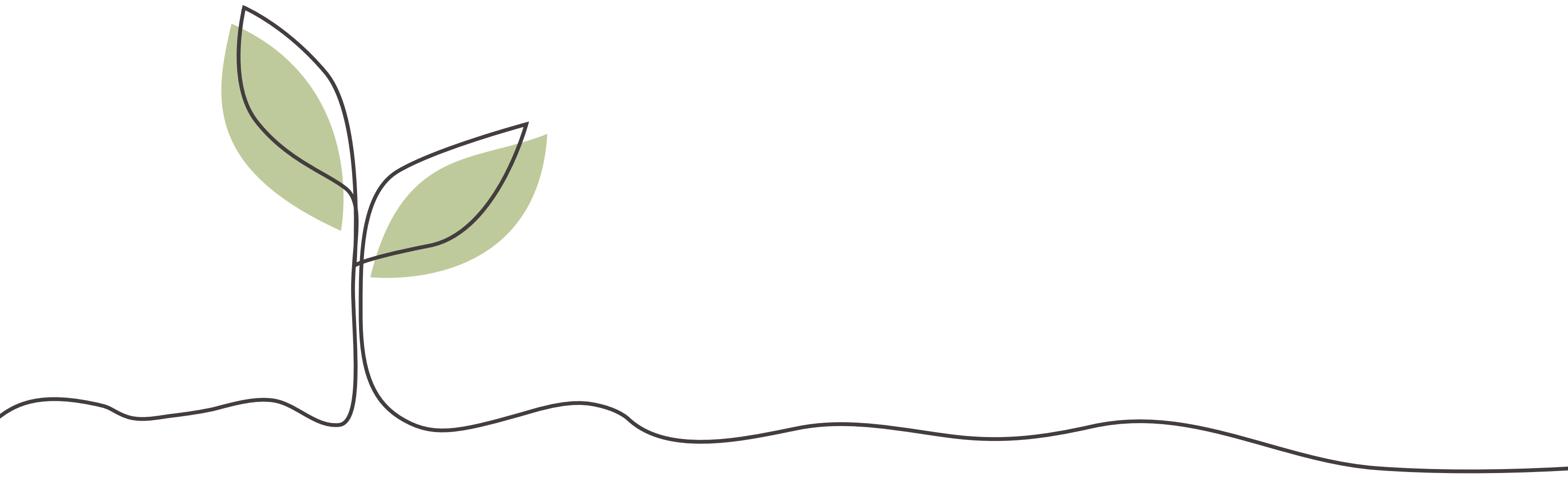
Recommended practice 8. Researchers, funders, intermediary organisations: Evaluate co-production products, processes, and the actionability of the science of individual co-production projects, and disseminate these findings. As project evaluations accumulate, revise these recommended practices.

GUIDING PRINCIPLE #3:

Build connections across disciplines and organisations, and among researchers, decision makers, and stakeholders

Recommended practice 9. Funders, universities, agencies, and governments: Create and grow the capacity of boundary organisations dedicated to co-production of actionable science.

Recommended practice 10. Funders, managers, universities, research organisations, agencies, and NGOs: Create incentives (e.g. increased impact metrics) for academic researchers to consider co-production of actionable science as a rewarding line of work.



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Chapter 3.

PLANNING

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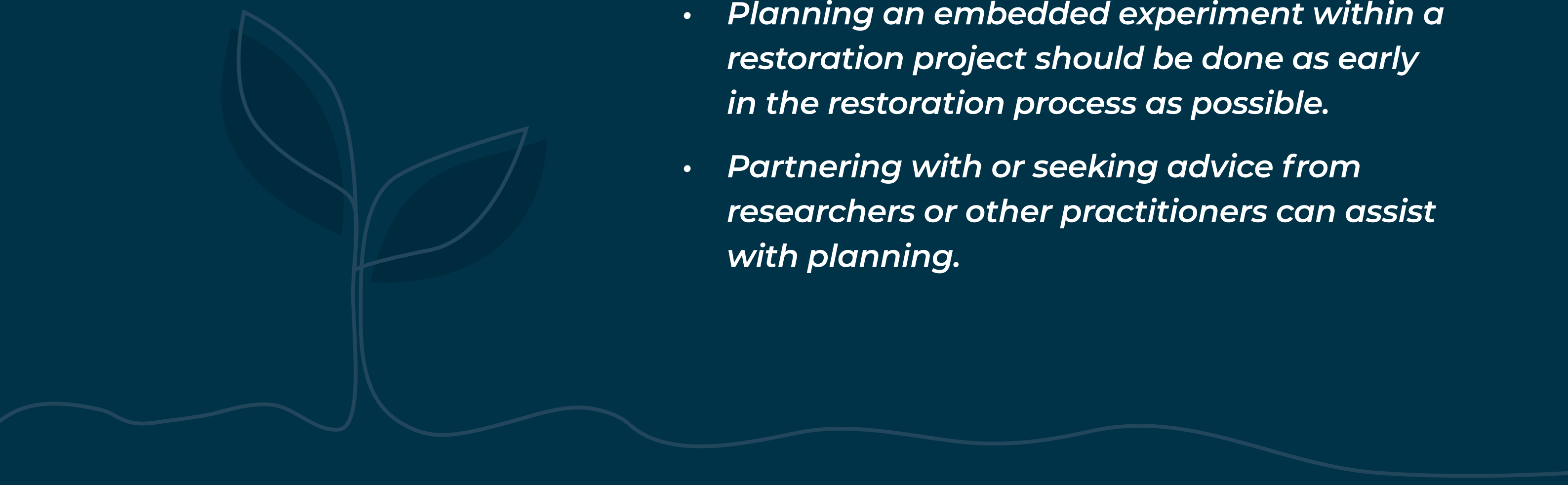
SUMMARY

- *Planning an embedded experiment is an essential component of restoration activities.*
- *Establish aims, goals, and objectives as part of the planning process.*
- *Planning an embedded experiment within a restoration project should be done as early in the restoration process as possible.*
- *Partnering with or seeking advice from researchers or other practitioners can assist with planning.*



PLANNING AN EMBEDDED EXPERIMENT IN RESTORATION

Planning is an essential but often hurried component of many ecological restoration activities. Even short-term ecological restoration projects may run for several years and follow a life-cycle that requires planning around stakeholder engagement, site-assessment, defining targets, implementation, monitoring, evaluation, reporting and feedback. Similarly, planning an experiment to be embedded within a restoration project requires considerable extra deliberation including thinking about what the experiment is seeking to do, how this will influence the design, whether a short- or long-term answer is expected or both, and by whom and how the monitoring be done. Ideally, embedding experiments into restoration projects should begin early in the planning phases of the overall restoration project. The process of planning and running a restoration project is similar to that required for an embedded experiment but they are not the same.

ESTABLISHING AIMS, GOALS, AND OBJECTIVES

It is useful to make a distinction between 'aims', 'goals' and 'objectives' of the restoration project within which the experiment will sit. The project aim is what you are trying to achieve in the longer term and can be a relatively general statement (see Table 3.1 for a hypothetical restoration project example). The project goals are a finer level of detail in planning with reference to the target community or ecosystem that you choose to use to guide your restoration outcomes. The goals indicate the status of the target that you are aiming to achieve and the timeframe for this to occur. Your project objectives then specify the changes and intermediate outcomes needed to achieve your project goals and represent metrics against which you can measure the outcomes of the project. Ideally, therefore, your goals will be S.M.A.R.T. (i.e. specific, measurable, achievable, relevant, time-limited).

Embedding an experiment within a restoration project has many benefits and can assist in answering key ecological questions faced by the restoration sector. Not every restoration project should include an experimental design as there are economic, social, logistical, and experiential implications and these may be beyond the capacity or capability of the individual or group undertaking the activity. Furthermore, at times funding bodies may not allow adequate timelines for appropriate and thorough planning. However, if the inclusion of an experiment embedded within a project is desired, it is best planned early to ensure optimal benefit.

Designing an experiment that is well planned and rigorously implemented offers the opportunity of delivering high quality science that flows back to support continual improvement in ecological restoration practice and outcomes.

Table 3.1 Hypothetical example of a restoration project's aim, target, goals, and objectives

Project aim	To restore Yellow Box – Red Gum woodland to a particular site from which it has been cleared
Project target	The Yellow Box – Red Gum woodland reference vegetation community or ecosystem against which the restoration will be compared (i.e. reference site)
Project goals	Restore 10 ha of vegetation that has an intact and recovering composition, structure, and function resembling those of the project target
Project objectives	The restored site has within 10 years: • an assemblage of at least three canopy dominant, five mid-storey and three native herb plant species that are characteristic of the project target; • a density of 300 stems/ha of native plant species; and • survival and flowering of at least 70% of planted species.

ESTABLISHING A HYPOTHESIS

It is essential that a clear experimental question is established, and that the experiment follows the scientific method of collecting and statistically analysing data to test an informed, well-constructed hypothesis. i.e. observe, question, develop a hypothesis, test the hypothesis through data collection and analysis, evaluate your findings and disseminate your conclusions. This may require additional preparations before implementing the restoration project (e.g. leaving aside control areas, collecting seed from a wider range of populations).

Designing experimental questions that specifically address the restoration knowledge gaps of a particular ecosystem, landscape, species, or natural resource management issue will maximise the future use of those results. Answering questions directly relevant to a local problem is useful to local land managers, and the experiments themselves have a greater chance of success with the support of the local on-ground delivery agents and managers. Over time and with ongoing establishment of a national network of experiments embedded within restoration plantings, individual sites can be used to address very context-specific questions with data analyses across the network of experiments building a story of more general patterns.

PLANNING TO MANAGE OVER TIME

When establishing experiments, especially those expected to run over years and decades, critical planning is required to ensure the long-term benefits of the experiment are not compromised. For example, no amount of data collected from an experiment can make up for poor design and implementation. Furthermore, failure to meet stakeholder expectations can have lasting consequences for future collaborations. For the experiments supported by these guidelines, it is also imperative to acknowledge at the outset that the experiment itself may not be implemented for 2-3 years or may even be retrospectively fitted to existing ecological restoration projects. In this following section, we explore and provide recommendations and checklists in relation to planning around several key areas.

PLANNING CHECKLISTS

Checklists can be extremely helpful when planning to help order activities and ensure that activities are undertaken as expected. Below is a series of suggestions to develop checklists that can be used when planning an embedded field experiment. These checklists have been assembled based on practitioner and researcher experience and contain points that should be considered and discussed prior to progressing to the next stage of setting up an embedded experiment. However, they are not intended to be an exhaustive list of topics to be covered. Rather, they aim to stimulate thoughts, discussions, and exploration of the proposed experiment. It is also important to remember that you may get to the end of the planning stage and decide not to proceed for any number of reasons (e.g. poor seasonal outlook for planting, loss of key stakeholders). In this case, it is important that you explore ways to manage these barriers to success in case another opportunity should arise and carefully document and store your project plan for easy retrieval.

CHECKLIST 1. Project governance

GOVERNANCE CHECKLIST	POINTS TO BE CONSIDERED
Project team	• Develop clear statements outlining project team roles, responsibilities and expectations for the life of the experiment.
Stakeholders	• Determine stakeholders (people and agencies) including why they have an interest and influence on the project's planning, implementation or outcomes. • Develop clear statements outlining stakeholders' roles, responsibilities and expectations for the life of the experiment. • Identify whether a project or research partnership needs to be developed or formalised. • Consult with traditional owners about cultural sensitivities, site access, traditional ecological knowledge on the target species, and potential participation in the project.
Funding and resourcing	• Ensure that budgets have been estimated and agreed by the funding body. • Agree and confirm amongst the project team and stakeholders the financial and in-kind contributions and allocations for project components. • Ensure financial management and cost recovery protocols are in place.
Capability and capacity	• Ensure there is sufficient capacity to undertake this experiment for its full duration, including over longer time frames. • Determine if any training will be required and, if so, determine who needs training and who will do the training. • Determine if any permits will be required and who will need them (e.g. for plant collection, weed spraying, 4WD competence).
Barriers to success	• Explore resource, social, cultural and ethical barriers to stakeholder engagement. • Consider staffing turnover and knowledge transfer to match the expected length of the experiment (project teams and governance arrangements can vary due to staff turnover).
Motivation and continuity	• Explore how to maintain engagement and activity in the short, medium and long term.
Communications	• Determine how often, when and using what type of communication (e.g. phone, video) the project team will meet. • Determine if a formal communication plan is required and who will prepare and implement it. • Establish protocols for resolving disagreements and conflicts of interest.
Data and knowledge	• Determine who will be the data custodian as well as what will be the intellectual property sharing arrangements, authorship of reports and research papers, and moral rights to data. • Identify who will analyse the data and has adequate capability. • Ensure that protocols are agreed for managing sensitive data. • Ensure that metadata (dataset description) are established and maintained.
Achievements, learnings and legacy credits	• Define how success will be measured. • Determine how learnings will be disseminated and by whom. • Identify how contributions will be acknowledged.

CHECKLIST 2. Experimental objectives

EXPERIMENTAL OBJECTIVES CHECKLIST	POINTS TO BE CONSIDERED
What are the collective objectives for this experiment, and does this bring about any project or funding conflicts?	• Clearly define the experimental question/s. • If there are different experimental objectives among stakeholders, discuss how this will be addressed. • Identify any conflicts of interest amongst stakeholders between the experimental and project objectives. • Ensure that the experimental question/s align with the broader project scope (see Checklist 3).
Experimental feasibility, practicality and scientific rigour	• Determine if the experimental question is complex and requires the development of a research partnership. • Ensure that the experimental design is appropriate to be able to answer the experimental question/s.
Timeframes	• Establish a timeframe that has scope for flexibility should unexpected events occur that delay the experiment from being established or monitored.
Metrics, analysis, reporting and evaluation (see also Chapter 5)	• Determine what metrics will be measured and why. • Determine over what timeframe and frequency will the metrics be measured. • Determine how to ensure the consistency of measurements over time. • Determine if the metrics are likely to change over time. • Prepare standardised data collection templates and protocols. • Identify who will analyse, review and report the data. • Identify who will write up the experimental results.
Risks	• Determine if there are human health and safety or ethical risks that need to be considered, and how to mitigate against these. • Identify if there are genetic or animal ethics risks that need to be considered and how to mitigate against these. • Determine if there are financial risks to be considered. For example, ensure the research funding matches the expected length of the experiment, including monitoring and reporting. • Consider potential requirements to minimise the vulnerability of the experimental site to climatic variability or disturbance (e.g. fire, hail storms, flooding). • Determine how to ensure research funding is available throughout the experiment. • Identify if there are any other risks to the experiment and how to mitigate against these.
Achievements, learnings and legacy credits	• Determine how learnings from the experiment will be used to improve planning practices.

CHECKLIST 3. Project objectives

PROJECT OBJECTIVES CHECKLIST	POINTS TO BE CONSIDERED
Objectives for the project, and project management	• Clearly define the overarching project objectives and ensure that the project can encompass the experimental component (see Checklist 2). • Ensure that project management and review arrangements are in place for the full timeframe of the project and experiment. • Ensure that the database platform is appropriate to hold the data collected during the project and its ongoing maintenance is supported. • Ensure that appropriate members of the project team and stakeholders can access and modify the database. • Identify project reporting timeframes and requirements (e.g. for funders).
Project site/s	• Identify an appropriate project site/s and the reasons for its selection. • Identify if the project site is easy to access and how to ensure access at relevant times for all appropriate people (poor access can cause difficulties if long-term and regular monitoring is required). • Assess the possible risks to the project site (e.g. fire, flood, clearing, disturbance) and how to address these.
Target or reference sites	• Determine if a target/reference site is to be used and its characteristics. • Identify which attributes of the target/reference site will be used to guide the restoration goals.
Storage of site details	• Identify how and where to store details about the location, access and access permission For the experimental site and target/reference site (including tenure). • Identify how these details will be updated.
Co-benefits	• Assess if there is an opportunity to create additional benefits from the experiment that may enhance the restoration (e.g. through carbon sequestration, generating or reinstating cultural values, connecting isolated sites or fragmented populations).
Is the project using in situ species or will species need to be planted?	• Determine if there are any existing plants *in situ* that may interact with the experiment either through presence, as seed sources, or as habitat for other target ecosystem component species. • Where relevant, identify plant, tube stock or seed sources sufficient for the project and ensure that their availability matches the project timeframe.
Site establishment and maintenance	• Determine whether any site work or maintenance will be required (e.g. feral and weed management, herbivore-exclusion fencing). • Identify who will be responsible for site maintenance and its costs. • Assess how long the site maintenance will be required. • Determine if removal of natural regeneration within the experimental Plots will be required to prevent confounding or biasing of the results (e.g. through competition for resources).
Tenure of the target site	• Assess how secure the site tenure is. • Identify what permissions are required to access the site and if appropriate licences have been obtained. • Determine if there are any ethical considerations related to accessing or using the site (e.g. cultural heritage values, threatened species presence).

PLANNING TO IMPLEMENT THE EXPERIMENT

Once an experiment is designed, considerable effort is still needed to plan exactly how it will be implemented within the overall project. Things to be considered include how to differentiate the experiment from the rest of the site (e.g. Does it need fencing or highly visible pegs so it can be found later on?), and what changes to established ecological management practices might be required (e.g. Are appropriate management skills available for any proposed management of fire, exotics or grazing pressure? Do plants need an identifying tag? Is there enough seed to undertake the experiment? Will more staff be required to undertake the experiment?).

For restoration involving plantings, there is considerable interest in understanding the most appropriate species for a particular site and how species and populations will respond to environmental change and climate change. Species choice is usually straightforward and based on those found close to the restoration site except where provenances from other places are selected to trial to enhance climatic resilience. However, if the site has a long legacy of anthropogenic disturbance and only has a small component of the remnant above- and below-ground ecosystem left or has changed significantly (i.e. it is a ‘novel’ ecosystem; Hobbs et al. 2009), then different species may be required. Examples of novel ecosystems include mine-site tailings where species are often planted hoping to remediate conditions back towards an ecosystem state that can be restored (Laghlimi et al. 2015). Irrespective of species choice, having enough seed to undertake the experiment is essential. For example, a recent collaboration between Greening Australia and CSIRO to test 16 provenances of Eucalyptus viminalis on the Monaro Plain in NSW (**https://www.greeningaustralia.org.au/projects/monaro-comeback/**)required two years to collect seed before the experiment could be planted. Overcoming logistical constraints is key to embedding an experiment in restoration activities.

Similarly, it is important to evaluate the potential risk to the target restoration ecosystems or species under current and future climate change. Habitat suitability models (also referred to as species distribution models or ecological niche models) can be used to evaluate whether the local suite of species will maintain suitable habitat into the future (e.g. Butterfield et al. (2017) and Harrison et al. 2017). These authors identified a subset of the local species which are likely to have suitable habitat into the future but also identified other native non-local species that might also be suitable. For more about assessing habitat suitability see Box 3.1. Information gathering can help to design experiments to explore a range of outcomes.

PLANNING FOR ONGOING EXPERIMENTAL INPUTS AND MAINTENANCE

If physical management and maintenance of the site is part of an experimental design (e.g. exclusion of herbivores from parts of the site to test the effects of those interventions), this might be done by the same people collecting data, or by other members of the partnership. There needs to be clarity in early project discussions about whose responsibility it will be to fund and undertake maintenance such as repairing fences and weed control. If there is ongoing management that is not an experimental treatment (e.g. removal of weeds across the site from time to time), there again needs to be coordination among partners to ensure that planned activities are done in a coordinated way and that they are recorded.

In summary, embedding an experiment within restorations projects requires good planning, including thinking about the questions the experiment is trying to address, roles and responsibilities and logistical considerations. For these experiments to be successfully established we suggest that this planning is done early as it is extremely difficult if not impossible to retrospectively gather data once a restoration site has been planted. Partnering with or seeking advice from researchers or other practitioners, especially those who have conducted similar types of experiments to those you are planning, can be extremely helpful (e.g. see Bush Heritage Australia’s Climate Ready Revegetation **https://www.bushheritage.org.au/projects/nardoo-climate-ready-revegetation** and Greening Australia’s Climate Futures Plots. **https://www.greeningaustralia.org.au/climate-future-plots/**). We cannot stress too highly that carefully planning your experiment is critical to ensure that the data you are gathering is statistically sound.

BOX 3.1

PUCA: AN R PACKAGE TO IDENTIFY POTENTIAL PROVENANCES FOR ECOLOGICAL RESTORATION IN A CHANGING CLIMATE

The Provenancing Using Climate Analogues (PUCA; Harrison et al. 2017) package provides one approach to implementing the climate-adjusted provenancing strategy of Prober et al. (2015) together with population genetic concepts through the R statistical computing language. The package can be accessed at **https://rdrr.io/github/peteraharrison/PUCA/**, and requires minimal skills in coding (e.g. copy/paste three lines of code to download and then open the graphical user interface).

PUCA reduces the multidimensional environmental variation at a given site being restored using a principal components analysis (PCA). The dissimilarities between the restoration site and each distribution record of a target species in multivariate space (defined by the retained principle components) are then estimated and used to determine which provenances to sample (Fig. 3.1). Identified provenances are additionally screened to determine whether they originate from fragmented landscapes.

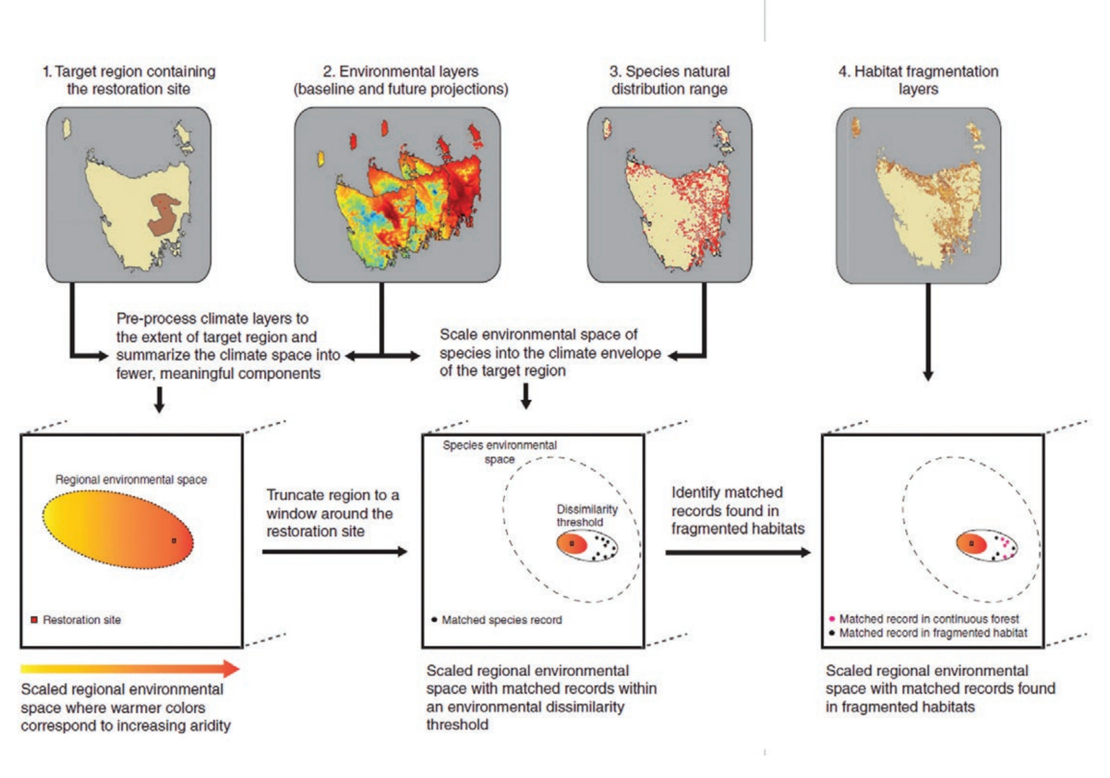


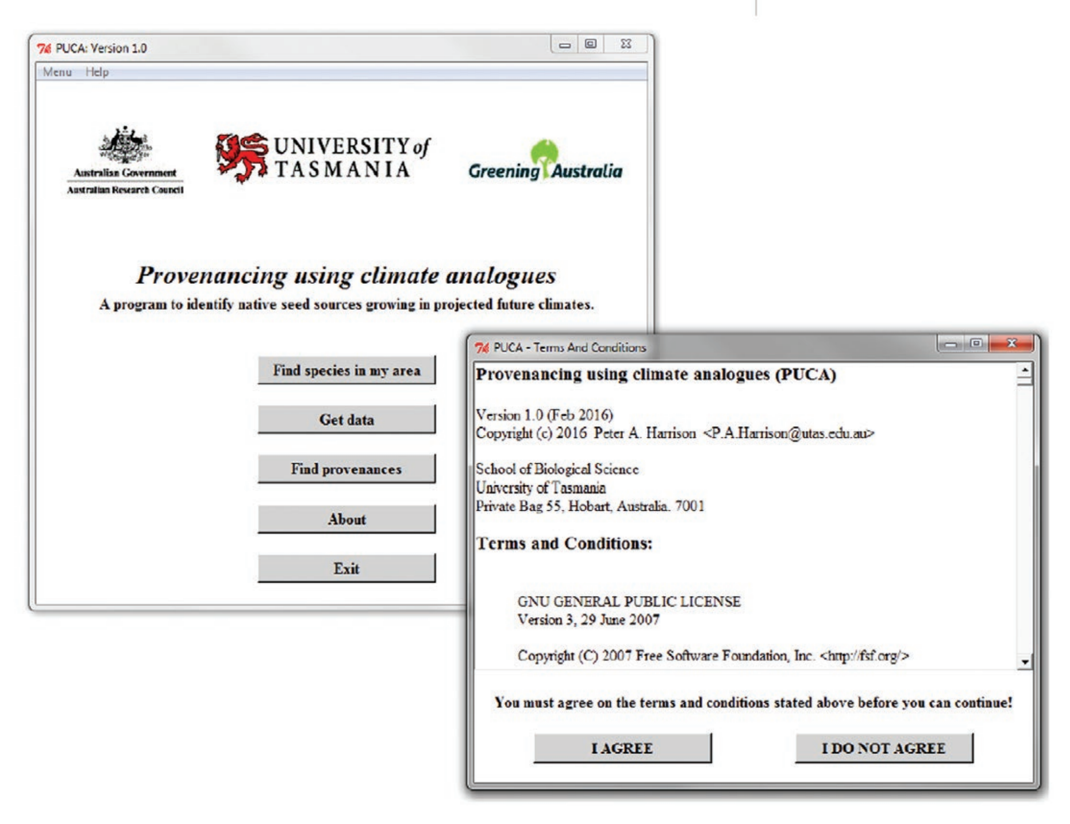
Figure 3.1 Conceptual flow diagram for PUCA. (Figure from Harrison et al. 2017).

Box 3.1 continued following page....

PUCA has a graphical user interface (Fig. 3.2) that links with the Atlas of Living Australia (https://ala.org.au/) and the Global Biodiversity Information Facility (https://www.gbif.org/) to acquire distribution data for specific species if required with built in filters to identify potential outliers due to misidentification. Climate surfaces are obtained from WorldClim (Hijmans et al. 2005) and fragmentation layers can be developed using MODIS satellite imagery. It also provides the user the ability to upload and use their own environmental surfaces (e.g. soil) as well as distribution data. This flexibility makes this tool widely amendable and applicable to any geographic region.

There are three core functions in the current version of the software package. 'Find species in my area' (Fig. 3.3) allows a query to either the Atlas of Living Australia or the Global Biodiversity Information Facility based on the geographic coordinates of a site being restored and a given radius. There are options to return either plant or animal taxa, or both. Selecting a specific species will download the data and store within the current R session, and then map the known distribution of the species.

The second core function is 'Get data' (Fig. 3.4) which provides the ability to upload (i.e. import) or download distribution and environmental data. Currently, only climate data can be downloaded



Provenancing using climate analogues

A program to identify native seed sources growing in projected future climates.

Provenancing using climate analogues (PUCA)

Version 1.0 (Feb 2016)
Copyright (c) 2016 Peter A. Harrison <P.A.Harrison@utas.edu.au>

School of Biological Science
University of Tasmania
Private Bag 55, Hobart, Australia. 7001

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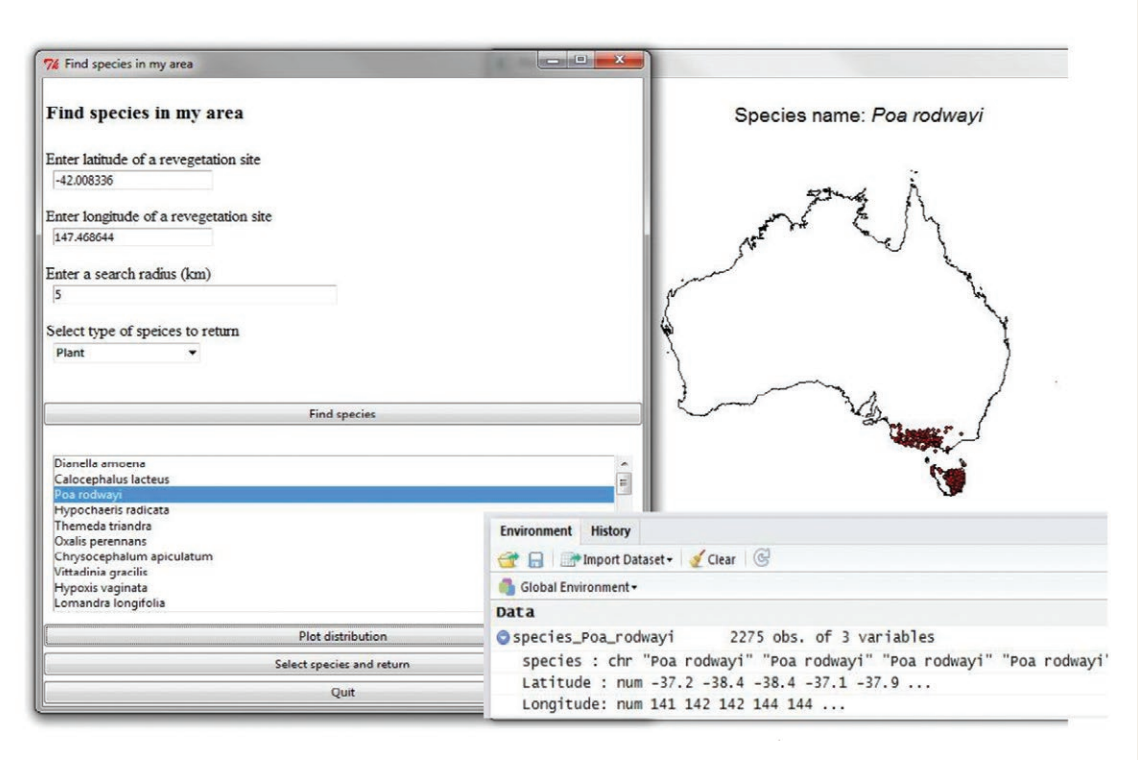
You must agree on the terms and conditions stated above before you can continue!

Figure 3.2 The graphical user interface for PUCA.

Box 3.1 continued following page....

using the ‘I need to download data’ tab, however, there is no limit to the data which can be uploaded into the program.

The third core function is ‘Find provenances’ which is the main utility function of PUCA. After selecting the species for which to identify provenances and the environmental variables to use, a log window will appear (Fig. 3.5) which details the progress of PUCA. Once finished, the best matching provenances are returned to the main console window, along with the geographic coordinates of that distribution record, the dissimilarity index, the geographic proximity to the restoration site, the georeferenced location of the provenance and a flag indicating whether a distribution record is from a potentially fragmented site (Fig. 3.5). These results are additional plotted as a heatmap to further guide where to sample (Fig. 3.5).



Enter latitude of a revegetation site
-42.008336

Enter longitude of a revegetation site
147.468644

Enter a search radius (km)
5

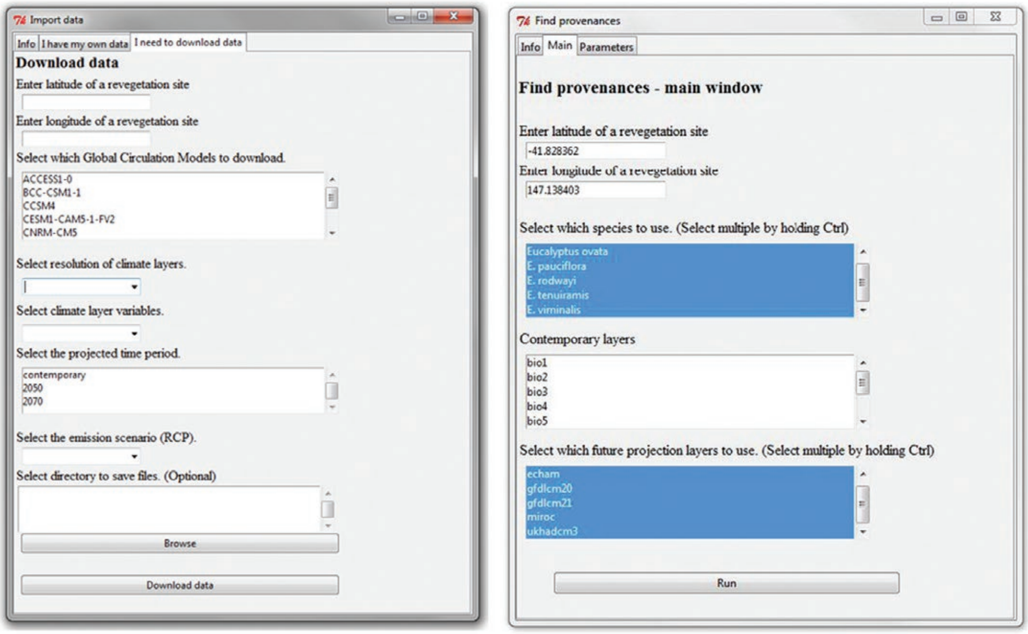
Select type of speices to return
Plant

Dianella amoena
Calocephalus lacteus
Poa rodwayi
Hypochaeris radicata
Themeda triandra
Oxalis perennans
Chrysocephalum apiculatum
Vittadinia gracilis
Hypoxis vaginata
Lomandra longifolia

```
Data
species_Poa_rodwayi       2275 obs. of 3 variables
  species : chr "Poa rodwayi" "Poa rodwayi" "Poa rodwayi" "Poa rodwayi'
  Latitude : num -37.2 -38.4 -38.4 -37.1 -37.9 ...
  Longitude: num 141 142 142 144 144 ...
```

Figure 3.3 The graphical user interface for the ‘Find species in my area’ core function of PUCA. Shown is the search results for *Poa rodwayi* which is local to a restoration site in Tasmania, and the downloaded data which are stored in the R session.

Box 3.1 continued following page....



Download data

Enter latitude of a revegetation site

Enter longitude of a revegetation site

Select which Global Circulation Models to download.

ACCESS1-0
BCC-CSM1-1
CCSM4
CESM1-CAM5-1-FV2
CNRM-CM5

Select resolution of climate layers.

Select climate layer variables.

Select the projected time period.

contemporary
2050
2070

Select the emission scenario (RCP).

Select directory to save files. (Optional)

Find provenances - main window

Enter latitude of a revegetation site

-41.828362

Enter longitude of a revegetation site

147.138403

Select which species to use. (Select multiple by holding Ctrl)

Eucalyptus ovata
E. pauciflora
E. rodwayi
E. tenuiramis
E. viminalis

Contemporary layers

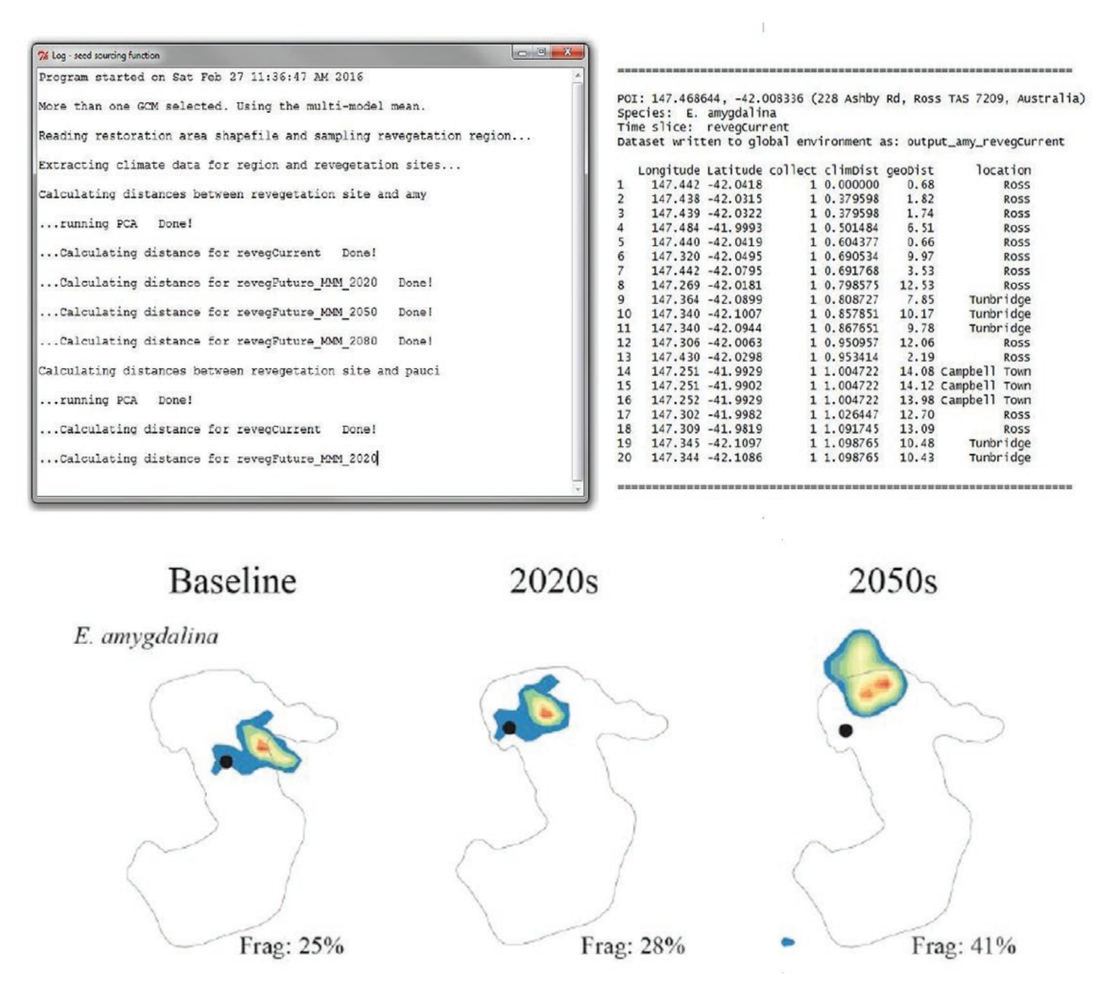
bio1
bio2
bio3
bio4
bio5

Select which future projection layers to use. (Select multiple by holding Ctrl)

echam
gfdlcm20
gfdlcm21
miroc
ukhadcm3

Figure 3.4 The graphical user interface for the 'Get data' core function of PUCA. Shown on the left is the tab which allows climate data to be downloaded from WorldClim (www.worldclim.org). On the right is the graphical user interface for the 'Find provenances' core function of PUCA, where you can select which species to find provenances, the climate variables to use, and the global circulation models for the future climates.

Box 3.1 continued following page....



```
Program started on Sat Feb 27 11:36:47 AM 2016

More than one GCM selected. Using the multi-model mean.

Reading restoration area shapefile and sampling revegetation region...

Extracting climate data for region and revegetation sites...

Calculating distances between revegetation site and amy

...running PCA   Done!

...Calculating distance for revegCurrent   Done!

...Calculating distance for revegFuture_MMM_2020   Done!

...Calculating distance for revegFuture_MMM_2050   Done!

...Calculating distance for revegFuture_MMM_2080   Done!

Calculating distances between revegetation site and pauci

...running PCA   Done!

...Calculating distance for revegCurrent   Done!

...Calculating distance for revegFuture_MMM_2020
```

```
==================================================================

POI: 147.468644, -42.008336 (228 Ashby Rd, Ross TAS 7209, Australia)
Species:  E. amygdalina
Time slice:  revegCurrent
Dataset written to global environment as: output_amy_revegCurrent

   Longitude Latitude collect climDist geoDist        location
1    147.442 -42.0418       1 0.000000    0.68            Ross
2    147.438 -42.0315       1 0.379598    1.82            Ross
3    147.439 -42.0322       1 0.379598    1.74            Ross
4    147.484 -41.9993       1 0.501484    6.51            Ross
5    147.440 -42.0419       1 0.604377    0.66            Ross
6    147.320 -42.0495       1 0.690534    9.97            Ross
7    147.442 -42.0795       1 0.691768    3.53            Ross
8    147.269 -42.0181       1 0.798575   12.53            Ross
9    147.364 -42.0899       1 0.808727    7.85       Tunbridge
10   147.340 -42.1007       1 0.857851   10.17       Tunbridge
11   147.340 -42.0944       1 0.867651    9.78       Tunbridge
12   147.306 -42.0063       1 0.950957   12.06            Ross
13   147.430 -42.0298       1 0.953414    2.19            Ross
14   147.251 -41.9929       1 1.004722   14.08 Campbell Town
15   147.251 -41.9902       1 1.004722   14.12 Campbell Town
16   147.252 -41.9929       1 1.004722   13.98 Campbell Town
17   147.302 -41.9982       1 1.026447   12.70            Ross
18   147.309 -41.9819       1 1.091745   13.09            Ross
19   147.345 -42.1097       1 1.098765   10.48       Tunbridge
20   147.344 -42.1086       1 1.098765   10.43       Tunbridge

==================================================================
```

Figure 3.5 The log file window detailing the progress of PUCA for each species (left) and the console output for the target species (right), which returns the geographic coordinates of the identified distribution records for *Eucalyptus amygdalina* that matches the restoration site, where to collect (1) or not (0), the dissimilarity measure (climDist), the geographic proximity to the restoration site (geoDist) and the locality of the provenance. The bottom figure is the heatmap of where to sample for a given period for the restoration site (black dot) and the percentage of points that occur in fragmented provenances. Hot colours represent higher density of climatically matched distribution records.

BOX 3.2

EMBEDDING A PROVENANCE EXPERIMENT INTO A REVEGETATION PROJECT

This case study is based on a provenance experiment (Hancock et al. 2013) and indicates the steps needed to embed a provenance experiment into a revegetation project.

1. Establish the experimental question

Question — Do plants grown from locally-sourced seeds have superior performance compared to plants grown from non-locally sourced seeds of the same species? This experiment compares survivorship and growth of plants grown from local versus four non-local seed sources, using six species commonly used in revegetation in the Cumberland Plain in NSW (*Acacia falcata*, *Bursuria spinosa* ssp. *Spinosa*, *Eucalyptus crebra*, *E. tereticornis*, *Hardenbergia violacea* and *Themeda triandra*). The species are grown from seed to tube stage at Macquarie University and transferred as tube stock to two sites in the Cumberland Plain.

2. Select seed sources

The selection of provenance material reflects the underlying research question e.g. seeds should be sourced from near the planting site (local provenance) and from a pre-determined selection of distant locations (non-local provenance). Where possible, seeds were collected from wild populations at similar times for each species. It was impractical to collect seeds for four non-local provenances for all species so seeds were sourced commercially. Seeds used in the experiment were as uniform as possible, apart from their provenance. For example, where choices were available, the seeds were similar in collection date, the number of parents the seeds were collected from, and the number of plants in the population. The exact location of the seed sources were also recorded. These details are important to ensure that the seeds are of the same age (some seeds will deteriorate when stored), maternal effects are similar (this is a consideration for short experiments e.g. three months) (Roach & Wulff 1987), there are no adverse fitness effects due to low genetic diversity, and the environmental distances of the different collections to the local seed source are known. Unfortunately, this information is not always available.

3. Determine the experimental design and number of plants needed

The design selected comprised two sites. Each site had six species, each with local provenance plants and four non-local provenance plants, with 15 replicates each. The total planting was 900 individuals (450 at each site; 150 plants per species)

Species (a):

Provenance 1 = 15 rep for each site x 2 sites = 30 plants

Provenance 2 = 15 rep for each site x 2 sites = 30 plants

Provenance 3 = 15 rep for each site x 2 sites = 30 plants

Provenance 4 = 15 rep for each site x 2 sites = 30 plants

Provenance 5 = 15 rep for each site x 2 sites = 30 plants

(only 10 replicates needed for the field; 5 extra plants)

4. Germinate seeds and pot up plants

A small percentage of seeds from each seed source was tested for viability. In this example, germination was not tested but this step is useful to inform the number of seeds to sow (always sow more than is needed for the experiment). The most important rule in this step is to treat the different provenances of each species in the same way. For example, the same dormancy breaking treatment, the same potting mix and watering regime were used. Trays of seeds were carefully labelled with the correct provenance and species. Trays and pots were randomly moved around the glasshouse so that one provenance did not receive more or less sunshine or water

Box 3.2 continued following page....

than the others. As soon as a germinant (or seed) was put into an individual tube or pot, a tag was allocated to the individual with its unique number and its provenance. An example is shown in Figure 3.1. All procedures and materials used (e.g. seed raising mix, potting mix, fertiliser) were recorded so that the experiment can be duplicated by others.

5. **Select seedlings for the field site**

   More plants than were needed for the experiment were grown. Extra seedlings allow for:

   - plants to be selected that are of uniform size;
   - plants that die within the first few weeks/month to be replaced; and
   - plants to be replaced in the event of a disaster at the site, e.g. the site may get flooded or burnt.

6. **Select planting site(s)**

   In this example, two sites were chosen that were as similar (soil, topography, and climate) as possible to enable the results to be applicable to the region (Cumberland Plain). If only one site was chosen, the results are only applicable to that site. Soils at the two sites are derived from the same substrate and soil testing established that there are no differences in nutrient levels, clay content etc. The amount of shading at each site was similar (negligible).

7. **Prepare site**

   The preparation for planting was conducted in the same manner at each site. For example, herbicide use, depth of mulch and watering regime was similar at both sites.

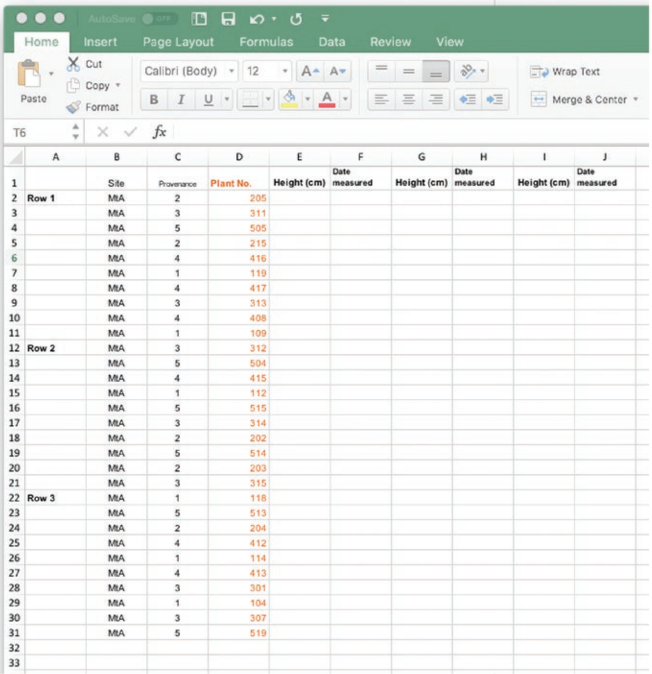
8. **Design planting layout**

   Steps were taken to ensure that the position of each plant could be identified for the duration of the experiment. More than one notation of the plant's position was recorded i.e. identified on a map of the site and documented on a measuring sheet (Fig.3.6). Plastic and aluminium tags were secured to and next to the plant and planting hole respectively (note that plastic tags will deteriorate over time). See Chapter 4 for further details on experimental design and planting layout.

9. **Planting at the site(s)**

   All plants were measured in the glasshouse before planting at the site. The measurement taken depended on the species. For example, height from soil to apical meristem for woody plants, stem diameter for vines, and basal circumference for clumping grasses. Taking a preliminary measurement and subsequent regular measuring, at least in the short term, provides some data in the event of a disaster occurring at the site if all of the plants die before the completion of the experiment.

   At both sites, planting holes were dug using an auger with volunteers planting by hand and watering.



	A	B	C	D	E	F	G	H	I	J
1		Site	Provenance	Plant No.	Height (cm)	Date measured	Height (cm)	Date measured	Height (cm)	Date measured
2	Row 1	MtA	2	205						
3		MtA	3	311						
4		MtA	5	505						
5		MtA	2	215						
6		MtA	4	416						
7		MtA	1	119						
8		MtA	4	417						
9		MtA	3	313						
10		MtA	4	408						
11		MtA	1	109						
12	Row 2	MtA	3	312						
13		MtA	5	504						
14		MtA	4	415						
15		MtA	1	112						
16		MtA	5	515						
17		MtA	3	314						
18		MtA	2	202						
19		MtA	5	514						
20		MtA	2	203						
21		MtA	3	315						
22	Row 3	MtA	1	118						
23		MtA	5	513						
24		MtA	2	204						
25		MtA	4	412						
26		MtA	1	114						
27		MtA	4	413						
28		MtA	3	301						
29		MtA	1	104						
30		MtA	3	307						
31		MtA	5	519						
32										
33										

Figure 3.6 Example of unique plant numbering and position of individual plants at the field site, ready for data input. Note that this is for one species only.

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IMAGE: Embedded experiment at Peniup, Western Australia, evaluating trade-offs between carbon and species and functional diversity of plantings. *(Photo credit Suzanne Prober)*

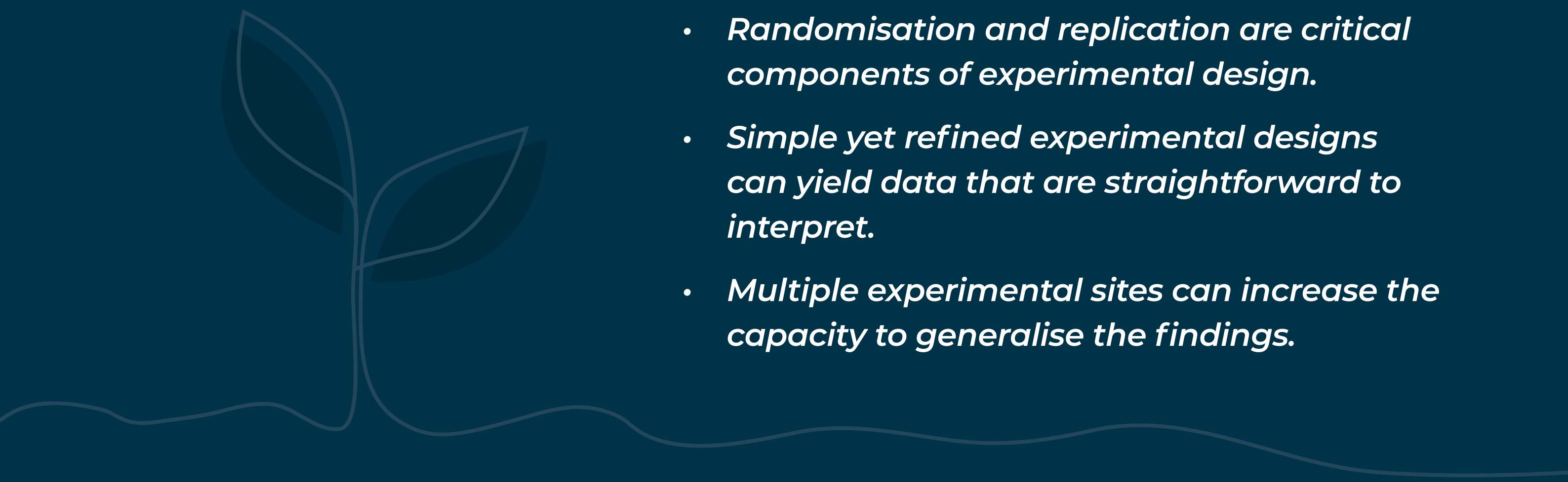
Chapter 4.

EXPERIMENTAL DESIGN

Paul D Rymer, David Bush, Peter A Harrison, Sacha Jellinek, Nicholas Macgregor, Suzanne M Prober, Rachel Standish

SUMMARY

- *Experiments can be manipulative or comparative, including plantings and management actions.*
- *Experiments include treatments of which at least one should be a control.*
- *Randomisation and replication are critical components of experimental design.*
- *Simple yet refined experimental designs can yield data that are straightforward to interpret.*
- *Multiple experimental sites can increase the capacity to generalise the findings.*



INTRODUCTION

Purposeful experimental design is essential for ensuring that key questions can be assessed in embedded experiments. Experimental design is typically part of good planning for any ecological restoration project, especially those that aim to improve biodiversity, ecological function, and resilience to disturbance. However, designing embedded experiments that enable learning from investments in ecological management or restoration is substantially less common. In many cases, outcomes of ecological restoration activities are confounded by a weak experimental design, or the outcomes are simply not measured, and as a result these activities provide little new knowledge to the wider restoration sector for improving the outcomes of future ecological restoration. The outcome of a restoration project is likely to be far more effective if it includes an embedded experiment where there are clear objectives for adaptive management that may be needed in the future.

In this chapter we provide a brief overview of experimental design principles and provide examples of common designs, to empower anyone to effectively and efficiently design and implement experiments to address key natural resource management questions (see Chapter 1).

DESIGNING AN EXPERIMENT TO ADDRESS A KEY QUESTION

It is critical that the main research question is well defined prior to developing the experimental design. In this chapter, we assume that a question has already been determined through the planning process (see Chapter 3), and focus on how to design simple experiments to answer this question.

At the core of every experiment is the comparison of different **treatments** (terms in bold are defined in the glossary, Appendix 2). Treatments are the different plant materials (e.g. species or provenances) or different approaches (e.g. agronomic techniques or fire regimes) being compared. Treatments can include a number of **factors** (e.g. plant species, sowing depth) with multiple **levels** (e.g. factor 1 (four plant species), factor 2 (two sowing depths). **Experimental design** refers to the selection of treatments (combination of factors and levels; e.g. eight treatment combinations of plant species and sowing depth), the number of replicate (i.e. **replication**) plots or **experimental units**, plot and size arrangement, and site selection. All of these components determine the relative power of an experimental design to detect treatment effects, and our ability to address the main question.

Key aspects to be considered when choosing an appropriate design include the number of treatments, the size of plots, how much replication is required, and how to randomise treatments and experimental units to allow for robust statistical testing. The more complicated an experimental design becomes the more challenging it is to monitor and interpret the results. Simpler experimental designs may yield more useful data than complicated designs that are impractical to implement and to interpret.

CHOICE OF TREATMENTS AND LEVELS

- Choice of treatments is underpinned by the experimental question that is defined in the planning phase. First, determine the potential treatments and treatment levels you could use to answer your question. Then, consider the resources and technical knowledge available to implement the treatments.
- Including a 'control' treatment (i.e. a treatment that involves doing nothing or applies standard practice or 'business as usual' management) is a powerful way to test the benefit of new restoration and management options. The control is a reference for treatment comparisons.
- Apply at least one other treatment to compare to the control treatment, or at least two independent treatments (different levels of a factor, or combination of factors and levels) if you are not using a control. If the factor is continuous (can have any value, e.g. amount of fertilizer or planting density) it may be necessary to include multiple levels to determine the optimal level.
- Experimental treatments may be sites and regions where plant materials or planting approaches are tested to determine where they are most effective. In such cases, your design will be guided by a network of experiments enabling greater generalisation of results.

The treatments selected will define the size and complexity of the experiment, and it is recommended to keep the treatments simple. Treatment design refers to the combination of treatments selected. Some common treatment designs are described on the following pages.

COMMON TREATMENT DESIGNS

SINGLE FACTOR WITH TWO LEVELS

The simplest experiment consists of a single factor with two levels (e.g. nil and moderate fertiliser addition; Fig. 4.1). Even these very simple experimental contrasts can provide insights and information to improve best practice in ecological restoration, especially when installed across a range of sites.

Figure 4.1 Single factor (fertiliser) with two levels (+/- fertiliser).

SINGLE FACTOR WITH MULTIPLE LEVELS

Some factors can have several levels that can be meaningfully applied within an experiment to test the outcome of different plant material or methods. An example of a single factor experiment with multiple levels might be a test of the plant establishment success following four different soil amendments (three different levels of fertiliser application and the unfertilised control; Fig. 4.2). An alternative example could be testing the establishment success of five different provenances (four levels with different provenances and a local provenance control).

TWO FACTORS INDEPENDENTLY APPLIED

It is common for two independent factors to be considered in a single experiment, without applying all possible combinations of the two factors. For example, different levels of fertiliser may be of interest along with different species, but it may not be feasible to apply all combinations with the available resources (e.g. limited space or funds) (Fig. 4.3). In some cases, it may be known that particular species fail under certain conditions, so specific treatment combinations could be excluded. In experiments with two factors applied independently, the outcomes will be similar to the single factor designs above, with the advantage that the effect of each selected factor combination can be estimated in a single experiment. Data from such experiments can be analysed separately for each factor, or alternatively with each treatment included in the analysis as independent treatments.

The limitation of not applying the full treatment combination is that it is not possible to determine if the main factors interact, such that the effect of one factor is dependent on the other factor. For example, you may be interested in knowing which species has the best establishment at your site (i.e. factor 1 = species), and if the application of fertiliser enhances initial growth and establishment (i.e. factor 2 = fertiliser). Let us say there are three species and two fertiliser levels, which would be six treatment combinations requiring more space and other resources than currently available. So, the two factors are applied independently: (1) three species planted with control fertiliser application; and (2) the dominant species planted with enhanced fertiliser *and* control fertiliser. The findings should show

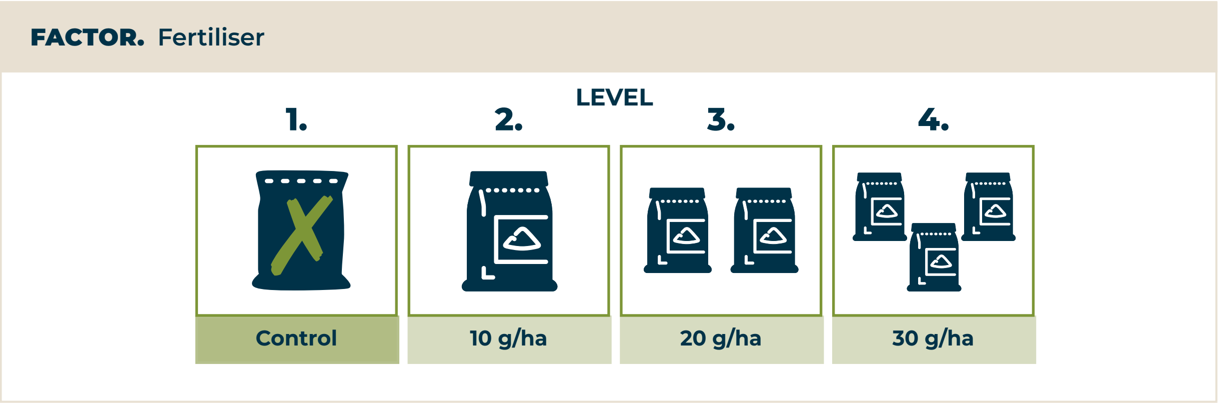


Figure 4.2 Single factor (fertiliser) with multiple levels (0, 10, 20, 30 kg/ha).

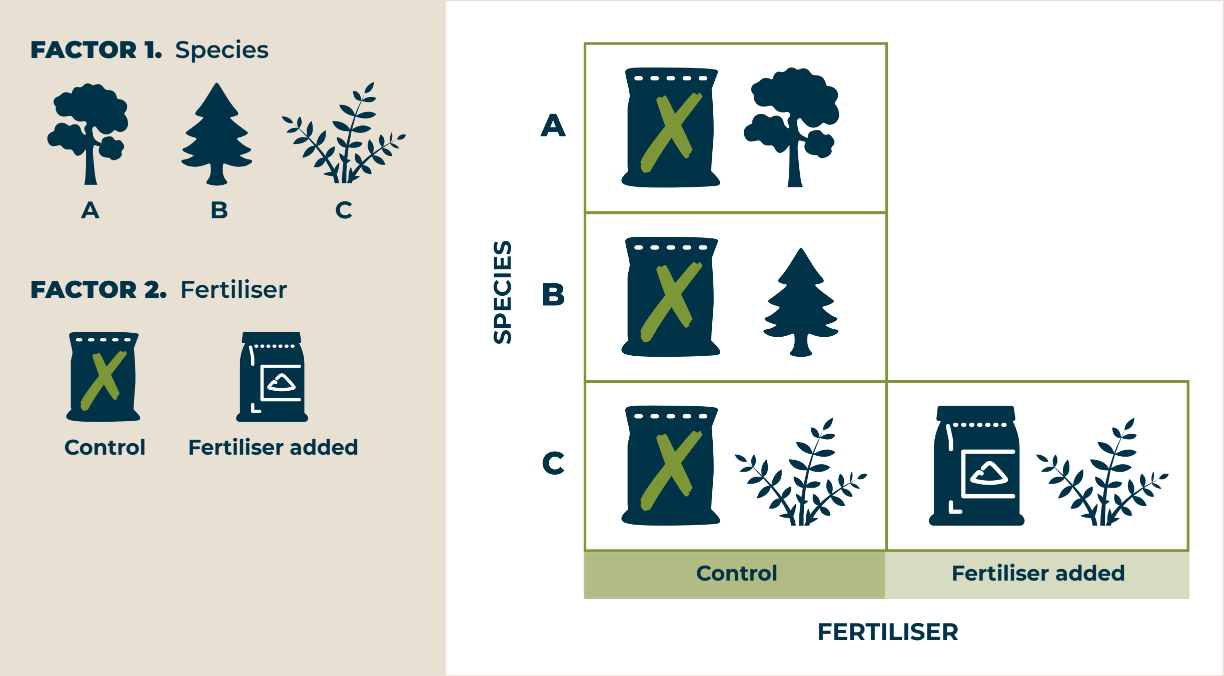


Figure 4.3 Two factors independently applied (species A – fertiliser, species B – fertiliser, species C +/- fertiliser).

which species has the best and worst establishment under control conditions, and if fertiliser improves establishment of the dominant species, but it will not be able to determine if fertiliser improves establishment for all species. In some cases, fertiliser may reduce establishment (e.g. in the case of natives sensitive to fertiliser application such as plant species in the Proteaceae family).

TWO FACTORS IN A FACTORIAL DESIGN

Factorial designs, in which all possible combinations of factor levels are included, are powerful in being able to determine the main effects (i.e. the independent effects of each factor, such as species or planting method), as well as any potential interactions between the main factors. For example, an experiment might have species selection (species 1, species 2, species 3) as one factor and planting method (unfertilised, fertilised) as a second factor. All three species will be planted in fertilised and unfertilised plots. This generates six treatment combinations (3 species x 2 planting methods). Importantly, a factorial design will determine if some species do better with fertilisation, while others do better without fertilisation (i.e. interaction of the factors) (Fig. 4.4). Case Study 6 describes an example of an embedded restoration experiment with a fully factorial design.

Although it is enticing to design complex experiments, we recommend they are kept simple, with no more than two factors being implemented per experiment unless there is suitable support and clear outcomes. For example, the two factor experiment above with three species and two fertiliser treatments may be established in sites with different soil types (i.e. potential three factor interaction). Likewise, the number of treatment levels should be considered carefully to ensure the experiment is manageable. The number of treatment combinations can easily blow out given this is a multiple of the number of levels in each of the treatments (e.g. 10 species x 2 fertilisers = 20 treatment combinations). At this point it would be important to consider whether the main question can be addressed with fewer comparisons. For example, is it is really necessary to include all treatment levels (e.g. all species), or is an alternative design an appropriate compromise (e.g. two fertiliser treatments applied to plots of mixed species)?

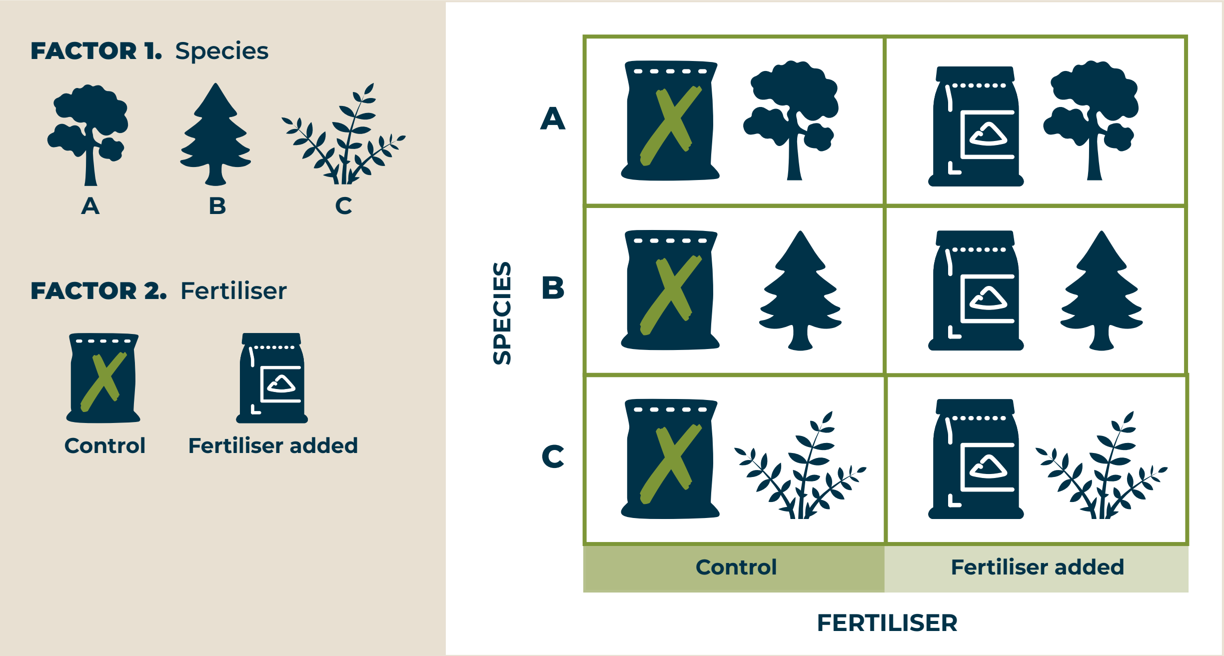


Figure 4.4 Two factors (species, fertiliser) with factorial design (species A +/- fertiliser, species B +/- fertiliser, species C +/- fertiliser).

PRINCIPLES OF EXPERIMENTAL DESIGN

Once treatments have been decided, there are three key principles that must be incorporated into a robust experimental design: (1) **randomisation**, (2) replication, and (3) **blocking** (Green 1979).

1. RANDOMISATION

To ensure that the test is statistically valid and not confounded.

Randomisation of the treatment combinations within an embedded experiment is essential so that treatments can be directly compared to each other. Results are confounded when the differences among treatments cannot be separated from other unmeasured factors that may be responsible for the observed differences, such as light, water, nutrient levels or biotic interactions (Fig. 4.5). For example, imagine testing the differences in survival between two species to determine which may be best to use in restoring a woodland community. In an experimental planting, species 1 is planted on the lower slope of a hill and species 2 is planted on the upper slope of a hill. It is found that species 2 has lower survival than species 1. However, in this example, differences in survival cannot be attributed to the species choice alone, as inherent environmental differences in the planting location (i.e. lower vs. upper slope) cannot be separated from the species effect. Might species 2 have done better in the lower slope position where the soil moisture availability may be higher? This question cannot be answered from the chosen design and the effects of slope and species are confounded. While this example provides an obvious demonstration of confounding, the problem can arise even though the planting site looks uniform, due to undetected variation (e.g. underlying uneven soil types) that impacts on the response. A simple way to avoid confounding due to undetected site heterogeneity is by randomising the treatment combinations in all plantings. In the previous example, this would be done by randomly allocating plants of each species to the lower and upper planting locations on the slope.

Another source of confounding can arise due to temporal differences in treatment application and establishment of the experiment. Using the same example as above, imagine that species 2 was planted two months after species 1, in a different season. The experiment is measured after 1 year of growth in the field trial, and statistical analysis identifies a significant difference in species performance, with species 1 outperforming species 2. The results are confounded by planting time. A way to resolve this could be to randomly allocate a subset of each species to the two planting times (and locations). Similar confounding can arise from different groups of people (e.g. planters or assessors) working at different locations or times. This highlights the importance of keeping detailed records of the planting schedule (and who assesses components of the experiment) to enable potential confounding factors to be incorporated into the statistical analysis (see random blocking factors on the following pages).

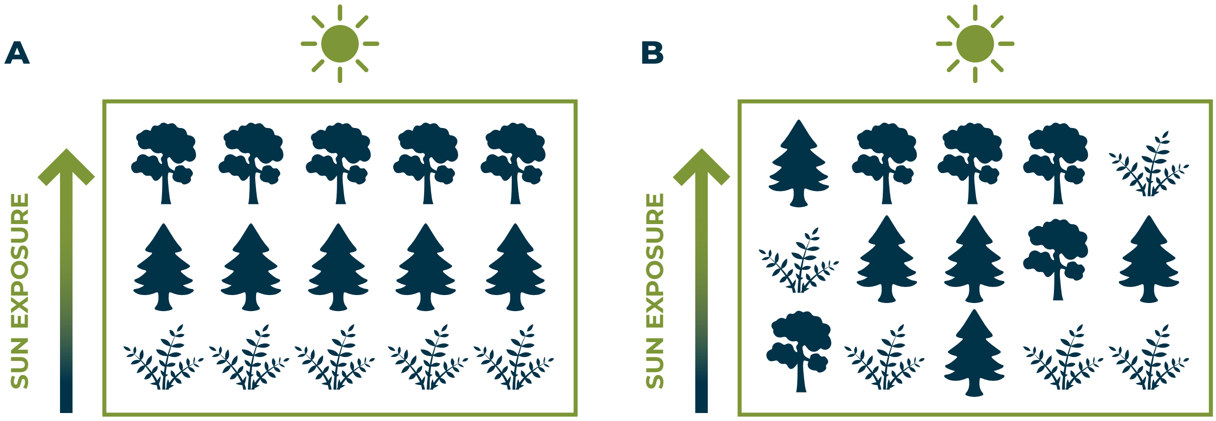


Figure 4.5 Randomisation of treatments is critical to minimise confounding from known and unknown environmental variation. (A) Non-random treatments results in different sun exposure for the three species, while (B) randomisation of the treatments distributes the environmental variation between species.

Randomisation can be achieved by random number generators, rolling a dice, drawing numbers from a hat, or tossing a coin, where the number of options is determined by the number of treatment combinations. There are freely available tools that can assist in randomising an experiment including spreadsheet software (e.g. Excel), freely available software packages (e.g. R randomize function), phone apps, and websites (http://www.randomization.com/). Randomisation of small samples can still lead to some bias in treatment allocation (e.g. control plots mostly at one side of the site), but this is less of an issue with large sample sizes. Ultimately, applying randomisation across an experimental site provides balanced arrangements that lessen issues associated with confounding effects (Fig. 4.5).

2. REPLICATION

To provide an estimate of experimental error.

Individual plants or plots may fail for many reasons, some of which will not necessarily be obvious. Variation in the success and failure of individual plants or plots might be affected, for example, by variation in treatment application (e.g. poor fire coverage), seed quality, nursery practices, site history, site preparation, establishment, and maintenance. Careful application of experimental treatments, randomisation (as discussed above) and reduction of variability that is not of interest in the experiment (discussed later) can help to address experimental error; however, it is never possible to completely remove all background variation, especially in experiments in the field. Therefore, having just one occurrence of a particular treatment will not provide a clear answer about the success of that treatment. Replicating treatments within the experiment is essential to provide robust, statistically significant, results.

Replication can be applied at different hierarchical levels from individual plants to plots. Where relevant, measuring multiple plants or sub-plots within plots provides an estimate of the variability in the attribute being measured (e.g. plant growth or weed abundance). As a result, increasing the number of plants or sub-plots measured will provide a better estimate of the plot attribute (Fig. 4.6). However, the most important level of replication in an experiment is at the plot level, as it determines the statistical power of the experiment (i.e. the ability to detect significant results). In practice there is a maximum number of plants that can be accommodated at any experimental site, where the plot size (i.e. plants within plots) and the number of plots present a design trade-off (Fig. 4.6). For example, imagine sampling two provenances (i.e. a local and non-local provenance) and planting 200 trees of each provenance to test if the local has the best performance (e.g. growth, survival) at the trial site. One could implement a few (5) large plots containing 20 trees of each provenance in each plot, or many (20) small plots with five trees from each provenance. While the actual design depends on the specific question, for practical reasons here we would advocate 10 plots each of 10 trees of each provenance to estimate performance in provenance trials to maximise plot number while decreasing variability among plots (Fig. 4.6). The amount of replication required within a site depends upon the variation within and among the treatments, as well as the effect size (i.e. difference between the treatments) you want to detect. High levels of replication are required to detect small differences (or effect sizes) among treatments, but if small differences are not considered ecologically or economically meaningful, such extensive replication may not be justified.

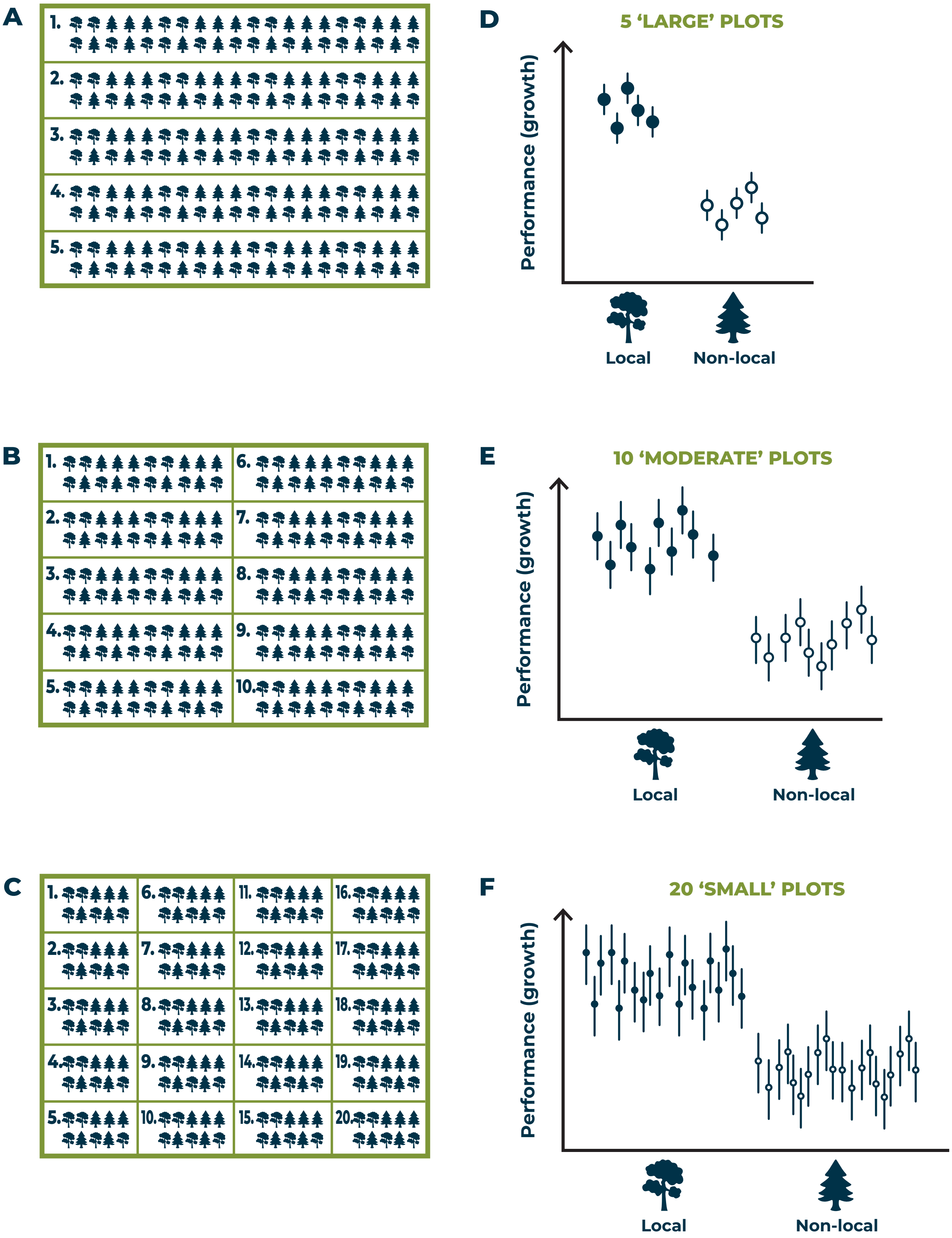


Figure 4.6 The effect of different plot sizes on estimates of performance for two treatments (local, non-local). (A) 5 plots with 20 trees, (B) 10 plots with 10 trees, and (C) 20 plots with 5 trees per plot for each treatment with corresponding average +/- standard error estimates of performance for each plot (panels D, E, and F, respectively). Plots of trees are shown with borders. Circles are mean values (native filled, non-native open), and the vertical bars are standard errors (estimate of variance among trees within plots).

Rules of thumb – A minimum of 20 plots or experimental units within an experiment is desirable to give enough power to detect moderate treatment effects. At least four replicates per treatment within a site are recommended if the experiment does not have additional site replication (Williams & Matheson 2002). Additional replicates within sites and the inclusion of multiple sites will provide greater statistical power. Multiple experimental sites will increase the capacity to generalise the findings beyond a single site. Provenance testing, requires greater levels of replication to capture genetic diversity and estimate plant trait and performance. Traditionally, four replicate plots with 25 plants (i.e. 100 plants) have been used to elucidate trait differences between provenances.

Replicated blocks within sites – Creating replicated blocks that each contain all treatment combinations within the experimental site provides greater capacity to account for spatial and environmental variation in the statistical analysis (see Blocking below). Blocks should be established across known environmental gradients or attributes (e.g. soil type), and designed to minimise the variation within each block. Blocks need to be large enough to fit all treatments; treatments are randomised within each block to distribute any remaining or unknown environmental variation. This will enable direct comparisons among treatments within blocks and the capacity to account for the differences among blocks in the statistical analysis.

Replication across sites – Blocks can be distributed across sites to replicate the experiment. The advantages of 'across-site' replication is firstly that the overall power of the experiment (i.e. the ability to detect statistically significant results) may increase due to the extra replication. In some cases, the desired number of replicated blocks may not fit within a single site, and several adjacent sites may be used to enhance the overall replication of the experiment. This has the added benefit of distributing the risk of failure, if one site gets flooded or burnt then the experiment may still be viable. Secondly, 'across-site' replication has the advantage that the results can be generalised to a wider range of conditions. For example, 'genotype-by-environment interactions' can be investigated with the same genotypes (i.e. species and/or provenances) planted across multiple environments (i.e. experimental sites) in a fully factorial design.

By establishing experiments across sites with different climatic conditions, the performance of different treatments can be tested to inform their interactions with climate and other site related factors. This is best achieved with replication within each site as well as across sites, noting that results can be complicated by the fact that multiple factors (e.g. climate, soil, disturbance, biotic interactions) may vary across sites. Such experiments are, nonetheless, powerful in determining the relative success of treatments (e.g. fire regimes, exotic species control or mixed species and/or provenances) under different climatic environments. For provenance plantings in particular, they enable identification of climate matched genotype(s) for maximising planting success, quantifying change in success with increasing geographic and climatic distances.

3. BLOCKING

To minimise the effects of site variability that is unrelated to treatment effects and to increase chances of detecting meaningful differences between treatments.

Accounting for non-treatment related variability between experimental units increases the chance of detecting a treatment effect. There are many ways to minimise variability, including:

- Selecting experimental sites that are as uniform as possible. It is recommended that sites with obvious environmental heterogeneity are avoided. In some instances, it may be possible to select the most uniform areas within a site, avoiding unsuitable patches and avoiding non-characteristic areas (e.g. near trees, watercourses, scalds, erosion gullies, uncharacteristic soils or nutrient run-on zones).
- Accounting for systematic site variation (e.g. a gradient up a slope or away from a watercourse) by applying treatments within **blocks** arranged across the major gradients (see Fig. 4.5b). Given most sites are environmentally variable, blocking groups of treatments where blocks containing at least one experimental unit of each treatment, is recommended. The variance among blocks can be accounted for in the statistical analysis, which can provide greater power in detecting treatment effects.
- Ensuring consistent management of non-treatment factors across all plots, or where that is not feasible, ensuring consistent management within blocks. For example, in a burning experiment, burning all plots assigned a burn treatment on the same day is best; if that is not feasible, burning all relevant plots within a block on the same day is optimal.
- Using buffer zones around experimental plots to minimise **edge effects**. For example, vegetation on the edge of large plots in bare fields can experience greater resources, light, and wind compared to plants in the centre of plots. Additionally, having buffer plants between replicate blocks is another option to avoid unintended interactions among the replicated treatments. Planting additional border plants or treating an area larger than the experimental plot are ways to create buffer zones.

Experiments can also be built into these buffer plantings, so it is not wasted investments. See Caste Study 4 for another example.

- Avoiding subsequent biases from different observers and monitoring times by distributing the observations among all the treatments. If multiple observers undertake measurements, ensure each observer samples some of each treatment (e.g., observer 1 assess blocks 1, 3, and 5, whilst observer 2 assess blocks 2, 4, and 6). Similarly, if monitoring events for the entire site cannot be complete at single time such that parts of the site will be monitored at different times, then at each time a subsample of the replicates for all treatments will need to be observed. Assigning an observer to a block containing all the treatments is a good approach because observer bias will be confounded with the block factor in the analysis (in the same way as planting date mentioned above).
- If a site is very heterogeneous then it is better to include more plot replicates, each of a smaller size (e.g. plots with fewer plants). While five plot replicates of 20 plants of each treatment might work well on a desirable, flat, even site, it may be better to have 10 plot replicates each of 10 plants (if not 20 plots of 5 plants) on a less-desirable, sloping site with a known soil gradient (see Fig. 4.6).

COMMON DESIGN OPTIONS

Once you have decided the main factors and treatment combinations that are going to be tested in the experiment you will then need to decide how to design the layout of your experiment, taking into account randomisation, replication and blocking. The following example designs are provided to help you to decide how to lay out replicates of your treatment combinations in the field.

COMPLETELY RANDOM DESIGN

A completely randomised design involves random allocation of treatments to experimental units at the site (Fig. 4.7 left). It is one of the simplest experimental designs. However, this design is less powerful than other, more complex designs in terms of capacity to account for variation within a site and is often best suited to sites that are relatively uniform.

RANDOMISED COMPLETE BLOCK DESIGN

Often, the experimental site will have known or subtle environmental heterogeneity present, for example, a visible slope, or variation in subsoil that is not detectable without deep excavation and soil analysis. It is best practice to assume there may be substantial within-site variation, and to adopt a randomised complete block design (Fig. 4.7 right). This planting design breaks the site up into contiguous or non-contiguous divisions called blocks (block replicates). This approach helps to account for any environmental variation within the experimental site. Importantly, each treatment must be present in each block (i.e. each block contains a complete set of treatments). Blocks should be arranged across the most obvious gradient at a site (e.g. from upper to lower slope, so that a replicate of each treatment occurs on each part of the slope). It is worth noting that randomised complete block designs are no more labour intensive to establish than the completely random designs and are often easier to keep track of due to the more systematic design. Hence randomised complete block is typically preferable for field experiments. Case Study 4 and 5 describe examples of embedded restoration experiments with a randomised complete block design.

SPLIT-PLOT DESIGN

Split-plot designs are a special case of the randomised complete block design. These designs are often applied when there is a need to impose one or more treatments at broader scales than other treatments. For example, management treatments, such as slashing, burning, or irrigation, often need to be applied at larger scales than other treatments (Fig. 4.8).

Split-plot designs are commonly applied in agriculture, mining restoration, vegetation management and forestry. For example, they can be used to assess the effect of irrigation treatments on different seedlots, or the effects of burning with or without exclosure from livestock grazing (Fig. 4.8). Split-plot designs come with specific terminology that describes the various stratum at which treatments are applied, and which have different errors associated with them in the analysis. In an experiment with irrigation and seedlot treatments, seedlots could be at the lowest stratum, termed the ‘sub-plot’ or ‘split-plot’, and the broad-scale irrigation treatment applied at the higher stratum, termed the ‘main plot’ (or ‘whole plot’). The main plots within blocks represent the replicates of the broader-scale treatment, and the sub-plots represent the replicates of the finer-scale treatments (Fig. 4.8). In an ecological restoration or forestry context, split-plot designs could be employed to optimise direct seeding applications (e.g. see Pinkard et al. 2017) by testing various treatments (e.g. wetting agents, polymer film, fertilisation, inoculation) at the sub-plot level and applying a broad-scale treatment at the main-plot level (e.g. scalping, insecticide, or herbicide). In mine site restoration, where large machinery is commonly employed for soil establishment or ripping planting lines, larger machine-created treatments may be installed as main plots, and smaller scale treatments (e.g. sowing time, species, provenance) may be installed as sub-plots in a split-plot design (Commander et al. 2013).

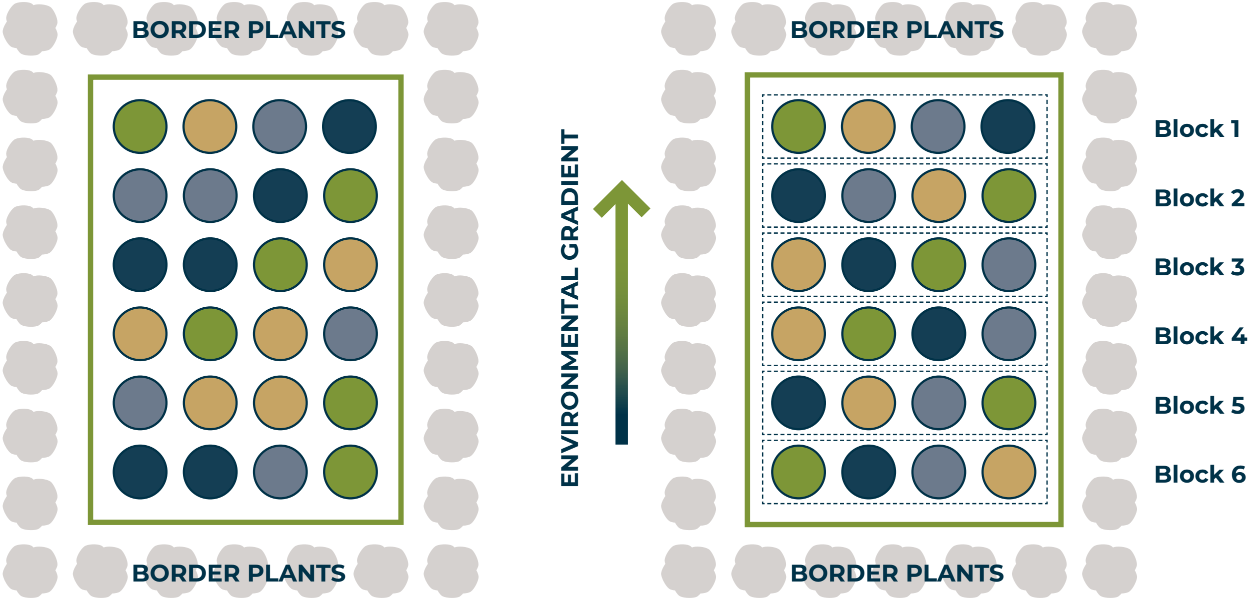


Figure 4.7 Completely randomised (left) and randomised complete block (right) experimental designs where each colour represents a plot with one of the four treatments (e.g. four seed provenances or four nutrient levels), with six replicate plots of each treatment. Randomised complete block is established at a site with an environmental gradient (e.g. soil water availability). Border plants in the grey area surrounding the experiment can provide a buffer around the edges. The designs depicted here can accommodate various plot sizes. Each circle can be representative of one plant (e.g. a single-plant plot), a group of plants, or a native vegetation patch treated in a particular way.

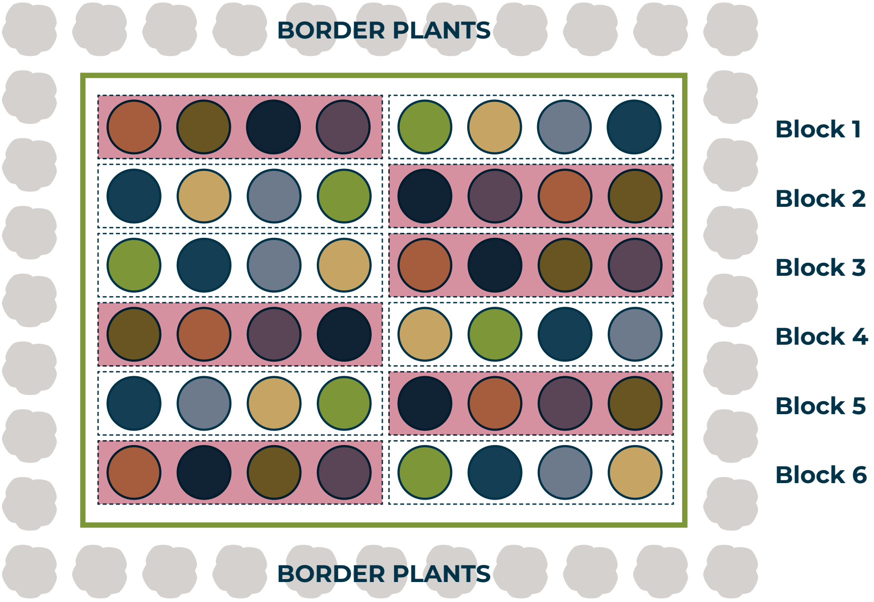


Figure 4.8 Split plot design with two factors fully factorially combined (fencing and burnt treatments). Each circle represents a 'sub-plot' randomly assigned to one of the four fencing treatments, given different colours (beige = open, green = low fence, light blue = wide mesh high fence, dark blue = fine mesh high fence). The red transparent rectangle represents the burnt treatment, that has been randomly assigned to 'whole plots' (in this case half of the block), for comparison with the unburnt control in grey. Border zone in the grey area surrounding the experimental site.

INCOMPLETE BLOCK DESIGN

We strongly advocate using balanced designs, particularly the robust randomised complete block design as already discussed. However, it is commonly the case that some treatments fail (e.g. Case Study 4), or it is not possible to apply all treatments to all blocks. For example, there might be insufficient plant material of some target species to establish enough replicate blocks of all treatments. Even when established as complete blocks with replication of all treatments, parts of the experiment might be damaged by stock intrusion, pest animal browsing, or drought events. The good news is that it is possible to design and analyse experiments when all or some treatments could not be established and/or measured in some blocks. In both cases, we would advise seeking advice from a statistician as the analysis is complicated and not easy to interpret.

In some cases, especially large trials involving numerous treatments, it will not be possible to fit all of the treatments into the homogeneous area defined as a block. There are a number of common situations where fine-scale spatial change in the site environment will be likely, such as moisture and soil texture gradients up a slope, nutrient gradients, and salinity levels in discharge areas. In such cases, an incomplete block design may be considered where each block contains only a subset of the treatments, but may better account for fine-scale variation. The designs are less straightforward to analyse for non-specialists and can be difficult to interpret. In many cases it will be possible to design the trial as a resolvable incomplete block design , i.e. one that still contains complete block replicates but has smaller incomplete blocks embedded within these. Such a design could be analysed as a randomised complete block design using straightforward analytics, however that may be suboptimum as finer-scale differences between the incomplete blocks within each complete block have not been accounted for. A proper incomplete block design analysis will account for these finer-scale differences and generally be a more efficient analysis for determining treatment differences. An example of a resolvable incomplete block design, with the position of the incomplete block aligned perpendicular to the direction of the trend of the environmental variation is shown in Fig. 4.9. Again, it is best to seek the advice of a statistician in designing trials using an incomplete block design. This is because selecting the size and arrangement of the blocks requires careful consideration, and it is desirable to use specialised software to assign the treatments to the incomplete block design to optimise the design and so improve capacity to interpret the analysis.

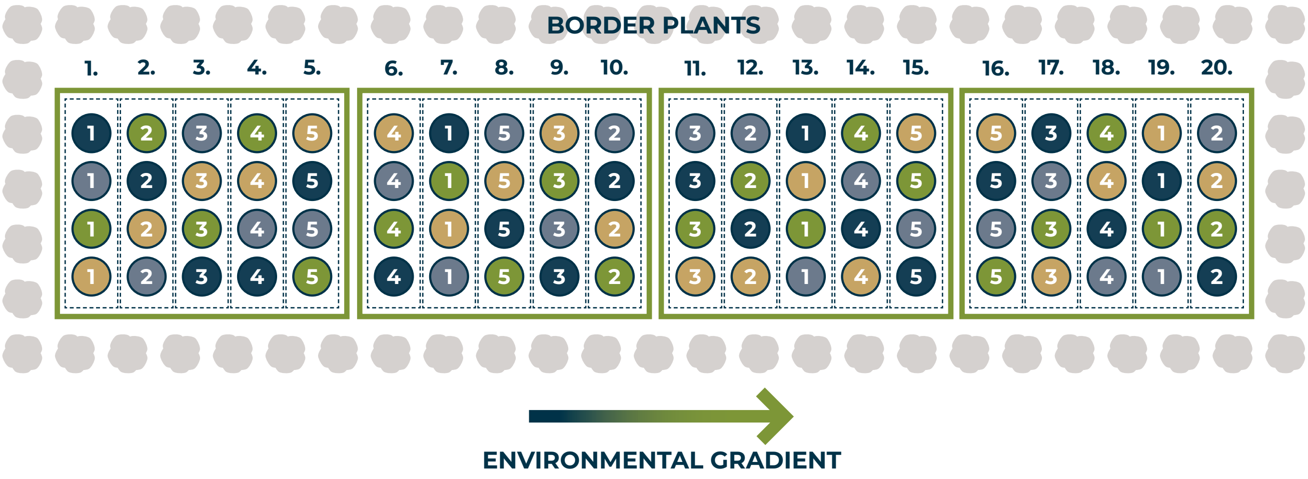


Figure 4.9 Incomplete block design with plants from five families (indicated by numbers 1–5) from each of four provenances (indicated by colours) of a species planted in 20 seedlots (long black dotted rectangles numbered 1–20) arranged in four blocks (large green rectangles) distributed across a strong environmental gradient. Small block sizes are required to avoid environmental heterogeneity within blocks. The 20 different seedlots are not able to fit inside a single block, resulting in each block containing a single family from each provenance. The design includes four replicates of each family.

DIVERSITY AND COMPLEXITY EXPERIMENTS

Approaches to restoring natural vegetation using plantings can vary from simplistic (e.g. single species or management option) to complex installations, the latter endeavouring to re-establish structurally complex communities at multiple strata (e.g. ground, mid-canopy and over storey species) for ecosystem function. Designs can also vary greatly from simple linear rows to complex blocking designs (see previous pages).

Importantly, the experimental designs described here can accommodate these different approaches. For example, an experiment might compare a smaller suite of target species within a more species rich planting. In this case, the experimental design would maintain all other aspects of the planting, such as plot size, planting density, and method of establishment to ensure any potential differences could be ascribed to the treatment factor 'species diversity'. It is important to consider the potential for above and below ground competition in plant diversity experiments; especially where understanding the plant performance of individual species is a key objective. However, even when key objectives are to understand assemblage, function, and resilience at the plot level, consideration should be given to standardising planting densities of different functional groups and plant sizes.

SITE SHAPE, SIZE, AND SURROUNDING LANDSCAPE MATRIX

The shape and size of experiments can vary greatly and are dependent on the questions being addressed. Indeed, some management options and outcomes can be tested at very small scales (e.g. weed control measures to enhance native forb species) whereas others, such as restoring native fauna through control of feral predators, may need to involve whole farms or landscapes. In embedded experiments examining outcomes for particular species or provenances, plants can be planted in long rows, or randomly planted across a landscape, or in patches or strips along non-linear and linear rip-lines.

Another important consideration regarding the shape and size of the experimental plot is the potential for edge effects, i.e. effects occurring at the boundaries of the plots associated with differing adjacent abiotic and biotic environments. Edges may be more vulnerable to weed invasions, for example, or plants at edges of plots in bare fields may have more resources to grow than plants in the middle of a patch. Edge effects can be minimised by selecting more compact shapes (e.g. a square plot will be less affected by edge effects than a long thin plot) or by maintaining or planting a 'buffer' around experimental plots. A planted buffer could comprise species that, for example, show a faster growth habit and provide early protection of the main experiment, or could comprise the same species/provenances being tested so that similar amounts of water and nutrients are available to all experimental plants. Alternatively, linear strips (1–2 plant width) in a uniform (open) landscape matrix may not require border plantings as all plants are on the edge with similar resources, light, and wind. This is common for plantings along road verges and fence lines around paddocks. Keep in mind though, that linear strips typically cross different soil and environmental conditions, therefore more compact or square plantings are preferred.

There are both statistical and practical considerations when choosing plot sizes (for further information see, for example, Williams et al. (2002)). Some key points to consider when choosing plot sizes include:

- Plots need to be large enough to demonstrate the stated outcomes — for survival of small seedlings, this may be a small area, whereas for characterisation of ecological resilience in whole plant communities or habitat qualities for vertebrates, plots will need to be much larger.
- Careful consideration should be given to the selection of plot sizes that allow for the treatments of interest. For example, in a species or provenance trial, they should accommodate the number of plants and plant spacing needed for experimental purposes (i.e. sufficient distances between rows and plants within rows), and treatments such as burning may need larger areas for application.

The recovery of species assemblages and ecosystem functions in a restored site, and thus its overall contribution to the conservation of biodiversity, can depend on larger scale factors associated with the composition of the surrounding landscape (Fig. 4.10). Landscape factors could be particularly important in determining the potential for cross-pollination with genotypes from outside sources, the ease with which native plants and animals can recolonise, and the vulnerability to weed invasion.

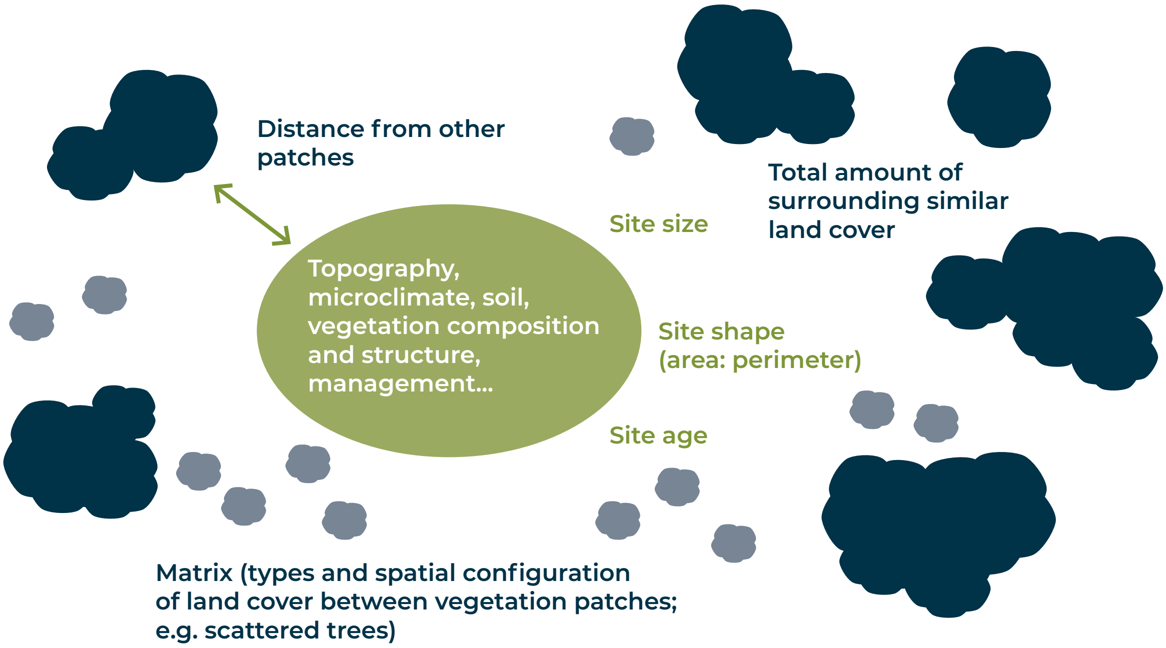


Figure 4.10 A simplified representation of a landscape around an experimental site (green oval) surrounded by other natural and semi-natural land cover (light and dark blue colours). Site biodiversity can potentially be affected by a range of variables at different spatial scales, from characteristics within the patch (white text), the size, shape and age of the patch (green text) and characteristics of the surrounding landscape (blue text) such as how far the new patch is from other patches of similar vegetation, the total amount of similar vegetation in the surrounding landscape, and the features of the 'matrix' between patches.

DESIGNS COMPARING SPECIES AND PROVENANCES

The goal of species and provenance trials is typically to identify the best species and provenances for ecological restoration at a given site by testing performance of treatment groups against the control treatment (which is often locally-sourced seed, e.g. Camarretta et al. 2020). For example, a species trial may assess which species is best suited to a particular environment, whereas a provenance trial may compare the performance of provenances of the same species originating from different climates against the local provenance. If trials are carried out across a number of sites, they will collectively provide a means to test how locally-adapted species and provenances are in nature and how far provenances can be translocated across the landscape. When conducting experiments that compare the performance of species or provenances, the most robust method is constructing a fully reciprocal design in which the local species or provenance from one site is tested in its local and non-local (foreign) environment against different species and provenances in their local and non-local environments.

Traditionally, species and provenance trials have been established with plants grown in nursery tubes (i.e. tube stock), mostly owing to the logistic efficiencies gained when applying treatments. Nonetheless, direct seeding is emerging as an alternative planting strategy to establish large-scale revegetation projects. With some consideration, direct seeding can be applied to establish species and provenance trials. Different species or provenances can be direct-seeded in adjacent rows, which should be randomly assigned within replicated blocks across the planting site. It may also be possible to compare different species or provenance mixes, rather than individual species, using the direct seeding approach. While different provenance mixes could be compared as treatments applied with direct seeding, it would not be possible to track the contribution of individual provenances without employing molecular approaches. The choice between using tube stock or direct seeding will depend on the questions. If, in the case above, the questions related to investigating adaptive differences among provenances of a species over a fairly small trial area, then the use of tube stock may be preferable over direct seeding as it would be difficult to apply the treatments accurately. For experiments that use direct seeding, we recommend either a randomised complete block design (Fig. 4.7b) with the application of a limited number of treatment combinations. However, if the question was to test the optimal mix of species or provenances to re-establish structural complexity for dependent organisms, then direct seeding would be a viable option that provides the capacity to easily vary seed and species composition.

DESIGNS COMPARING SPECIES DIVERSITY

Ecological restoration and management aims to establish diverse and functional ecosystems that are resistant and resilient to external pressures, including weeds, pests, disease and climate change. The level of species and genetic diversity required to establish and maintain functioning ecosystems remains largely unknown, however insights gained from the ecological literature suggest that many species are needed to maintain multiple functions (Isbell et al. 2018; Eisenhauer et al. 2018; Barry et al. 2020). Experiments in restoration and management testing the relationship between diversity and function are limited.

Diversity experiments can be complex given the number of interacting factors at play. There is a hierarchy of complexity in combining different trophic levels, strata, functional groups, species, provenances, and genotypes. It is therefore important to have clear questions and objectives before undertaking diversity experiments. In this case, diversity is the main factor under investigation, which can be manipulated at the plot level applying different diversity treatments (Fig. 4.11). For example, consider a grassland diversity experiment comparing plots with a monoculture of a grass species and plots with a mix of four different grass species. In this example, the monoculture plots would need to be established for each of the four grass species to account for the species differences before a valid comparison can be made with the four species mix (5 plot types: sp1, sp2, sp3, sp4, sp1+sp2+sp3+sp4). Rather than a monoculture versus four species, it might also be of interest to explore a gradient of species diversity (e.g. 1, 2, and 4 species per plot).

However, the number of different species combinations becomes very large and can quickly become too difficult to handle (4 single species plots + 6 two species plots, 1 four species plot; Fig. 4.11). Some of the species may be more successful in establishment and growth outcompeting other slow growing subdominant species. The plot size needs to be carefully considered with an understanding of the spatial scale of interactions likely to occur among species. As greater complexity is added to diversity experiments, for example different plant functional groups (i.e. grass, herb, forb, legume species) and strata (i.e. ground, shrub, tree), more thought is needed to address the likely functional consequences. For example, the addition of a legume species to the grassland diversity experiment would enhance nitrogen fixation to plots with the legume present, which would be expected to stimulate growth of the grass species. Here it would be best to include legume as

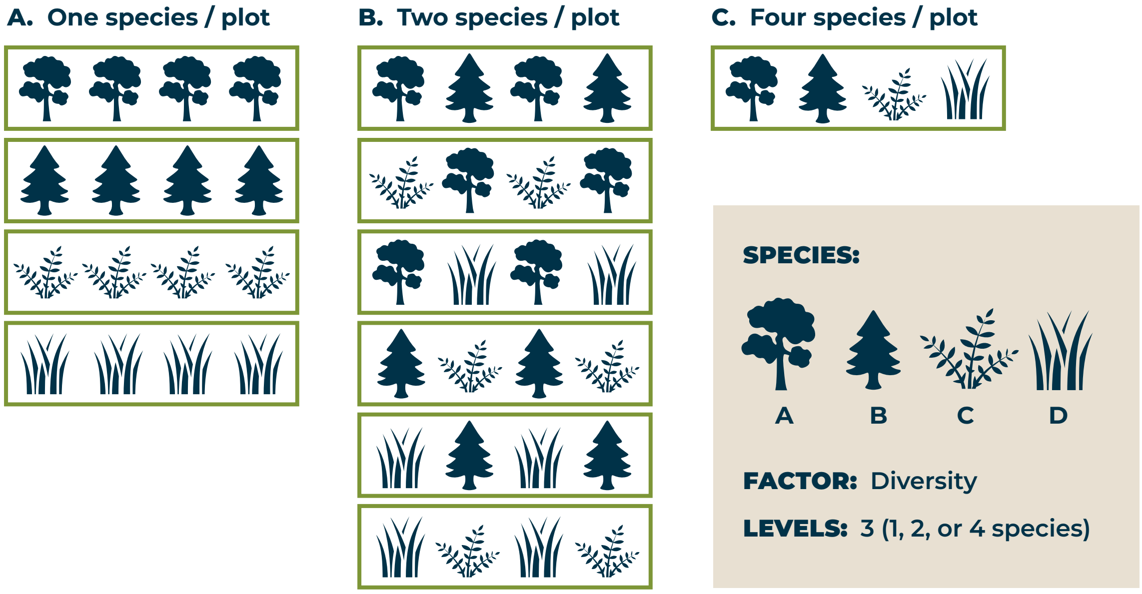


Figure 4.11 Experimental designs to test different levels of species diversity, while controlling for other factors including plant density and individual species contributions. (A) single species plots for each of the species; (B) two species plots with all species combinations; and (C) four species plots containing all species testing three different levels of species diversity.

a separate factor (+/- legume); however this would double the treatment combinations. In many cases it is better to keep additional factors constant (e.g. functional and structural composition) and focus on the main factor of interest, such as species diversity. It is important to note that experiments can be embedded within a larger restoration and management activities.

One of the better case studies is the Ridgefield Experiment in Western Australia (Perring et al. 2012). This experiment was established to evaluate two core questions: how different species assemblages influence the provisioning of ecosystem services and functions, and the maintenance of these ecosystem provisions under a modified and changing environment. These questions were addressed by designing an experiment with six treatment levels that compared the provisions of a monoculture planting, and plantings comprising mixtures of two, four, and eight woody native species, with an unplanted control. Plots were blocked to account for soil and aspect effects, with individual woody species randomly stratified within plots (see Perring et al. 2012 for further details on establishment technique). The experiment is a component of globally distributed network of trials (Paquette et al. 2018) that will enable generalisations about links between diversity and function.

Another example comes from the 'Ecology' trials established in Tasmania (Bailey et al. 2013; Camarretta et al. 2020). This experiment was established to determine the influence of genetics on the provisioning of ecosystem services, such as carbon sequestration and storage. Seed from two foundation eucalypt tree species was collected from 10 paired provenances (one of which was the local provenances), with six mothers sampled within each provenance kept as single tree seedlots to maintain the pedigree information. A total of 14 treatment plots, comprising monoculture, paired eucalypt, mixed eucalypt and other trees, eucalypt and understory, grass, and unplanted control, were blocked and replicated up to eight times at each of the three planting sites.

As such the Ridgefield Experiment in WA and the Ecology trials in TAS provide examples demonstrating the core principles of randomisation, replication and reduced variance in an experimental design to test core questions in ecology with clear applied outcomes for restoration.

DESIGNS COMPARING MANAGEMENT OPTIONS

Restoration and management of natural ecosystems often requires testing different active management options to develop the strategy to best sustain biodiversity and ecosystem function. While plantings are an important component of restoration of degraded landscapes, management of pests, weeds, disease, erosion and fire, for example, could be more appropriate in natural areas. The same principles of experimental design are important for testing different management options. In an adaptive management framework (Fig. 1.1), the current management practice acts as the control treatment to be compared to the new management option. The plot size may need to be large to enable the effective implementation of some management options (e.g. fire, fox baiting). Other treatments, such as weeding or fencing, can be applied to smaller plots. In combination, treatments applied at different scales could be implemented as a split-plot design (Fig. 4.8). As with all experiments it is critical to replicate, randomise and minimize local variability. In practice, it can be difficult to obtain more than the minimum three comparable replicate plots for large-scale implementation within regional parks and reserves. The assessment of biodiversity and ecosystem function could be undertaken in sub-plots to obtain an average for larger plots; however it should be noted that the sub-plots are not independent and considered pseudo-replicates in statistical analyses.

KEEPING TRACK OF THE DESIGN

In the field, plants and/or plots need to be able to be easily relocated to keep track of the treatments during implementation and monitoring of the experiment. It is important to draw a site map and label all of the plots, or draw on top of an aerial photograph with plots relative to a permanent landscape marker (e.g. building, rock formation). Plots should be mapped with a GPS recording the exact position the corner of each plot and marked on the ground with a permanent metal fence post. For more complex or large-scale experiments it is valuable to map and mark sub-plots or rows. The exact layout of individual treatments and plants should be developed into the site map, which should be saved and stored for monitoring.

Labelling plots and plants is important to confirm the position and identity of the treatments and replicates. Some plot treatments may be obvious, for instance ripping, whereas others may not be as noticeable, like fertiliser application. Treatments which may be obvious at implementation may not be visible one or ten years later. Replicates also need to be labelled so that, during monitoring, the same plants or plots can be compared over time. Hence, long lasting labelling of every aspect of the experiment is crucial. Metal tags are useful in fire-prone areas. Metal pins can be used to mark the position of plants, so that they can be relocated if they are hard to find if vegetation grows up around them, they are heavily grazed or if they die.

Labels can be as simple as different colours and numbers or more detailed descriptions of the treatments, position and replication. The simple labels will be based on a code that needs to be easily interpreted and embedded into the site map and details of the experiment. A code may be needed as sometimes all the treatment information, such as species name, replicate, pre or post-treatment may not fit on a label. It is also important to develop a code with some redundancy (e.g. unique plant ID and block number and position), to ensure mistakes in recording the code are minimised or able to be corrected. Make sure the code is written down and kept safe so that the person monitoring can decipher the code. More information on labelling plants can be found in Monks et al (2018).

DESIGN CHECKLIST

Similarly to planning, checklists can be extremely helpful when designing experiments to help ensure all aspects of the experiment have been considered. Below (Table 4.1) is a series of suggestions to develop checklists that can be used when designing an embedded field experiment.

Table 4.1 Suggestions for developing checklists to be utilised when designing embedded field experiments

Question	• What is the key question?
Treatments	• What are the treatments? • What are the factors and their levels? • What is the treatment design (e.g. single factor with two levels, single factor with multiple levels, two factors)?
Variables	• What will the response variables be? i.e. Which of the properties affected by the treatments will be measured?
Randomisation	• How will the treatments be randomised?
Replication	• What are the experimental units (e.g. individual plants, plots)? • How many replicates will there be? • How many plots and/or sites?
Variability	• How will local variability be minimised?
Experimental layout	• Which experimental layout will be used (e.g. completely random design, randomised block design, split plot design, incomplete block)?
Keeping track	• How will the design be recorded, both at the site and in the record keeping system?
Cost	• How much will the experiment cost to implement (plant purchase, travel, staff time)?

LAST WORD

Green's ten principles of experimental design (modified from Green, 1979).

1. State your question clearly and concisely.
2. Testing an idea necessarily includes a control.
3. Survey the experimental site to identify environmental variation.
4. Blocking is appropriate to address spatial or temporal heterogeneity.
5. Each block should contain all treatments, which need to be randomised.
6. Replication of blocks is essential.
7. Verify your sampling method is measuring what you think it is.
8. The size of the experimental unit should reflect the size, density, and distribution of the organism you are sampling.
9. Test the assumptions of the statistical tests applied to the data.
10. Stick by your result even if it is unexpected.

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Chapter 5.
MONITORING

Martin Breed, David Carr, Bob Godfree, Nola Hancock, Peter A Harrison, Barry Heydenrych, Sacha Jellinek, Justin Jonson, A Jasmyn J Lynch, Nicholas Macgregor, Rachel Standish, Kathryn Williams

SUMMARY

- *Targeted monitoring gathers specific data pertaining to the designed experiment.*
- *Surveillance monitoring assesses general aspects of the trial over time, potentially answering longer-term questions outside of the trial's designed purpose.*
- *It is important to carefully consider and plan what will be monitored, the timeframes for data gathering and how the monitoring will be resourced.*
- *Establishing good data gathering and record keeping practices is essential.*
- *Careful consideration of what baseline data to gather is essential, not only for the designed experiment, but to ensure added value is captured from long-term surveillance.*

WHAT IS MONITORING?

Monitoring is the systematic collection of data or information over time, often at regular intervals, but also opportunistically. In the context of ecological restoration experiments, it can have different motivations and uses. There is a difference between targeted monitoring, which focuses on the specific questions the experiment was established to investigate, and surveillance monitoring, which is designed to detect change over time and involves gathering long-term data on performance of single or multiple trials to improve overall restoration success (Preece et al. 2020). Monitoring therefore provides the data for analysis and interpretation of the experimental results. It also provides information to determine whether a restoration project is tracking towards successful completion, which may be part of statutory or regulatory requirements, and underpins management decisions required to keep the project on track. Establishing a good monitoring plan incorporating baseline data capture not only sets up an experiment to answer the questions for which it was originally designed, but also provides the data foundations that will allow the trial to be adapted, or additional trials established, to answer future questions.

Good monitoring requires prior planning to address a complex set of issues, some of which are detailed below. They include the design of monitoring, deciding what and how to monitor, data collection methods and other practical considerations. However, it must be emphasised that monitoring cannot be planned and considered in isolation; rather, considerations of monitoring design must align with the questions to be investigated through the experiment and the planned approach for data analysis. It is best to develop the monitoring program at the same time as the experimental design, to ensure that you know what to measure, how to measure it and how often to measure, to ensure that the monitoring program will produce the information required and that it is resourced sufficiently.

It is often the case that targeted monitoring of those aspects of the experiment for which it was initially designed are well planned, but establishing a good, long-term surveillance monitoring strategy is neglected – often because it is not clear how this might be funded and implemented over years and decades. However, failure to establish good baseline data for measures of interest may limit the usefulness of the experiment in future. For example, failure to monitor and quantify levels of insect infestation early in the life of a trial, initially designed to assess herbicide effectiveness, might later compromise the opportunity to study the effect of leaf browsing on survival. While it is not possible to monitor everything, it is worthwhile considering what basic aspects of a trial might be worth measuring in addition to the target traits and responses.

MONITORING DESIGN

A monitoring programme should not only be designed against the set of questions that the experiment specifically aims to address (see Chapters 3 and 4) but should also aim to keep track of some basic, common aspects of the performance of the experiment, such as monitoring of establishment success, the impact of management treatments and survival and fitness traits – all aspects that underpin the success of revegetation programmes. There is a range of ecological and social outcomes that might be sought from a restoration project that could be investigated experimentally. Thus, there is a wide range of data that could be specifically targeted for collection, determined by the experimental goals.

Ecological monitoring of restoration experiments could focus on collecting data, often at specified intervals post experimental establishment, on any of the following: early stages of plant growth and survival; plant or animal reproduction and recruitment/colonisation; ecological community attributes such as diversity or resilience to disturbance; and ecosystem processes such as soil water infiltration or carbon sequestration. Monitoring of social outcomes of experiments could aim to measure the benefits of collaboration among practitioners, scientists and policy-makers, the barriers to success of network experiments, the benefits for human health and well-being, or implications of how society views and perceives the new plantings.

RECORDING INPUTS

Targeted monitoring begins at the inception of an experiment, and inputs and decision-making processes should be documented. Inputs or variables to record will depend on the type of experiment, but may include details of the site, experimental design and any plantings that are part of the experiment. More examples for each of these are given on the following pages.

Details of experimental sites:

- Site location, scale and principal contacts (e.g. land holder, practitioner, researcher);
- The general geographic coordinates and datum of the site;
- GoogleEarth or similar satellite imagery from the most recent and prior captures;
- Preparation methods (e.g. weed and pest control, scraping);
- Topography (e.g. riparian area, hillside, gully) and aspect of site;
- Area, shape and perimeter of the site, and perimeter:area ratio of the site (see 'Spatial data' in Chapter 6);
- Amount of remnant native vegetation around the site (e.g. within 500m, 1km, 10km radius) and distance to nearest patch of natural vegetation;
- Hydrological regimes of the sites;
- Types of weeds and pest animals present and their densities and control measures;
- Site land use history, including historical clearing, past grazing regimes, past mining activities, recent fertiliser and herbicide use; and
- Site preparation, if any (e.g. landforming, scalping, ripping, clearing, topsoil application).

Details of experimental design:

- Date of treatment applications;
- Method of treatment application (e.g. type and method of herbicide application, planting type);
- Geographic source (provenance) of any seed or seedlings included in treatments.
- Soil moisture at time of treatment application;
- Weather history at point of treatment application (e.g. leading up to plantings or experimental burns);
- Other treatment details (e.g. fire intensity, quality of seedlings, type of fertiliser or herbicide); and
- Detailed diagram of spatial layout of the experiment, clearly identifying treatments applied to each plot and experimental hardware such as pegs, tags, fixed sample points etc.

Details of plantings (for studies involving plantings):

- Seed viability and germination, health and size of seedlings at planting, and variation among seedlots or species;
- Planting or seeding equipment used and settings on equipment (depth, spacing for direct seeding);
- Any watering undertaken during or after planting;
- If any wetting agents or similar were used during planting, or if any pest animal deterrents were used on the plants;
- If the plants were guarded, and what guards were used; and
- Who planted the site (contractors or volunteers) and how well planting was undertaken.

WHAT AND HOW TO MONITOR?

Having identified the research questions to answer, and before the experiment begins, design of the monitoring strategy should consider the following:

- **Response variables** — Which variables provide the best and most practical measures of the ecological and/or social outcomes sought?
- **Predictor (or explanatory) variables** — Which variables might it be important to measure to help explain variation in the response variables? (e.g. seedling survival might be expected to depend on weed abundance).
- **Timing, frequency and duration** — How frequently (e.g. annually), and during which seasons (e.g. after the summer months, during flowering or after extreme weather events), should the different types of data be collected? Over what period will data need to be collected to have a good chance of detecting an effect?
- **Methods** — What specific methods should be used, what equipment is needed for taking measurements and do you or your staff need any training?
- **Scale** — Are small plots of seedlings being counted, or large areas of land monitored using remote sensing? Will measurements be undertaken across the whole plot or in sub-samples?
- **Data collation and storage (see Chapter 6)**— How will data be collated and stored to facilitate widespread usage? Will there be any sensitive data and intellectual property issues? What quality controls need to be in place to ensure quality data are collected?

Design of targeted monitoring should be guided by the research question (e.g. shrub seedlings might be measured to investigate whether fire enhances shrub recruitment), and by doing a thorough review of previous studies, including peer-reviewed literature. Further, consult with partners that might have done similar studies in the past. Perhaps most importantly, if you are part of a network doing the same or similar experiments, you will be able to share ideas and decisions, and consider who your other stakeholders may be (see Chapter 2). Also, this will identify the resources (both in terms of staff time and equipment requirements) required for monitoring so that they can be incorporated into the project schedule and budget.

RESPONSE VARIABLES

There are many potential response variables that could be measured, depending on the type of experiment. Some of these include:

- **Early stages of the plant life cycle**
    - Germination, survival, growth, and development of species of interest;
    - Proportion of seedlings surviving at different time intervals; and
    - Seedling growth rates (e.g. relative growth rate).
- **Reproduction and recruitment** – the next generation of plants and persistence of populations
    - Proportion of plants flowering, with mature fruits;
    - Mean seed crop and viability per plant; and
    - Number of seedlings appearing that were not planted, and their growth/height etc. over time.
- **Vegetation** – structure and composition
    - Canopy cover and potential die-back;
    - Diameter or height of plants (e.g. diameter at 10 cm or 130 cm above ground), and derived variables such as basal area and total above-ground biomass;
    - Number of native and weed plant species;
    - Percentage ground cover of different variables and plant types (e.g. grasses, forbs, weed species, bare ground, litter and log cover etc.) or, if possible, conduct a full species composition inventory;
    - Location data on species survival and growth (e.g. map or differential GPS coordinates with photographs to cross-reference); and
    - Functional traits (e.g. specific leaf area, wood density).
- **Ecosystems** – development of or change in ecosystems, including occurrence, abundance, and species richness of animal taxa
    - Number and change in plant, animal, fungal, bacterial species and abundances;
    - Occurrence and abundance of individual key species of interest; and
    - Ecosystem functions – e.g. water infiltration, surface runoff interception, shade, wind shelter, attraction of pollinators, nutrient cycling, soil turnover.
- **Social and economic benefits**
    - Number and length of training visits;
    - Number of people involved in citizen science activities;
    - Attitudes and perceptions of landholders and community groups/members to conservation activities, and how these attitudes and perceptions change over time;
    - Indigenous partner involvement in the experiment;
    - Ecosystem services such as pollination of crops and wind/soil erosion protection; And
    - Temperature, hydrology, weather, and other abiotic changes.

PREDICTOR VARIABLES

It is important to measure other variables that may explain the results (predictor variables), including unplanned or unregulated variables. These may include:

- **Plant characteristics**
    - Provenance of seeds sown or greenstock planted (see Recording Inputs); and
    - Plant health prior to planting.
- **Initial site characteristics** (see Recording Inputs previous page)
- **Plot characteristics**
    - Soil physio-chemical characteristics in each plot prior to treatment application; and
    - Disturbance (e.g. vehicles, erosion, exclosure breaches) that occur on plots or the site during the experiment.
- **Biotic factors**
    - Presence and density of herbivores over time;
    - Presence and density of weed species in each plot and changes in these over time;
    - Presence of pathogens over time;
    - Initial vegetation composition and structure in each plot; and
    - Presence of beneficial organisms (e.g. pollinators, seed dispersers) in each plot.

- **Weather**
  - Rainfall, temperature, soil moisture at regular intervals; and
  - Extreme events (e.g. storms, fire, hail, flooding, extreme maximum and minimum temperatures and their duration).

FREQUENCY AND DURATION OF MONITORING

Design of the timing and duration of data collection associated with targeted monitoring needs to be tailored to the questions to be answered, the focal species, available sites, and other resources. However, if there is potential for longer term surveillance of the site to be useful, baseline measurements should be performed to prepare for this eventuality.

For example, a 12-month experiment might give valuable information about germination and initial development and survival of seedlings, resprouting of individuals after fire, or effectiveness of a herbicide, but will not be long enough to gather data on longer-term ecological impacts over different climate cycles (e.g. drought or heat waves). Monitoring over many years would be needed to study changes in vegetation structure and species composition over time (Jellinek et al. 2020). Further, monitoring should also take place after extreme events have happened (e.g. heat waves). Consideration of longer-term surveillance monitoring of this sort should be made during the planning phase along with targeted monitoring. Even if it is not clear whether surveillance monitoring will actually be carried out, or at what interval, collection of some key baseline data (i.e. the data against which future changes will be measured) at the start of the experiment will make surveillance monitoring more useful especially those relating to long-term survival and fitness (e.g. growth and reproductive characters). Collecting baseline data at the start of the experiment will allow data gathered later to be compared to a clearly defined baseline.

While certain response variables might be essential or beneficial to survey at a particular time of year (e.g. flowering, germination, herbaceous species), or at the same arbitrary time each year (e.g. soil microbes), others (e.g. tree stem diameter) could be measured at any time. However, thought should be given to selecting a suitable interval between measurements — there is little point in gathering data in slow-growing species if significant change over the period is not detectable.

Some variables might require much more frequent monitoring than others. For example, it might be appropriate to monitor seedling survival and development at weekly or monthly intervals immediately after germination/planting, or to monitor growth of saplings at six-monthly intervals or on an annual basis until the designed experiment reaches completion. Monitoring of vegetation structure and species composition, survival or growth traits of established or mature vegetation might only be required on an annual or occasional basis, and similarly, monitoring frequency of other organisms such as soil microbes would be determined depending on expected rates of change. Trait handbooks offer advice on which traits to measure and why (Cornelissen et al. 2003; Pérez-Harguindeguy et al. 2020). A new nation-wide database is a useful resource too: 'AusTraits' is an open-source database of trait data for a growing list of Australian native plants (Falster et al. 2021; **https://austraits.org/**).

DATA COLLECTION METHODS AND EQUIPMENT

A wide range of methods may be available to assess any particular variable of interest. These range from field measurements (e.g. species composition surveys, counting individual plants, measuring stem diameter, annual photopoints), to automated data collection (e.g. motion-sensing cameras to detect animals; temperature and moisture loggers), and remote sensing methods such as aerial photography (e.g. from a drone), (Harrison et al. 2021; Robinson et al. 2022) or satellite data and platforms that integrate these data (e.g., E-mapper; **https://emapper.com.au/**). Data collection and curation are described in detail in Chapter 6. See also methods in National Committee on Soil, Terrain (Australia), and CSIRO Publishing (2009), Commonwealth of Australia (2013) and methods employed by the Terrestrial Ecosystems Research Network (**https://www.tern.org.au/**).

Spatial data is an important component of monitoring and should be as accurate as possible. At present, uncorrected GPS signals are accurate to approximately 5 m, but in coming years GPS location accuracy is expected to increase to 10 cm throughout Australia, and to 3-5 cm in urban areas (**https://www.ga.gov.au/scientific-topics/positioning-navigation/positioning-australia/about-the-program**). This new infrastructure (due to be completed by 2024) should allow individual plants to be accurately located, although tagging individuals will also be necessary to ensure rigorous data collection. Reference photos of individual plants can also be highly beneficial for relocating specific trial elements.

PRACTICALITIES OF MONITORING

Ongoing monitoring needs to be planned and resourced just as thoroughly as the initial preparation of the site and establishment of the experiment. This includes building in the flexibility to cope with changes to partnerships, staff, land ownership, resources, and other factors over time. The following sections consider several issues that need to be considered:

STANDARDISATION OF DATA COLLECTION (SEE CHAPTER 6)

When different people are likely to be collecting data over time, it is important to make sure that data are collected in a consistent way. For example, Case Study 9 describes a project to establish standard methods that community groups in Victoria can use to monitor the success of revegetation projects. Attention should also be given to developing standardised methods of recording (including choosing methods that are not likely to vary much among different observers, standard sheets for recording data and detailed documentation of the methods used). Electronic data capture has several benefits including the reduction of transcription errors and the ability for in-field error-checking (forms can be set up to automatically query entries that are outside predefined bounds — trees taller than 2 m in a newly established planting, for example). For long-term projects, thought also needs to be given to the infrastructure that might be needed at a site to help later surveys collect consistent information from the same sites and plants. For example, marking the site with metal tags; using permanent posts to mark observation points or corners of experimental block; recording detailed spatial information in a GPS unit (depending on spatial resolution at the site, a map may also be required); recording detailed information on site planting design (e.g. species or treatment locations within the monitoring site); consistent and pre-printed data sheets.

PLANNING WHO WILL UNDERTAKE AND PAY FOR THE MONITORING

It is essential that data are collected in the right way and at the right time. Therefore, it is important to agree at an early stage on who will be responsible for different aspects of data collection and curation. This will help ensure that nothing is missed and that if multiple people/organisations are going to visit the site, they can coordinate their activities where possible. It will also help to highlight resource gaps that might need to be addressed. Monitoring roles can change over time, particularly in long-running projects (see Chapter 7). Plans can be revised to reflect this but remember that continuity (ongoing comparability of data from year zero) of a long-term data stream is paramount: if methods are changed then so too is the ability to answer the original question or to monitor environmental changes. A key to maintaining continuity is assigning a trial custodian to have oversight of the experiment and associated activity, maintain meticulous documentation, and for that oversight to be clearly handed on if that person leaves.

Practicalities of actually recording data in the field also require considerations. For example, there are pros and cons of using data loggers vs. weather stations, hand-written vs. direct electronic (e.g. tablet) data collection, waterproof paper, scanning and storage of original datasheets or recordings. Key reference points, plot layout and treatment allocations for embedded experiments should be identified on site plans and GPS coordinates collected. The role of remote sensing and/or drone imagery has increased dramatically over the last decade and will continue to do so, perhaps becoming a cornerstone of long-term monitoring, but until then, field work and hands-on monitoring is still required.

PRACTICAL ARRANGEMENTS FOR SITE ACCESS

As part of planning the timing and frequency of data collection, and the people who will be responsible for doing it, the logistics of accessing the study sites need to be considered. For example, is access possible year-round or are there limitations on when or how frequently the site can be visited? Is the site accessible after heavy rain? Are petrol vehicles prohibited on site in order to lower fire risk? Are protocols in place for vehicle and equipment hygiene to prevent the spread of weeds or diseases? If a site is not owned by a member of the core group, what are the required arrangements for keeping landowners informed about planned visits and access to sites? Who is responsible for site maintenance and management? Is a scientific licence required (e.g. for research in reserves or threatened ecological communities)?

MAINTAINING A DETAILED LOG BOOK OF VISITS AND A MASTER DATA FILE

It is essential to keep detailed and accurate records of visits to the site, when they occurred, who undertook the monitoring and what monitoring work was done. This information should be collected in a log book (or database/eLog book, see Chapter 6). As well as helping in the coordination of fieldwork (e.g. to avoid gaps and duplication), this information can be useful when later analysing the data — for example to check the exact dates on which particular information was collected, or to incorporate the effects of different observers collecting data into statistical analysis. The data collected in these log books should then be collated in a master document, which can be used to guide data interpretation and reporting.

HAVING A ROBUST AND FLEXIBLE PLAN FOR ONGOING RESOURCING

A resourcing plan should be developed to clearly identify the likely resource requirements over time and consider ways of addressing them (e.g. through grants, partner contributions, volunteers). Maintaining monitoring in the long term can be particularly challenging. Monitoring of many projects is unfortunately disrupted or dropped completely after the initial phase of the project as a result of factors such as staff turnover, funding cuts or an initial grant running out. These risks should be acknowledged up front: though the means to carry out long-term monitoring may not be clear, this is not a reason to set up the experimental monitoring programme without plans to gather baseline data that will give context to future measures and observations. Options should be considered to enable data collection to continue in the face of potential limited or fluctuating resources in the future. One option might be to have a core program of simple ongoing surveillance monitoring that could be augmented by more intensive data collection for shorter periods if resources become available for specific projects. Contingency plans also need to be made to ensure that if the people/organisations initially responsible for monitoring are unable to continue, other arrangements can be made to avoid gaps in data collection. Can some data be easily collected by the landholder, such as regular photos from photopoints? For example, photopoint monitoring has been used to keep community stakeholders updated with progress on an urban restoration project in Perth (**https://rehabilitatingroe8.org/**). Connection to a larger network of sites doing similar experiments may also facilitate long-term engagement and resourcing.

DATA ANALYSIS

Experimental design and data analysis considerations are covered in Chapter 4. Typically, the experiment will have been designed for a specific purpose and the targeted monitoring in the early stages of the experiment will be complementary to the experimental design and analysis strategy. However, over the longer term, the experimental design may change significantly due to mortality, recruitment, and other dynamic ecological process — effectively, the experimental design will no longer be the same as it once was. It may be necessary to reconsider the approach to analysis to deal with factors such as severe imbalance and spatial variation. Seeking statistical advice in this eventuality may therefore help shape what and how data are gathered and what ongoing surveillance monitoring is required.

MONITORING CHECKLIST

Similar to planning and design, checklists can be extremely helpful when monitoring experiments to help ensure all aspects of the monitoring have been considered. Below (Table 4.2) is a series of suggestions to develop checklists that can be used when monitoring an embedded field experiment.

Table 4.2 Suggestions for developing checklists to be utilised when monitoring embedded field experiments

Inputs	• Record your inputs.
Response variables	• What are the response variables?
Predictor variables	• Which predictor variables will be monitored?
Time	• How frequently will the site be monitored? • For how long?
Methods	• What methods will be used to monitor the site? • What equipment will be used? • Does anyone require training?
Data collection	• How will the data be recorded (e.g. paper, tablet)?
Cost	• How much will monitoring cost (staff time, travel, equipment)?
Analysis	• How will the data be analysed?

IN A NUTSHELL

This chapter has covered the practicalities of what and how to monitor experiments in ecological restoration. It detailed how to record inputs (e.g. details of the experimental setting), what data types to monitor (e.g. response and predictor variables) and some practicalities that may present hurdles or opportunities during monitoring (e.g. standardisation of data collection, costs, site access, data analysis). In a planting trial for example, we suggest a bare minimum is to collect data on seedling establishment at 1–2 years after trial initiation, from a known quantity of sown seeds or planting seedlings, which can be paired with soils and climate data (e.g. Bureau of Meteorology) to determine a basic metric of restoration trial success. We have suggested other variables that can be added to address project aims and stakeholder interest, and depending on availability of funding. Monitoring is essential to determine the degree of success achieved through a restoration intervention. Case Study 7 describes the reasoning behind selecting what and how to monitor in an embedded restoration experiment.

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Chapter 6.

DATA MANAGEMENT

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SUMMARY

- *Curating data and ensuring that it is collated and stored robustly are essential components of ecological projects.*
- *Metadata must be up-to-date and provide information on the data that is being stored.*
- *Data standards ensure that groups and researchers can share, exchange, and understand data in a standardised format.*
- *Sharing of data, either through 'open data', where it is free and openly exchanged, or through restricted use and data sharing agreements can allow your data to be more widely used.*

INTRODUCTION TO DATA MANAGEMENT

Data management is a crucial component of any embedded ecological restoration experiment (Grose et al. 2021). It enables those involved in an experiment to carry out planned analyses to complete the experiment, allows for projects to be refined and adaptively managed over time, and helps make data available for potential further analysis in the longer term. However, only a fraction of the ecological data that has been collected over time in Australia is easily discoverable or accessible, and much of this data is unusable due to the way it has been collected or stored, or because there is a lack of appropriate metadata (data that provides information about other data) on the collection methods that were used (Reichman et al. 2011). It is critical to collate and store data in a robust and accessible format with up-to-date metadata, especially when collecting and synthesising data from long-term, large-scale, and trans-disciplinary projects. These comprehensive projects are becoming more common and feasible with increasing technological advancements such as apps, sensors and remote sensing which make it easier to collect field data (Ladouceur and Shackelford 2021). For example, the FAIR Guiding Principles (findable, accessible, interoperable, reusable) have been developed to enhance the reusability of data, and enhances the ability of machines to automatically find and use data (Wilkinson, et al. 2016).

As data sources become more diverse, people can use databases to help overcome challenges related to collating, integrating, synthesising, and analysing different data types (Ladouceur and Shackelford 2021). Databases provide an accessible means to add and share data and results between different stakeholders. A well-designed, consistent, and accessible database ensures that data can be stored and updated over time while being accessible to other researchers and practitioners. Such a database enables stakeholders to better understand and quantify how their on-ground activities are achieving biodiversity and social benefits (Walker and Meyers 2004).

This chapter outlines ways to gather, store, and curate data using standardised and robust methods that allow organisations or individuals collecting experimental data to compare their results and to make connections between sites within a broader network of studies. It also ensures accessibility of data into the future. Specifically, this chapter focuses on how to store restoration data, some of the databases that currently exist nationally and internationally to maintain such data, and considerations on data accessibility. We discuss these sections considering embedding experimental trials within the broader restoration activities.

COLLATING AND MANAGING DATA

Collecting a common set of attributes at the site, species, and provenance level provides the ability to collate data from across a network of experimental trials to develop a database that can be interrogated to address overarching questions at local, regional, and national scales. In this section we outline how best to manage and store treatment and monitoring data (see Chapter 5), and detail some of the basic response variables that could be used to assess restoration success. While this is not an exhaustive list of the different types of data that can be collected, we aim to provide a starting point upon which further data can be added as circumstances require (see Appendix 1).

DATABASE METADATA

Central to any database is maintaining detailed and up-to-date documentation that outlines changes to the database and basic metadata, and which collectively ensures the longevity of the database beyond a single researcher/practitioner. The rules that outline how data is described and recorded are known as data standards. Data standards allow groups and researchers to share, exchange, and understand data in a standardised format. A widely used minimum data standard developed for species occurrences and specimens is Darwin Core, which is a ‘set of terms and definitions that facilitate the exchange of information about the geographic occurrence of organisms and the physical existence of biotic specimens in collections’ (**http://www.tdwg.org/standards/450**)(TDWG 2009). A glossary of terms used in Darwin Core can be found online (**http://rs.tdwg.org/dwc/terms/**).

An emerging standard developed specifically for ecological data in Australia is the Australian Biodiversity Information Standard (ABIS), developed by the Terrestrial Ecosystems Research Network (TERN) and the Australian Government. More information about ABIS can be found at **https://github.com/ternaustralia/ontology_tern**.

Metadata should also conform to government standards, which in Australia are currently Australian Standard AS 5044-2010 (**https://agls.gov.au/**).

Detailing version changes (e.g. version 1 to version 1.1) of any database provides a mechanism to track changes to key sections. Ideally it reports on when the changes were made, by whom, the reason for the changes, and what changes were made. Having this information allows people newly accessing the data to understand how the database has evolved and which versions to revert to in case of errors.

The metadata can be created by specifically defining the data maintained in a database (see Box 6.1). For example, in the Australian Provenance Trial project collated by Harrison et al. (University of Tasmania, unpublished), information on species, provenances, trial locations, and response variables from the trials is maintained as separate spreadsheets in an Excel workbook. There are two additional spreadsheets, one that details changes to specific spreadsheets, and the other that details the metadata where each spreadsheet has (i) a description of the data maintained and the purpose of the spreadsheet, and (ii) the column headings and a description of the data within each column including the unit of measurement.

Units of measurement can include the units used when the data was collected or notes specifying if traits were measured in a contrasting way to traditional practices (e.g. measuring diameter at breast height (DBH) at 50 cm above the ground rather than at the standard 1.3 m). Recording the date when data was collected is important to monitor changes in treatment (e.g. species or provenance) performance. Dates can be represented as either the actual calendar date assessed or recorded in years/months since establishment or treatment application. To ensure attribution, the data can be appended to the name of the trait measured (e.g. dbh_0405 could represent DBH measured at 4 years and 5 months post plant establishment, but this will only be meaningful to others if the meaning is explicitly recorded in the metadata).

BOX 6.1
RECORDING PROVENANCING DATA IN TRIALS INVOLVING PLANTINGS

Reporting and maintaining detailed information on the species and provenances used in a planting is a critical first step of any revegetation project and underpins our capacity to test, for example, species and provenance differences and how this response may be associated with the test environment. At the species level, recording the scientifically accepted taxonomy (e.g. family, genus, and species) and the lifeform (e.g. tree, shrub, grass), provides a hierarchical partition of the data for analysis. At the provenance level, the level of detail that is required to record site and experimental details should at least include:

- A unique identifying name for the sampled provenance;
- Consistent recording of geographic coordinates and datum of the source populations, for example recording latitude (Y) and longitude (X) in decimal degrees using the Geocentric Datum of Australia 2020 (GDA2020);
- Finer detail information such as the sampling of separate mother trees within each provenance and whether the seed from the sampled mother tree was maintained as single-tree seedlots or whether the seed was bulked to produce a provenance bulked seedlot; and
- Whether the provenance was from a fragmented population (see Fig. 7.5.3 in Case Study 5).

Examples of how to set up provenance trials are provided in Jellinek and Bailey (2020).

When recording species and other taxa, remember that taxonomies change and it may be necessary for future users of your data to update your taxonomic lists. This will be easiest if you:

1. Use a standard, accepted taxonomy, either the National Species Lists (**https://biodiversity.org.au/nsl/ and https://biodiversity.org.au/afd/home**) or a state- or territory-accepted taxonomic census, and
2. Record the source as well as the name for each taxon. For example, instead of simply recording *Eucalyptus globulus*, record ‘*Eucalyptus globulus* sensu (according to) Brooker & Kleinig (2006)’. That way, if the meaning of Eucalyptus globulus changes over time, future workers will be able to know exactly which *Eucalyptus globulus* you meant.

SPATIAL DATA

It is vital, as a part of any database, to accurately record and provide spatial data of the places or areas where conservation activities have been undertaken, or where individual species are being monitored. Spatial data require basic information to be recorded, in the form of a unique identifier such as 'PolyID' (for individual polygons), 'PointID' (for individual points) or 'LineID' (for line data). When recording information on the ground, the datum (a reference frame for precisely representing the position of locations on Earth) must be recorded (the most recent Australian datum is Geocentric Datum of Australia 2020 (GDA2020)). Careful consideration should be made to the naming conventions of spatial attributes to avoid spaces and shortened or hybridised terms that are indiscernible to others. For attribute names that require shortening, a list of the full name and critical details of the attribute should be kept in a README text file to accompany the spatial data. Many academic and government organisations utilise the Esri software suite of spatial tools where vector data is saved as shapefiles. Vector spatial data from Esri software should follow the Open Geospatial Consortium (OGC) best practices (**https://docs.ogc.org/bp/16-070r4.html**). Additional spatial data best practices can be found at **https://www.ogc.org/docs/bp**.

DATA CURATION AND STORAGE

How and where data is stored, and who manages that data are key considerations when establishing a database. Increasingly, organisations require the creation of a data management plan at the inception of a project to ensure internal and external access both presently and into the future. Poorly stored and managed databases reduce the visibility and reusability of the data they contain.

Project funding considerations should account for the operational costs of hosting and maintaining a database both during and after the initial project is completed, or transferring the data to another repository. Costs may be reduced if opportunities exist to utilise an existing repository, however, accessibility, user friendliness, data management, and ongoing costs require careful consideration.

Ensuring that the database will not be affected by funding cycles, or short/long-term lack of funds, is important. Even if the project does not have long-term funding, identifying if that data will be easily accessible to other people and projects into the future is an important aspect to consider. For example, locally stored databases such as in Microsoft Access can be relatively easy to set up and manage. But this information are not easily accessed outside of their local computer network and can easily be lost or forgotten, and issues can arise because of incompatibilities between software versions. Some options to manage these disadvantages are to ensure the data are backed up and software versions are updated when relevant, and to store the files in more broadly accessible locations (e.g. within-organisation share drives, or in the Cloud). Databases exclusively stored in the cloud can often be more expensive to establish and manage, although they have the benefit of easy accessibility and sharing among users, providing longevity to your data.

Ideally, experimental information and monitoring data should be stored in a centralised database that contains all the national data for ecological restoration experiments. Databases that may be able to hold such data are shown below (Table 6.1), along with their advantages and disadvantages. Long-term datasets extending to 30 years or more generate invaluable data about how restored areas change. 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.

Table 6.1 Some of the established database platforms often employed to store biological data, along with the pros and cons of each platform

DATABASE	PROS	CONS
Australian Government's Biodiversity Data Repository (BDR)	• Managed by the Australian Government • Provides key biodiversity and environmental data for information products, advice, analysis, and tools • Highly defensible, robust, quality data • Built using the ABIS standard, which is ideal for ecological datasets • Still under development at time of publication	• Still under development at time of publication
ArcGIS Collector or Survey123	• Cloud based database that allows users to collect spatial data along with other information • Allows set-up of individual data forms and fields • Allows sharing of data within and between organisations	• Requires an ArcGIS license (expensive for non-academic or government users) • Some training may be required
Databases managed by Atlas of Living Australia (ALA 2019)	• Data freely and publicly available • App available (Biocollect) • Solutions can be custom-built to a user's requirements (will likely require funding) • Data can be uploaded using templates and an online platform	• Fee for some applications • Not so focused on plot-based data • Focused on species and occurrence data rather than complex ecological data such as plots
Data repository managed by Terrestrial Ecosystem Research Network (TERN)	• Data freely and publicly available • National, publicly accessible long-term repository • Designed to host all ecosystem science datasets • Web-based data submission and analysis tools • Supports search and access with citation information • Custom-built data integration platform for plot-based ecology data	• Externally hosted on ARDC NeCTAR infrastructure and can be impacted by host maintenance schedules

DATABASE	PROS	CONS
Data Integration Partnership for Australia (DIPA)	• Managed by the Australian Government (Australian Bureau of Statistics) • Informs the development of emerging social, economic, and environmental policy priorities	• Limited utility to groups outside of the Australian Government
DATAPLAN (Tree Breeders Australia)	• Sophisticated management of trial data which maintains detailed attribute metadata for each category of data recorded including species and provenance, trial site, and response traits • Handles very large datasets (> million data points) • Accessible through user rights which has different administrative roles • Easy interrogation through search and filter functions • Data entry using tab delineation which can be uploaded via a text/csv file or copied and pasted • Custom-built to a user's requirements and links to TREEPLAN/PLANTPLAN	• Requires training • Initial setup investment cost with an annual membership fee
Microsoft Access	• Relatively simple to set up and manage and locally stored • Available with MS Office Pro versions • Self-managed • Easy to query and export results • Compatible with statistical programs such as R • Compatible with GIS programs such as ESRI ArcGIS	• Data integrity affected by too many users • Some training needed to develop a well-structured database • Not directly cloud-based • Not accessible by multiple users outside of a central location
Microsoft Excel workbooks (not a database)	• Very simple to set up and manage • Locally stored • Free with MS Office • Compatible with statistical programs such as R	• Difficult to query and arrange data • Hard to manage very large datasets • Not accessible by multiple users
State and Territory Biodiversity Databases (e.g. Natural Values Atlas in Tasmania, WildNet in Queensland, BioNet in NSW)	• State and territory government based persistent data repositories • Important data aggregators, so data becomes integrated with other datasets • Important contributors to Atlas of Living Australia and Biodiversity Data Repository • Contributed data used extensively for conservation planning	• Variable data models • Sometimes limited capacity or resources to host data

QUALITY CONTROL AND TRAINING NEEDS

CONDITIONS FOR DATA ACCESS

The sharing and collating of experimental data on, for example, species and provenance trials across multiple study sites through databases often provides unprecedented insights into otherwise complex biological processes. Making data available on public domains is becoming increasingly common, especially when publishing scientific manuscripts. Indeed, many core funding agencies are now making it mandatory that data originating from associated grants be made available on public domains. There are benefits in sharing data, including providing opportunities to standardise data entry, survey methodology and reproducible data analysis techniques (Reichman et al. 2011), and there are standards and protocols around how to share, use and cite such data (Zimmerman 2008). Nevertheless, collating data into larger databases which are in the public domain raises several key considerations concerning data accessibility, including intellectual property in particular, that need to be overcome.

At the simplest level, a database can be maintained on a public server which can be accessible without any constraints. While this may be advantageous, it can also be a deterrent for organisations due to loss of control over data. Alternatively, accessibility to data can be controlled though request systems which require potential users of the data to contact specific researchers who maintain control of the data. For example, the Southwest Experimental Garden Array (**https://www.sega.nau.edu/data**) provides a code of ethics which outline the conditions for data use and provides a summary of the available data including whether it is publicly available and details for the point of contact. Other systems, such as DATAPLAN, which is a module within PLANTPLAN (**http://www.plantplan.com/index.php**), allocate user roles to participating organisations to track access and changes to data. Such roles can include public (where this data is available for public access), read only, and read/write. This is a similar logic to database access used by the Atlas of Living Australia, where users can be allocated five different data sharing options (**http://www.ala.org.au**):

1. Available to all users without restrictions;
2. Available to all users with general restrictions – used for non-commercial purposes and/or Share Alike data;
3. Subset of data available to all users – where some of the data elements are restricted, such as the presence of endangered species;
4. Data is available to a restricted audience; and
5. Only metadata is available to a restricted audience.

DATA SHARING

It is your choice, or potentially the choice of your institution or funding body, whether and how your data gets used by other people or organisations, and how they attribute that data in their results and publications. It is important to specify the appropriate attribution for your data in open data sharing environments. You should provide statements regarding the contribution of authors and data providers, and clearly state whether you allow the data to be accessed, used, or disseminated by others. You may allow your data to be free and openly exchanged, or you may wish to restrict the use of your data, especially if it contains information regarding threatened species. Always ensure that you provide intellectual property information and access agreements to ensure your data is cited correctly to ensure data citations appropriately acknowledge work undertaken by other researchers. Data repositories often suggest how to cite their collections, noting that this is a fast-developing area, and the ways data is cited may differ to how scientific literature is cited (Cousijn et al. 2019).

Making data available so it can be used by others is known as data sharing. Data sharing platforms have grown in recent years, and there are a number of publications that outline what these platforms are and what they provide (Michener 2015). Data sharing platforms provide opportunities to standardise data entry, survey methodology, and reproducible data analysis techniques (Powers & Hampton 2019) by providing standards and protocols around how to share, use and cite this data (Zimmerman 2008). However, there are many social challenges associated with 'open data', and how to adequately curate and attribute this data (Culina et al. 2018). Some collaborative experimental networks (e.g. **Nutrient Network**, Index of biodiversity surveys for assessments) aim for an inclusive approach to publication of studies using shared data. These include an expectation to invite data contributors to participate in a study and co-author associated publications, which has sometimes resulted in effective global collaborations.

Data sharing agreements are sometimes necessary components of collaborative data arrangements, ensuring data can only be used in the manner agreed between the data owner and the user. It is worth considering how complex your data sharing arrangements need to be as developing agreements across a diversity of data providers can be complex and time consuming. This is particularly important when data aggregators make their datasets available for public use and dissemination by a third party.

Creative Commons allows people and organisations to legally share data and knowledge so that it is equitable and accessible. It provides copyright licenses that are free and simple, so that copyright information is stored in a standardised way, and so the public can have a way to use and share your data. These standards to data use are globally recognised.

REPORTING

Providing reports on the outputs and outcomes of projects to a range of funding bodies, such as philanthropic organisations or government agencies, can be difficult and should be taken into consideration when choosing how and where data will be stored.

Some databases, such as the Atlas of Living Australia, have the ability to link back to government reporting systems such as generating reporting fields for the Federal Government's Monitoring, Evaluation, Reporting and Improvement Tool (MERIT). It is also possible to get other databases to generate similar reporting fields (e.g. ArcGIS Survey123), for state-based funding agencies. Having a system set up for reporting on your projects may save you time when reports are due, and may also provide valuable information for communicating your project outcomes in other forums.

RESOURCES

- FairSharing.org
  - A catalogue of databases
  - **https://fairsharing.org/databases/**
- Open Geospatial Consortium
  - **https://www.ogc.org/**
- The Knowledge Network for Biocomplexity
  - International repository intended to facilitate ecological and environmental research
  - **https://knb.ecoinformatics.org/about**
  - Uses Metacat (**https://knb.ecoinformatics.org/knb/docs/**) and Data Observation Network for Earth – DataOne (**https://www.dataone.org/**)
- The National Centre for Ecological Analysis and Synthesis
  - **https://www.nceas.ucsb.edu/data-science**
- Creative Commons
  - **https://creativecommons.org/about/program-areas/open-data/**
- Terrestrial Ecosystem Research Network (TERN)
  - **https://www.tern.org.au/**
- Atlas of Living Australia (ALA)
  - **http://www.ala.org.au**
- Southern Tree Breeding Association (STBA)
  - **http://www.stba.com.au/about**
- Index of biodiversity surveys for assessments (IBSA, Western Australia)
  - **https://www.wa.gov.au/service/environment/environmental-impact-assessment/program-index-of-biodiversity-surveys-assessments**

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IMAGE: Monitoring restoration trial at Gaskell sand mine, north of Perth (Western Australia), of Lauren Svejcar and Bruce Burns. *(Photo credit Rachel Standish)*

Chapter 7.
CASE STUDIES

Tanya Bailey, Andrew F Bennett, Guy Boggs,
Martin Breed, David Bush, Nick Gellie, Peter A Harrison,
Barry Heydenrych, Sacha Jellinek, Justin Jonson,
Shaun Kennedy, Andrew J Lowe, Ben Miller, Russell Miller,
Tim O’Brien, Brad Potts, Rachel Standish

Case Study 1.

Clarendon Carbon Biosequestration Project, South Australia

Nick Gellie, Shaun Kennedy, Martin F Breed and Andrew J Lowe

The Clarendon Carbon Biosequestration Project (Fig. 7.1.1) was established to support the delivery of SA Water Corporation's Greenhouse Offset Initiatives asset program. The project carried out 160 ha of native revegetation work on a property located 1.5 km north of the Clarendon township. The site forms part of the catchment for Clarendon Weir, which in turn contributes to the Happy Valley storage and the drinking water for over half of Adelaide's population.

The initial phase of revegetation comprised planting an array of tree seedlings across the available 160 ha of former grazing paddocks to provide a readily measurable carbon sink that will accumulate as the trees grow toward maturity. The biodiversity component of the project comprised the establishment of localised populations of understory species that will contribute to the long-term resilience of the land cover.

INTERVIEW HELD WITH:

- **Shaun Kennedy**, SA Water Corporation
- **Dr Nick Gellie**, University of Adelaide

HOW DID THE PARTNERSHIP FORM?

The partnership formed when Shaun contacted Martin Breed, then at the University of Adelaide, after reading an article written by Martin that discussed local provenance selection in ecological restoration. The concepts proposed in the paper aligned with questions that Shaun was considering in plantings being undertaken by SA Water.
In particular, Shaun was focussed on building resilience in their planting to address challenges presented by the high level of fragmentation (<15% remaining vegetation).

> ***'We thought collecting local provenance may be a problem within a changing climate but didn't know what the alternative could be. Reading some papers suggested there were options.' Shaun Kennedy, SA Water***

Discussions between Martin and Shaun highlighted the opportunity that SA Water's planned planting program of 160 ha may provide for testing different approaches to provenance selection. This provided a 'real life' testing of theory with a large sample size (n = 1,410 plants), while supporting SA Water's goal of delivering a biodiverse offset project that would be climate ready and survive long term. While this provided significant in-kind support for the project, funding for the research was sourced by the University of Adelaide through the Australian Research Council (ARC).

SA Water was undertaking the restoration of the catchment site and had budgeted for the planting of 60,000+ trees. They also picked up the cost of separately rearing and georeferencing in excess of 1000 individuals with three different provenances at the planting stage, which made the experiment possible. The ARC enabled the experiment through funding, but it would not have been possible without a progressive land manager (Shaun) and an engaged corporate citizen (SA Water).

WHO WAS INVOLVED IN THE PARTNERSHIP?

The partnership was conceived and initiated by Shaun Kennedy (SA Water), Professor Andrew Lowe (The University of Adelaide) and Dr Martin Breed (Flinders University). The university researchers recognised the potential to identify the key priorities facing stakeholders and also recognised that the partnership presented a good opportunity to engage with a restoration practitioner who was trying to achieve these priorities. From Shaun's perspective, the partnership also required logistical support from experienced supply and delivery contractors who were able to implement the embedded experiment proposed by researchers.

As this partnership matured, it provided research infrastructure for students (including Nick Gellie, Craig Liddicoat, and Dona Kireta) which in turn has fostered new funding, partnerships and research opportunities in soil microbiomes and pollination services at the same site (e.g. BioPlatforms Australia, Environment Institute and Australian Genome Research Facility; Rural R&D for profit).

WHY WAS THE PARTNERSHIP VALUABLE?

The benefit of setting up the experiment as part of a broader stakeholder network meant that there were opportunities to obtain advice from people who have had a range of experience in ecological restoration. Shaun noted that researchers have greater opportunity to read and access relevant literature and so Shaun gained value from their expert advice. From the research perspective, the concept of setting up a living system that will flower and exchange genetic material was seen as highly valuable.

The partnership also provided a central theme (e.g. local adaptation) for the development of Nick Gellie's PhD project. The results confirmed some of Shaun's fears about seed provenance at the site and helped to change the approach taken by SA Water for seed collection. Before the project, locally sourced seed was considered an 'industry rule' and was used exclusively. The practice was modified when the project revealed that a composite provenance could provide better outcomes (e.g. improved and statistically tested height, survival and pathogen resistance).

In just a few years, the research partnership has directly and indirectly resulted in four peer reviewed papers co-authored by research and practitioner partners. The relationship was still active at the time of this case study.

WHAT WAS IMPORTANT FOR MAKING THE PARTNERSHIP A SUCCESS?

A key driver of the success of the partnership was the recognition by Shaun that the revegetation industry is evolving. There is a lot to learn about how we restore ecosystems and achieve desired outcomes. Partnering with the research community is valued by Shaun as it provides an opportunity for this shared learning to continually improve the industry. Large-scale ecological restoration projects provide important opportunities to test fundamental questions about how ecological function can be successfully improved. Shaun has a number of questions, from soil biology to pollination services that he would like explored for the benefit of the industry.

But the partnership was not without its challenges. Shaun felt some of the logistic and workload complexity associated with embedding an experiment into a restoration planting can be underestimated for both the researcher and practitioners. Integrating research-driven timelines and expectations with large-scale restoration project management controls and uncertainties caused by variable weather or contracting relationships for a project can be difficult. Good planning at the start of the project, clear communication and having an experienced contractor really helped in this project. Practical aspects of fitting into a workplace, such as occupational health and safety (OH&S) compliance, were also important.

Different communication and planning styles between the partners influenced the project. For example, it was felt that the researcher partners preferred to use written communication (e.g. 'email me your experimental design') while the practitioners preferred workshopping/whiteboard-based planning. The record keeping and monitoring priorities of each partner can be different, and it was important to identify clearly what was needed.

Andy, Martin and Nick welcomed Shaun to the University of Adelaide and participated in meetings to discuss ideas within the university environment. The shared contribution of knowledge to interpretation of the project's results was recognised through co-authorship of a peer-reviewed journal article. The relationship built between the University of Adelaide and SA Water was underpinned by a sense of trust that evolved from a genuine willingness to help each partner achieve their goals in research and improve restoration outcomes.

Recognising the value of this approach, the relationship is being built on for future studies with the chronosequence provided by SA Water planting sites, providing space-for-time studies looking at different soil microbial development and pollinators.

Figure 7.1.1 Nick Gellie measuring plant traits in the provenance trial at the Clarendon site. *(Photo credit Nick Gellie)*

Case Study 2.

Warren and Donnelly Rivers Restoration Project, Western Australia

Guy Boggs

The Warren and Donnelly Rivers are two iconic river systems of the south-west corner of WA. Each passes through regions containing unique flora and geology. The Warren River has a catchment of 4,500 km² and a main channel 300 km in length. The Donnelly catchment basin is 1,600 km² with a 150 km long main channel. Both river systems suffer from a variety of environmental threats such as weed infestations (e.g. blackberry), salinity, feral pests and human disturbances. The project restored a 120 km expanse of riverbank by planting 602,633 native seedlings. The restoration sites exist as a result of 'blackberry decline syndrome' and of chemical control programs over recent years. The project was funded by the Australian Government's Clean Energy Future Biodiversity Fund.

INTERVIEW HELD WITH:

- **Lee Fontanini**, Project Manager, Warren Catchments Council (WCC)
- **Dr John K Scott**, Honorary Fellow, CSIRO

HOW DID THE PARTNERSHIP FORM?

In the early 2000s, researchers based at CSIRO Floreat (WA) were looking for partners to assist with trialling the release of new biological control agents for blackberries. The new agents were strains of the blackberry rust fungus that had been selected, with Manjimup in south-west WA as a potential release area. Blackberry was a key issue for the WCC which already had considerable experience in the herbicide control of blackberry in the Manjimup area and had participated in earlier releases of biological control agents (in the 1980s and 1990s). In addition, the WCC had a strong history of collaboration on land management issues with the Manjimup office of the Department of Biodiversity, Conservation and Attractions (DBCA).

Whilst releasing new strains of the rust, unexplained declines of blackberry infestations were found within the Warren and Donnelly River catchments. This 'decline' was affecting large areas of blackberry on the riverbank, presenting an excellent opportunity to undertake riparian restoration. Sufficient background information had been collected when a funding opportunity became available through the Australian Government's Biodiversity Fund. The WCC were very keen on undertaking the restoration in a scientific context and in taking climate change into consideration, so capitalised on the partnership with DBCA to develop the project and obtain funding.

WHO WAS INVOLVED IN THE PARTNERSHIP?

The partnership involved:

- Practitioners from the WCC (Kathy Dawson, Lee Fontanini, Andy Russell) and the Manjimup office of the DBCA (Ian Wilson).
- Researchers from CSIRO (Dr John Scott, Paul Yeoh), DBCA (Dr Margaret Byrne, Dr Tara Hopley, Dr Terry MacFarlane), The University of Western Australia (Helen White) and Murdoch University (Sonia Aghighi, Dr Treena Burgess).
- Contractors; nursery growers, including a Forest and Products Commission nursery and weed management contractors.
- Funders from the Australian Government's Department of Environment and Energy.

The project was large and complex, and a governance structure, including an overarching committee, was established that helped guide the project and provided representation and integration of project activities by the partners involved.

The research and practitioner partners met regularly to ensure the project fulfilled the requirements of their organisations. Broader engagement with the community was a key component of the project, recognising the important role that the local community played in supporting the project and partnership. Local contractors participated in the project and experimental activity providing local knowledge and supporting adoption of research findings.

Postgraduate students were also recognised as playing a particularly valuable role in the long-term partnership, addressing research questions, and generating and analysing new data for field application. The co-supervision of students also supported links to scientists within the universities.

WHY IS THE PARTNERSHIP VALUABLE?

Restoration of complex ecosystems involves many interacting facets and thus benefits from partnerships with a broad range of expertise and capability. The initial work on blackberry control was feasible because of the integration of science and practical application in a management context and provided a solid foundation for an integrated restoration project. The co-design and joint development of the restoration project enabled all partners to identify their contribution to achieving the overall agreed objectives.

Obtaining funding was a key enabler for the project and the joint development of the funding application contributed to its success. An important aspect of the collaboration between the research and practitioner community was that it facilitated development of innovative solutions to the challenge of restoration along a major river system within existing vegetation complexes and this likely contributed to the success of the application.

Scientific knowledge enabled the on-ground management activities of the project to be implemented in an innovative and effective manner. The on-ground management experience of practitioners enabled the science to be embedded in a real-life context and the project to address key questions in practical restoration. Key science components focused weed management and seed sourcing in a climate change context. The weed science ensured that the weed management strategies were effective so that weeds would not overcome restoration plantings. Research by the DBCA was undertaken to determine the genetic make-up of the plants and to identify genetic zones for provenance selections to provide information for the design of seed collection activities undertaken for the project.

The staff in the WCC and the DBCA Manjimup office provided local knowledge to inform and guide the experiments and also provided access to considerable support that reduced the cost and resources required for the science component. For the WCC, the partnerships with CSIRO and the DBCA brought valuable scientific information and advice to the project that helped support decisions in management of complex biological systems.

WHAT WAS IMPORTANT FOR MAKING THE PARTNERSHIP A SUCCESS?

The success of the partnership was based on trust and mutual respect, along with effective engagement to achieve a common objective. The funding application was developed jointly and the project was co-designed with ongoing active engagement of all partners. Open communication between the partners in all stages of project planning and implementation was important in maintaining the relationships and ensuring project success. Local management of the project also contributed to its success. The WCC submitted the application and administered the project funds and most meetings were held in regional offices near the study location (Manjimup), with occasional meetings in Bunbury or Perth.

Community engagement early in the project also helped local people to understand and support the project, and local contractors were used where possible. Talks, presentations, and open days were keys elements of the community engagement that were undertaken throughout the project from the initial planning to completion. Project closure is a key stage in affirming a partnership and the success of the project was celebrated with several events involving the local community. A 'Riparian Restoration Manual' was published for landholders and community groups by the WCC with contributions from the CSIRO, DBCA, NLP and WCC staff. Journal publications were also produced, including a paper led by Murdoch PhD student Sonia Aghighi and co-authored by WCC, Murdoch and CSIRO staff. This reflects the shared approach to the project and recognised contributions of knowledge by partners.

IMAGE: Management of blackberry along the Warren River. Pictured Prof Giles Hardy (Murdoch University), Sonia Aghighi (Murdoch University), Lee Fontanini (Warren Catchments Council) and Dr John Scott (CSIRO). *(Photo credit: Paul Yeoh, CSIRO)*

Case Study 3.

Hanson Long-term Banksia Restoration Science Program

Guy Boggs

The Gaskell Sand Quarry has been operating for over 25 years, providing sand products to domestic and international markets. The quarry, now operated by Hanson Australia, is located in the northern suburbs of Perth on the Swan Coastal Plain. The company is aiming to restore approximately 570 ha of land from which sand has been extracted with a plant community closely resembling the original Banksia Woodland plant community. Hanson has a long history of partnership with Kings Park Science (within the Department of Biodiversity, Conservation and Attractions (DBCA)), which conducts research projects and trials to ensure rehabilitation criteria and best environmental practices are met.

INTERVIEW HELD WITH:

- **Dr Jason Stevens**, Program Leader, Kings Park Science (DBCA)
- **Mr Vern Newton**, Development Manager, Hanson

HOW DID THE PARTNERSHIP FORM?

The partnership between Kings Park Science, DBCA (then known as the Botanic Gardens and Parks Authority, BGPA) and Rocla Quarry Products, now within Hanson, predated both Vern and Jason. The partnership was formed when Stephen Elliot, Vern's predecessor, saw a need for science to help their company actively deliver on a vision to restore Banksia Woodland following sand extraction. Kingsley Dixon, the then Director of Science at Kings Park, was supportive of actively developing science to support the ecological restoration of Banksia Woodland. This relationship led to a PhD project being established and undertaken by Dr Deanna Rokich between 1996 and 1999. Deanna played a key role in building the partnership both as a student and later as an employee at Kings Park.

The partnership has been carried on for the past decade by Vern Newton and Jason Stevens, with a large number of people involved in projects at the Gaskell Sand Quarry site over the 25 years of partnership.

WHO WAS INVOLVED IN THE PARTNERSHIP?

Key partners in the early formation and development of the partnership were Prof. Kingsley Dixon (BGPA), Stephen Elliot (Rocla Quarry Products, now within Hanson), Deanna Rokich (the University of Western Australia (UWA) / BGPA) and Prof. Krishnapillai Sivasithamparam (UWA). Vern and Jason have been key people involved in supporting the partnership for the past 10 years.

The partnership involved a large number of researchers and students over the years. Importantly, the Rocla/Hanson organisation was very committed to the science partnership. This has been a core organisational value and has seen commitment and interest from workers involved across the operations of the organisation.

WHY WAS THE PARTNERSHIP VALUABLE?

Rocla made a decision early in project planning to deliver the best possible ecological restoration outcomes for the site. Given the limited knowledge and practical tools available in the 1990s, Rocla recognised that a science-based partnership would best enable this. This philosophy has carried into Hanson's operation and the partnership continues to improve restoration outcomes at the site. Vern also notes the partnership is highly beneficial to the organisational culture within Hanson, with staff across the organisation invested in and valuing the benefits of high-quality restoration.

The knowledge and on-ground outcomes gained from the science-based partnership have helped Hanson demonstrate their ability to implement successful restoration when securing future resources. While not actively sought, the site has gained broader recognition, with the company welcoming visitors from around the world and students or researchers from other Western Australian universities. The partnership has been awarded two prestigious 'Golden Gecko' Awards for Environmental Excellence: in 2008 for achieving restoration excellence, and in 2017 for the publication of a Banksia Woodland Restoration Guide.

Science delivery and capacity at Kings Park Science has been enhanced by the partnership. The partnership has supported students, externally funded grant success through the Australian Research Council, and directly through co-funded positions within DBCA. The site's value as a living laboratory continues to grow with new research opportunities being presented as the site matures.

The monitoring undertaken at the site also has been valuable for both partners. Co-design and implementation of the monitoring system, which has grown over time, presents valuable baseline and change data. These data are shared and support evidence-based decision making within Hanson's operations and new research opportunities with Kings Park and partners.

WHAT WAS IMPORTANT FOR MAKING THE PARTNERSHIP A SUCCESS?

Both Vern and Jason indicate that trust was fundamental to the partnership's success. Both parties understand and value each other's priorities. They actively work to ensure activities deliver on the needs of each partner and projects are designed to fit the capacity of the partner. This requires a flexible and proactive approach. Communication is fundamental, and both organisations encourage active communication between all staff.

Universities have been important in supporting the flexible approach adopted. During periods of low funding availability, universities provided access to students to continue research activity. Universities are also good partners because they can maintain activity despite change in government direction.

Vern believes that the company's belief in innovation and continual improvement rather than compliance has been another strong driver for the partnership's success. While the partnership has seen amazing progress, Vern recognises that there are still many challenges in Banksia Woodland restoration that science-based partnerships can address.

Case Study 4.

Practical example of a long-term provenance trial of *Eucalyptus cladocalyx*

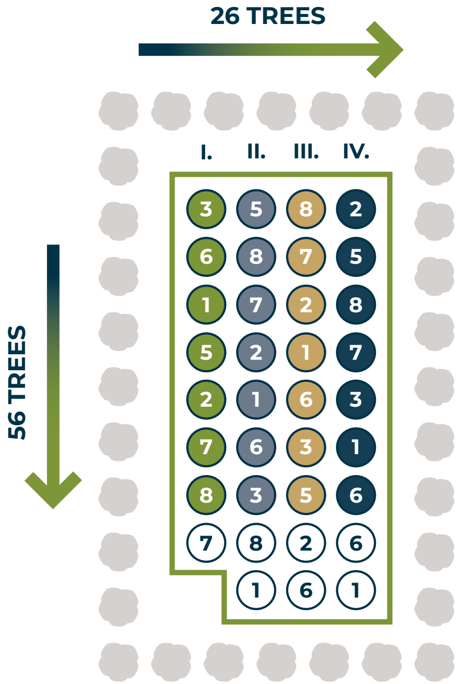
David Bush

A trial of Eucalyptus cladocalyx *was established in 2003 at Bundaleer, South Australia, within the natural range of the species by a consortium of researchers (the Australian Low Rainfall Tree Improvement Group) (Bush et al. 2009). The aim of the trial was to test seven different seedlots including the local provenance (South Flinders Ranges represented by Wirrabara), the Kangaroo Island provenance (represented by Flinders Chase), four cultivated sources and a seed production area source (Kersbrook). The researchers assumed, and hoped to prove, that growth of seedlings from the seed production area would be stronger as the trees there had been selected for good height and diameter growth. Seed was collected by forestrySA and the Australian Tree Seed Centre and each seedlot was assigned a seedlot number in the database for future reference and inclusion in future trials.*

The trial was a randomised complete block design consisting of four complete block replicates (I–IV, represented by different colours in Fig. 7.4.1), each containing seven plots, one each of the seven seedlots. The plots were randomly assigned to positions in the blocks, and each plot contains 36 trees of a single provenance established as tube stock. The site was prepared well in advance of planting by deep ripping planting lines (4 m apart), applying knock-down and residual herbicides and pegging out the plot areas with durable pegs. It was planted in winter of 2003. The plots were established with six trees per row (2.5 m spacing between trees) and six rows of trees (i.e. in 36-tree plots). The trial was surrounded by a buffer of *E. cladocalyx* planting stock.

This trial was part of a series to be established across several sites. The original specification was for eight different seed source treatments. However, seed did not germinate well for one of the seed sources (treatment 4). This treatment was omitted from this site but was included at others (Fig. 7.4.1).

As there were many extra seedlings of some other seedlots and space was available, these were planted in randomly-positioned plots to the south of the trial. While the main trial area (complete block replicates I–IV) can be analysed using the straightforward analysis of variance (ANOVA) technique (Williams et al. 2002), inclusion of data from the extra plots was made possible by using more advanced statistical methods.



TREATMENT	SEED SOURCE
1	• Leighton 1911 SA (cultivated)
2	• Bundaleer Prov trial (cultivated)
3	• Kersbrook seed production area SA (cultivated)
4	• Brown's Hill SA (cultivated)
5	• Keyneton plantation SA (cultivated)
6	• Flinders Chase SA (wild) (ATSC 20267)
7	• Wirrabara SA (wild) (20268, 20389, 20414)
8	• Lismore select VIC (cultivated)

Note: treatment 4 not planted at this site

- **7 seed sources (treatments)**
- **4 complete block replicates (I–IV), each with 7 plots**
- **36-tree plots (6 x 6 trees)**
- **7 additional plots**
- **1 row of buffer trees surrounding trial**
- **4 m between rows and 2.5 m between trees along rows**

Figure 7.4.1 ***Eucalyptus cladocalyx*** **experimental design showing the site layout and the treatments.**

ANALYSIS AND INTERPRETATION

In 2006, three years after planting, the trials were measured (Fig. 7.4.2 and 7.4.3). Survival was almost 100%. Traits measured included height and diameter at breast height (DBH, 1.3 m above ground)). The data were analysed using a technique that included the extra plots, but the result from a straightforward ANOVA analysis would have been almost identical. The graph below shows the differences in both DBH and height. These were found to be statistically significant. This result is expressed as a very low probability (p <0.001) of them being the same. The error markers on the blue DBH bars show the standard error of difference among treatments and indicate whether or not specific seedlots are statistically different from each other. For example, Kersbrook's DBH is statistically different from all other treatments, but Wirrabara and Leighton are not different from each other. The error indicators on the height bars can be used in the same way, but comparison between height and DBH is not possible. The result confirmed that selection at Kersbrook seed production area had resulted in improved growth rates (Fig. 7.4.3).

Figure 7.4.2 *Eucalyptus cladocalyx* growth in 2006. *(Photo credit David Bush)*

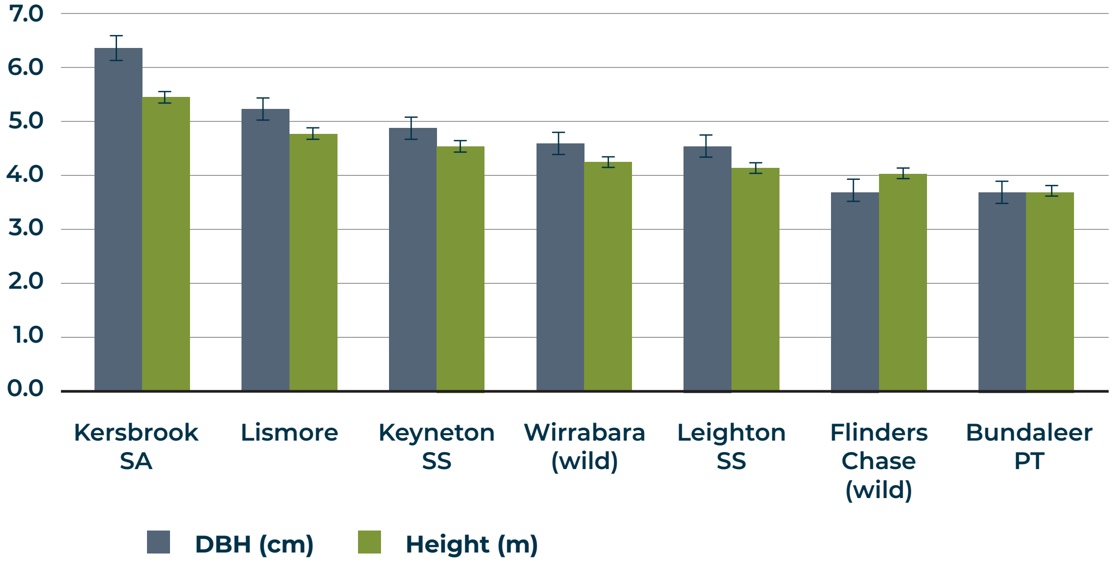


Figure 7.4.3 *Eucalyptus cladocalyx* tree diameter (diameter at breast height, DBH) and height for each treatment, three years after planting.

Case Study 5.

Establishing a network of provenance trials to inform eucalypt woodland restoration in the Tasmanian Midlands

Peter A Harrison, Tanya Bailey, Brad Potts

The Midlands of Tasmania is a key agricultural region which has undergone extensive anthropogenic modification over the past two hundred years, resulting in the fragmentation and deterioration of once extensive and biodiverse eucalypt woodlands. This region has been targeted for landscape-scale woodland restoration with the aim to reconnect existing vegetation remnants through 'corridors' and 'stepping stones', to improve habitat quality and facilitate the movement of native mammals and birds across the landscape from the Eastern Tiers to the Central Highlands of Tasmania (Gilfedder et al. 2021). However, a long history of site modification and extensive rural tree decline coupled with on-going climate change posed a challenge and added complexity to the appropriate choice of seed (Harrison 2021).

Greening Australia in collaboration with the University of Tasmania established a network of research trials embedded within 1000 hectares of restoration plantings across the Midlands to test alternative seed provenancing strategies (Bailey et al. 2021). The establishment of these trials followed a common multi-step protocol (Fig. 7.5.1). This case study details the process undertaken to establish a *Eucalyptus pauciflora* provenance trial where open-pollinated seed was collected and maintained as separate individual tree seedlots within a provenance. This trial was established at the Dungrove restoration site in the Southern Midlands of Tasmania, embedded within broader restoration plantings (Fig. 7.5.2).

IDENTIFYING PROVENANCES

The objective of the provenance trial was to determine the extent of intraspecific genetic variation in performance and environmental adaptation within *E. pauciflora*. To this end, 37 provenances were selected across the known geographic and environmental distribution of *E. pauciflora* in Tasmania (Gauli et al. 2014; Gauli et al. 2015; Gauli et al. 2013). This extensive sampling of the native gene pool allowed various provenancing strategies to be evaluated including the admixture (Breed et al. 2012), composite (Broadhurst et al. 2008), and climate-adjusted (Prober et al. 2015) strategies. Open-pollinated seedlots within provenances were kept separate to allow within provenance genetic variation to be assessed.

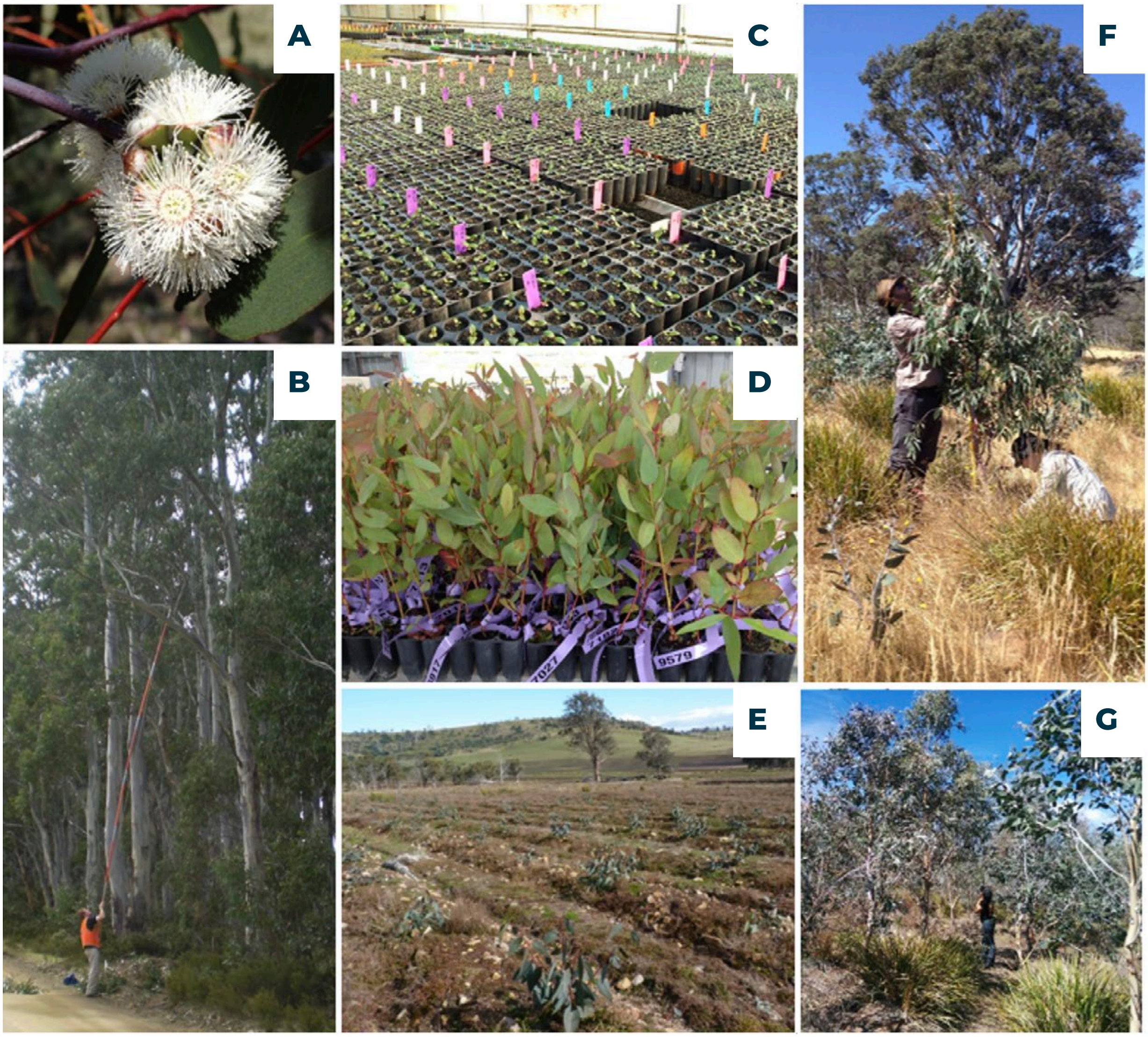


Figure 7.5.1 Steps in undertaking provenance trials, illustrated for *Eucalyptus pauciflora* in Tasmania. (a) Flowers of E. pauciflora: a widespread species being studied in field and glasshouse provenance trials in Tasmania; (b) seed was collected from open pollinated wild trees from provenances across the geographical distribution of *E. pauciflora* in Tasmania; (c) open-pollinated seedlots from each individual tree (family) were grown in separate seedling trays and randomised within a commercial nursery; (d) individual seedlings from each family were labelled and sorted into experimental designs ready for growing on in field trials; I planted common garden field trial of individually pedigreed *E. pauciflora* at 10 months of age; (f) tree height and stem diameter were measured in *E. pauciflora* provenance trial at 3 years 3 months of age, and (g) reproduction was measured at 5 years of age. *(Photos reproduced from Prober et al. (2016). Photo credits T Bailey (a, c, d, f), J Worth (a) and P Tilyard (e, g))*

COLLECTING AND STORING SEED

Prior to sampling a provenance, broad provenance information was collected, including the scale of isolation (i.e. fragmentation) following Borralho and Potts (1996), the presence of other eucalypt species, and stand characters such as the level of reproduction. Within a provenance, between seven to 16 individual trees were sampled at least 100 m or two-canopy heights apart to minimise the probability of sampling closely related individuals (Jones et al. 2007). For each tree, voucher specimens, small samples of foliage for DNA extraction, and photographs were taken; the scale of fragmentation following Borralho and Potts (1996) and geographic coordinates were recorded; and a unique identifier on a metal tag was permanently applied to the mother tree to maintain the pedigree of the offspring. Capsules were then harvested and placed within a paper collecting bag labelled with the provenance name, unique tree identifier, and date of collection.

GROWING SEEDLINGS FOR PLANTING

Weighed amounts of seed plus chaff of each individual open-pollinated seed collection from each tree sampled (hereafter ‘family’) were sent to a commercial nursery for propagation, each labelled with their unique wild mother tree identifier. To minimise any potential confounding issues during the propagation process, families irrespective of provenance were randomly allocated to a position within the germination house where they remained until seedlings reached plantable size (Fig. 7.5.1c). Seedlings from family trays were labelled and then, prior to transport to the planting site, sorted into their experimental design (Fig. 7.5.1d) — in this case it was into eight replicates of a randomised complete block, with each family represented once in each block.

The design can be summarised as follows:

Treatments: 37 provenances x average 10 families = 370 families

Complete block replicates: 8

Trees per block: 1

Total trees in trial: 370 x 8 = 2960

SITE PREPARATION PRIOR TO PLANTING

The trial site was prepared following a standard forestry silviculture approach where seedlings were planted along rip lines that were ripped and mounded (Fig 7.5.1e). Prior to cultivation, weed control was undertaken using a knock-down herbicide. After cultivation, replicate blocks were randomly assigned across the trial site (Fig. 7.5.2) with the geographic coordinates of each corner recorded using a differential GPS and marked using a semi-permanent metal stake. The bottom left-hand corner of each replicate was tagged with the block number and corresponded to the starting position of the first plant in each block. To exclude livestock and native marsupials the site was fenced with a standard stock fence.

PLANTING EXPERIMENT AND CHECKING

Seedlings with their unique label were planted into each of the eight experimental replicates using a team of two people per block. To ensure that the randomised block design was maintained, one person was assigned the planter with the other person handing the seedling for planting in the exact layout as in the trays from (iii). After planting, each block was checked against the original design by cross-referencing the position of each seedling using the unique identifier (Fig. 7.5.1e). This critical step ensured that the seedlings were planted in the expected order following the design plan with any anomalies noted, and provided the map upon which to undertake follow-up assessments (Fig. 7.5.1f, g).

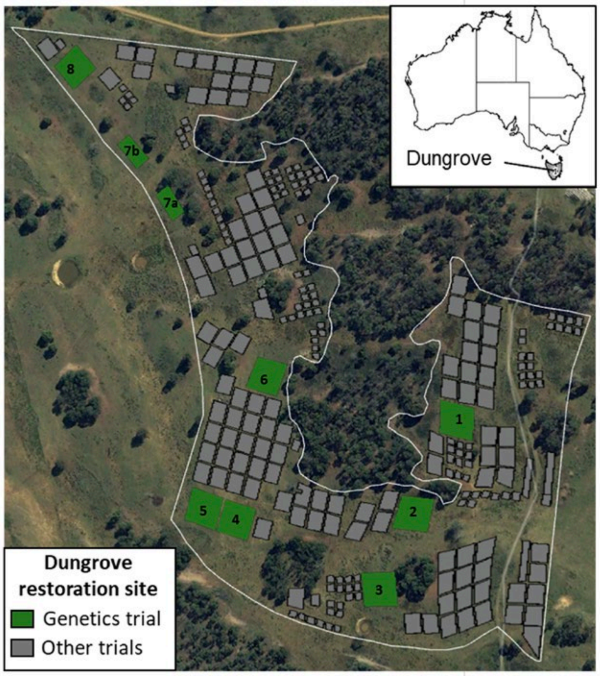


Figure 7.5.2 Location of the eight replicates (green polygons) of the provenance trials (referred to here as ‘Genetic trials’) embedded within the broader restoration plantings at the Dungrove site (white polygon outline). See Bailey et al. (2013) for description of other experimental trials (grey polygons) that have also been embedded at this site.

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Case Study 6.

Prescribed burning and weed management interactions in Perth’s urban bushlands

Russell Miller, Ben Miller

The management of urban bushlands is a complex issue with many interacting factors but few viable management options. A key issue in the urban bushlands of Perth, Western Australia is the invasion of exotic grasses, mostly originating from South Africa.

These grasses have a direct negative impact on native biodiversity, outcompeting native plants for limited resources. They also alter fire risk, favouring shorter fire intervals and broader fire seasons by rapidly accumulating biomass after fire, increasing fuel continuity in otherwise sparse post-fire vegetation, and drying out or ‘curing’ earlier in the fire season than native woody plants. In turn, more frequent fire can enhance the spread of invasive grasses by promoting seed germination and seedling establishment. Many invasive grasses can also resprout after fire and take advantage of the post-fire soil nutrient pulse to further enhance their growth. The pattern of invasive grasses promoting the spread of fire, and fire promoting the spread of invasive grasses is known as the ‘grass-fire cycle’.

The aim of this project was to examine the effects of different prescribed burning and weed management treatments on native plant communities, invasive grasses and fire risk in fire-prone woodlands around Perth. Researchers at Kings Park Science partnered with bushland managers in site selection, experimental design, treatment implementation and survey. The experiment was embedded in business-as-usual weed and fire management practices.

The first two replicate sites were established in Kings Park and Bold Park, two large inner-metropolitan parks managed by the Botanic Gardens and Parks Authority (BGPA). At these sites, three prescribed burning treatments (no fire, short or moderate return intervals) and two weed management strategies (none or standard BGPA weed management) were designated to each of six, 1.5 hectare treatment units.

The different treatments were applied across a full factorial design:

1. no prescribed burning and no weed management;
2. no prescribed burning and weed management;
3. moderate interval prescribed burning and weed management;
4. moderate interval prescribed burning and no weed management;
5. short interval prescribed burning and weed management; and
6. short interval prescribed burning and no weed management.

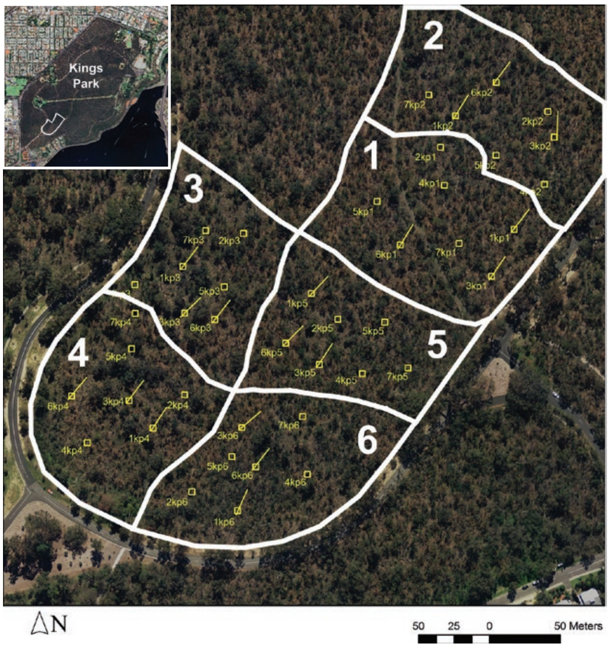
Given the challenges of implementing prescribed burning in a high profile urban environment without disturbing the site with many fire breaks, and the desire for management treatments to reflect standard management practices, the treatment units were neither replicated nor randomised within sites. Instead plots to be burnt and/or managed for weeds were located adjacent to each other in a pseudo-replicated design within each site. True replication occurred in the experiment with the design implemented in five bushland reserves across different years and seasons. While pseudo-replication within each site is not ideal and may reduce the statistical power of the experiment, it resulted from fundamental site constraints. Pseudo-replication can also be dealt with during data analysis by assessing spatial autocorrelation, averaging data from sub-plots into a single data point and employing mixed effects statistical models.

Within each treatment unit, seven sub-plots and three transects were established to measure native and weed species richness, cover and abundance, and fuel load and structure. Sub-plots followed a nested design to measure different components of the plant community at the appropriate scale. Annual plants were recorded within 0.5 × 0.5 m quadrats that were nested within the larger 4 × 4 m sub-plots which were used to record all perennial shrubs and geophytes (e.g. orchids) (Fig. 7.6.1).

The southwest corner of each sub-plot was used as the centre of a 10 m radius circular sub-plot for all tree species, and, for three of the sub-plots per treatment, as the starting point for transects. Sub-plots and transects were measured before the first treatments were implemented, immediately after first treatment and at regular intervals thereafter to follow the long-term impact of fire and weed management.

Now, nine years after these experiments were established, the study has been expanded to a total of five replicate sites partnering with local councils and a local university. The first short fire interval treatments have been implemented in

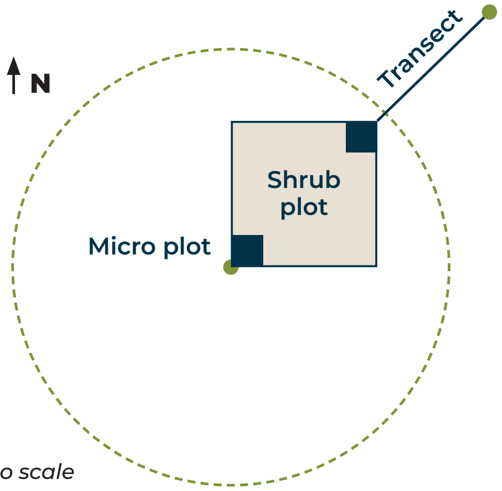
A



B

BLOCK	PRESCRIBED BURN TREATMENT	WEED MANAGEMENT
1	No fire	None
2	No fire	Standard
3	Moderate interval	Standard
4	Moderate interval	None
5	Short interval	Standard
6	Short interval	None

C



Not to scale

Figure 7.6.1 The Kings Park site showing the layout of the pseudo-replicated experimental design. True replication occurs across different sites in the Perth region. (a) Location and arrangement of treatment units where each treatment contains seven sub-plots (small squares) and three transects (SW-NE lines). (b) Assigned treatments for each unit, comprising three prescribed burning treatments (no fire, short interval or moderate interval) and two weed management strategies (none or standard weed management). (c) Nested sub-plot and transect design. Different sized quadrats are used to measure different components of the plant community at the appropriate scale.

the Kings Park and Bold Park sites, and results thus far confirm previous studies showing that fire enhances the spread and cover of invasive grasses, and that weed management is effective in reducing their cover. In the absence of weed management, fuel continuity attributed to invasive grasses is high, and might contribute to enhanced fire risk. We have also confirmed that fire encourages native species regeneration with many native seedlings establishing after fire, native perennial species increasing in abundance, and several native species that were not observed pre-fire have emerged from soil seed banks. Of the burnt treatment units, native species recovery was greatest in those that also received weed management, suggesting that competition from invasive grasses may depress native species regeneration. In Bold Park, where invasive grasses were already prolific before the experiment, native species abundance more than doubled after weeds were managed in the post-fire environment. While this long-term study has many years left to run, initial results show that failure to manage grass-fire interactions may lead to the degradation of ecological values and enhanced fire risk.

Case Study 7.

Monitoring a provenance trial in the Cumberland Plain Woodland

Nola Hancock

The following case study is based on a provenance trial established in 2010. The study compared survivorship and early growth of plants grown from local versus non-local seed sources (provenances) using six commonly occurring species, typical of the Cumberland Plain Woodland vegetation community in western Sydney, NSW (Hancock et al. 2013). Seeds from five provenances (one local and four non-local provenances) of each species were grown in a glasshouse and then transplanted into two field sites in western Sydney (a common garden experiment). In this experiment, early monitoring of plants was important to validate the field design and provide the basis for longer-term monitoring. This case study details the monitoring methods used for one of the six test species, Eucalyptus tereticornis*.*

We addressed the following questions before monitoring commenced:

1. Which plant traits (variables) will be monitored?
2. Which methods will be used to measure the traits and at what frequency will they be measured?
3. What equipment is needed for measuring? How will the measurements be recorded in the field?

WHICH TRAITS WILL BE MONITORED?

To determine which traits we needed to measure to answer our experimental questions we conducted a thorough review of the literature. The length of the experiment and the focal species also determined which traits to measure. For example, we considered that a 12-month experiment is not long enough to gather data on flowering or seeding for long-lived plants such as eucalypts. Therefore, in this case study, we measured survival, height, stem diameter, herbivory, and biomass to compare the performance of different provenances of *Eucalyptus tereticornis*.

HOW AND WITH WHAT FREQUENCY WILL THE TRAITS BE MEASURED?

To identify the best measuring approach we searched the literature for similar experiments. Using measuring approaches common to other studies allows for comparison of similar experiments and broad reviews of the published literature. However, we also considered whether new and improved measuring approaches were available.

The frequency of monitoring was determined by considering the traits to be measured, the amount of funding available, and the length of the experiment. We knew that mortality was likely to be highest in the establishment phase, so we regularly monitored for survival immediately after planting, and then with decreasing frequency (i.e. monthly, quarterly and then 6-monthly).

In this case study, we recorded the following data:

- **Survivorship:** We assessed plants as 'alive' (green leaves and/or stem) or 'dead' (no green anywhere on the plant or plant missing). Plants were scored on a weekly basis during the first six months and then monthly thereafter.
- **Growth traits:** Stem height and diameter measured before planting in the field and then every three months.
    - **Stem height:** Plants were measured in situ from ground to apical meristem using a tape measure (Fig. 7.7.1).
    - **Stem diameter:** Stems were measured using a calliper at ground level and two measurements were taken at right angles and averaged.
    - **Aboveground total biomass:** At the end of the experiment, after all other measurements were taken, the plant was cut at ground level, placed in a paper bag with the plant number written on the front. Plant material was dried for at least two days at 70°C, then weighed.
- **Functional traits:** All measured at experiment completion.
    - **Specific leaf area (SLA):** Five mature leaves per plant (fully expanded, unshaded and without herbivory) were collected from as close to the terminal apex as possible at the time of harvest. Fresh leaves were put in pre-numbered plastic bags and placed in an esky. Post field trip, the fresh leaves were scanned using ImageJ software (http://rsb.info.nih.gov/ij/download.html) and the area measured. The leaves were then dried for ≥ 3 days at 70°C and weighed. Measurements of the five leaves were averaged to calculate the average SLA per plant as per Cornelissen et al. (2003).
    - **Leaf width: length ratio:** Lamina length along the midvein and lamina width at the widest point were measured with ImageJ using the same leaves as for SLA.

Figure 7.7.1 Peri Tobias measuring stem height. At the end of the experiment, the plant was cut at ground level and placed in a paper bag ready for drying before weighing. *(Photo credit Nola Hancock)*

- **Herbivory:** The total amount of defoliation and leaf necrosis per plant was visually assessed at the time of harvest and scored: 0–1%, 1–5%, 5–25%, 25–50%, 50–75%.

WHAT EQUIPMENT IS NEEDED FOR MEASURING?

Before the field trip, we determined the traits to be measured and the equipment required for measuring these traits and for data recording. We also made sure that all measuring equipment was listed, accounted for and potential system failures and back up plans were in place before setting off to the field site. Based on experience from previous projects, we used two different methods to record data in the event of data being lost or a computer malfunction. We also pre-determined the order in which monitoring took place, which is especially important if any actions are likely to affect the result of the next measurement. For example, at the last monitoring event, if the plant material was to be harvested, dried, and weighed, all other measurements must be taken first. In this case, data were hand recorded and transcribed to an Excel spreadsheet the following day.

Below is the equipment list for the final monitoring day:

- Pre-prepared recording sheet to record date, field site location, name of monitor, location of plant, plant number, provenance number, measurement.
- Pencils x 3.
- Tape measure for stem height.
- Calliper for stem diameter.
- Secateurs and loppers.
- Brown paper bags with individual plant numbers written on the front, plus spare bags.
- Eraser.
- Plastic bags with individual plant numbers written on the front, plus spare bags and marker pens.
- Esky with ice to put plastic bags in.

For some sites, other items may be needed, such as first aid kits, food and water and communication equipment. We ensured that all equipment was available prior to the field day and for post-sampling processing, including leaf imaging equipment (scanning needs to be done while leaves are fresh) and ovens for drying plant material.

PARTNERSHIPS, DATA ANALYSIS AND REPORTING

This study was conducted in partnership with Macquarie University as part of a PhD, and as such, there were plans in place for data analysis and reporting. In this case, this study was published (Hancock et al. 2013).

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Case Study 8.

Carbon-funded ecological restoration at Peniup, southwestern Australia (2008-2018) monitoring restoration effectiveness

Rachel Standish, Barry Heydenrych, Justin Jonson

Peniup is a restored ex-farm property owned by Greening Australia that sits in the Gondwana Link corridor in south-western Australia. The Gondwana Link vision is to conserve and restore native ecosystems along the length of a 1000 km corridor that includes dry mallee woodlands and wet coastal forests (Bradby et al. 2016). Peniup was one of the first carbon-funded ecological restoration projects in Australia. In 2008, Peniup was planted and direct-seeded with native woody species using soil type and landscape position to inform choice of seedlings and seed mixes for nine soil-vegetation associations (Jonson 2010). Peniup has been monitored annually since 2008; there are reports of seedling establishment from sown seed (Hallett et al. 2014) and species richness, stem density and aboveground biomass at five years (Perring et al. 2015).

GOALS

The goals of the embedded experiment were to gauge success of restoration effort in different soil types by monitoring recruitment, persistence, and growth of native woody species in plots through time. In addition to the outcomes mentioned above, these data have been used to track community assembly and attrition rates for plant establishment from seed as described in Jonson (2010) and could be used to determine facilitation among species in seedling establishment phase (RJ Standish, unpublished data)

DATA

There are 42 permanent plots at Peniup; plots are 10 m x 10 scalp rows (~0.014 ha). Plots were randomly located within each of the nine soil-vegetation associations, with the number of plots per association ranging from three to nine to reflect the spatial extent of each association. Trees were planted and seeds were sown in the scalp rows, which created an ideal opportunity to collect spatially explicit presence and absence data for plants in these plots through time (Fig. 7.8.1). In the first year after restoration we also measured weed cover in quadrats within the plots (Fig. 7.8.2). In addition to these measurements we also measured stem diameter of trees and shrubs (Fig. 7.8.3). Photo monitoring has also occurred each year for ten years and some drone imagery of the restoration site has recently been captured.

Figure 7.8.1 *Acacia gonophylla* recruit at the Peniup Restoration site. *(Photo credit Rachel Standish)*

DATA OWNERSHIP AND RESPONSIBILITIES

Several people have helped with monitoring over the years. The core group was Justin Jonson, Rachel Standish, David Freudenberger and a Greening Australia representative (currently Barry Heydenrych). The data are jointly owned by the core group. Justin Jonson curated the data from 2008 to 2009, Rachel Standish from 2010 to 2013, and David Freudenberger from 2014 to 2018. Data are stored in a Microsoft Access database. Training has been ad hoc depending on the availability and willingness of student helpers. The members of the core group are routinely invited to co-author any publications of the data. Greening Australia manages the experimental site and provides on-site accommodation. The collaborative monitoring project has survived despite the core members having moved workplaces and changed responsibilities through time. This is due to a high level of commitment by individuals, as well as relatively low levels of resources required for maintenance and monitoring.

REPORTING

Monitoring has not been funded and consequently reporting has been limited (e.g. Jonson 2009, 2016). Publications have resulted from the combined efforts of core members (e.g. Jonson 2010), student researchers (i.e., Lauren Hallett) and via collaboration with people outside the core group especially Tim Morald, Mike Perring and Richard Hobbs. Monitoring has identified differential effects of soil type on seedling recruitment and survival: high and low respectively for sandy soils, and low and high respectively for clay soils (Hallett et al. 2014). Another finding is that soil-vegetation association, stem density, and species richness explain between 60 and 80% of variation in above and belowground biomass of woodland assemblages (Perring et al. 2015). From a practical perspective, this project has informed woodland restoration throughout the south-west region (Jonson, unpub. data).

Figure 7.8.2 Lauren Hallett, Justin Jonson (foreground) and Tim Morald (right) looking for seedlings in a scalped row within a plot at Peniup same period (2009 soon after restoration was initiated). *(Photo credit Rachel Standish)*

Figure 7.8.3 Rachel Standish and Tim Morald recording stem diameters of a mallee in April 2018, ten years after restoration was initiated. Note the absence of weeds and presence of native leaf litter in the foreground. *(Photo credit Mike Perring)*

INFRASTRUCTURE

Plots are marked with fence droppers and numbered with pressed metal tags. The availability of on-site accommodation, at no cost to researchers, has been key to the success of the monitoring effort allowing resources to be allocated elsewhere.

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Case Study 9.

Assessing restoration outcomes using standardised community-based monitoring methods in Victoria, 2019-2020

Sacha Jellinek, Tim O’Brien, Andrew F Bennett

Nationally, a large number of groups are involved in restoration activities such as revegetation, but there is still much to learn about the survival and growth of native plants after planting, and how this varies across sites and regions (Jellinek et al. 2021). In Victoria, a program undertaken by La Trobe University (S Jellinek and A Bennett) and the Arthur Rylah Institute for Environmental Research (Department of Environment, Land, Water and Planning represented by T O’Brien) sought to engage with Catchment Management Authorities (CMAs), Landcare groups, non-government organisations such as Greening Australia and Bush Heritage Australia, and other landholders to assess revegetation outcomes across the state.

The project sought to develop a standard monitoring protocol so community groups could assess the survival of plant species, an important first outcome of revegetation activities.

GOALS

The goals of the program were to: i) develop a monitoring protocol that community groups can use to collect information in a standard way to monitor planting outcomes; ii) assess the outcomes of revegetation, in terms of the survival and growth of planted trees, shrubs and understory plants; iii) determine the factors that affect variation in survival among different species and different regions, and iv) identify ways that data could be collected and stored electronically to help collate and analyse revegetation outcomes and provide results to the project stakeholders (Jellinek et al. 2021).

DESIGN AND METHOD

In the 2019 planting season (typically between June to October), organisations and individuals interested in trialling the monitoring method were asked to mark two or more monitoring plots (usually 50 m x 4 m in size) within a planting site and record the species and the number of each species planted within the plot area directly after planting (see Jellinek et al. 2020 for methods). The overarching design focused on describing the landscapes where the plantings were undertaken and the planting methods used, and testing how plant survival and growth was influenced by site and environmental variables.

Other information recorded included land use history, the goal of the planting, if the site had been restored previously, a description of the landscape being planted, and the site preparation undertaken and the planting techniques. The participants then revisited the site after the first summer (March to April 2020) and recorded all plants that were alive (to species level) in the plot and the average height of the first five plants of each species recorded. The presence of grazing and the cover of weeds and bare ground were also recorded on-site. Environmental and climatic variables were obtained by desktop analysis. Participants were also sent a questionnaire to assess their views on the ease of use of the monitoring methods, any factors that limited their ability to undertake the monitoring, and ways in which the monitoring could be improved.

DATA OWNERSHIP AND RESPONSIBILITIES

Data was initially collated and stored on a Microsoft Access Database at La Trobe University. Sites and plots were given an individual number, which related to a spatial database stored in ArcGIS.

RESULTS

Seven of the ten CMA areas in Victoria were included in this project, with a total of 62 sites and 123 plots being assessed by participants (largely Landcare groups, CMA staff or non-government organisation staff).

On average 10 species were planted at each site (max = 26, min = 2), with Port Phillip and Westernport, East Gippsland and Corangamite having the greatest diversity planted. Port Phillip and Westernport and East Gippsland CMAs also had the highest density of plantings – 4,000 to 5,500 plants per hectare. The average survival of the plants counted was 61%, with Port Phillip and West Gippsland having the highest survival rates and Corangamite the lowest (Jellinek et al. 2021). The amount of annual rainfall and if the plants had been protected by guards had substantial impacts on plant survival. Manna gum (*Eucalyptus viminalis*) and swamp gum (*E. ovata*) had some of the highest survival after the first summer, while woolly tea-tree (*Leptospermum continentale*) and sweet bursaria (*Bursaria spinosa*) had some of the lowest (Fig. 7.9.1).

The study participants generally found the monitoring method easy to understand and implement (86%, n = 22), and over 80% said they would be prepared to use the method in the future. Participants noted that they would be more likely to undertake future monitoring if there was funding for monitoring activities (68%), an online database for data entry and reporting (65%), and staff time allocated towards monitoring (28%).

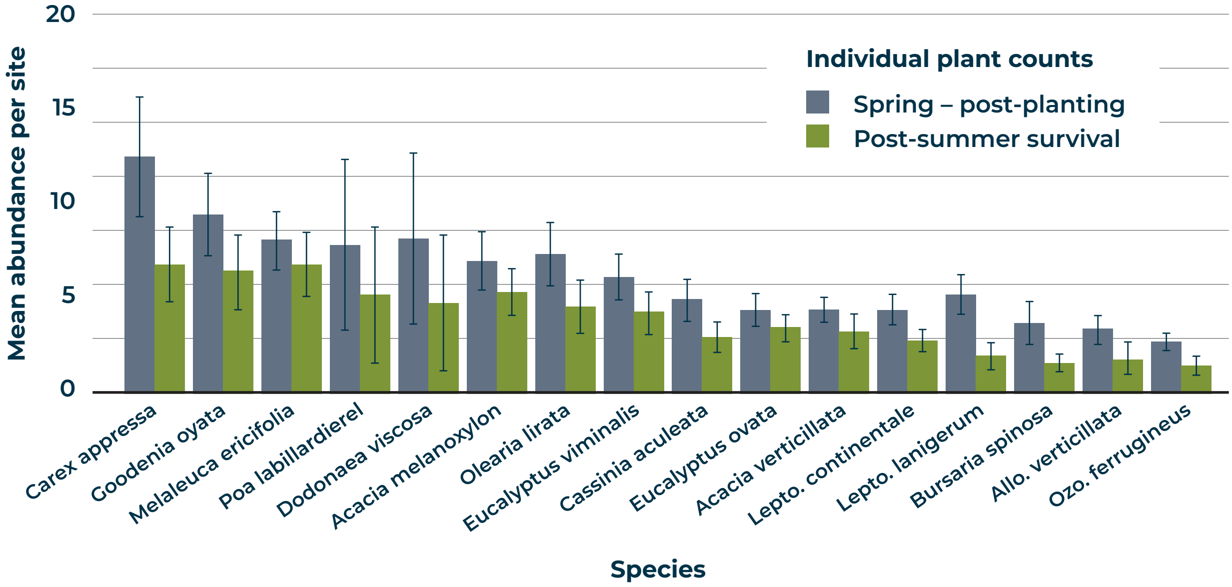

Figure 7.9.1 The abundance of the 16 most commonly planted species surveyed in spring after planting and after the first summer. Bars represent standard errors. Lepto. = *Leptospermum*, Allo. = *Allocasuarina*, Ozo. = *Ozothamnus*.

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Appendices

Appendix 1.
Glossary

Several terms taken from Gann (2019).

ACTIONABLE SCIENCE: Data, analyses, projections, or tools that can support decisions in natural resource management; it includes not only information, but also guidance on the appropriate use of that information.

ASSISTED REGENERATION: An approach to restoration that focuses on actively triggering any natural regeneration capacity of biota remaining on site or nearby as distinct from reintroducing the biota to the site or leaving a site to regenerate. Interventions include removal of pest organisms, reapplying ecological disturbance regimes and installation of resources to prompt colonisation.

BIOLOGICALLY MEANINGFUL RESPONSE: Statistical significance does not necessarily equate to ecological or biological significance. For example, it may not be biological meaningful if the treatment differences were less than 5% even if this was a statistically significant factor. Furthermore, a statistically significant 'factor' with multiple levels may not be biologically meaningful if the differences cannot be interpreted (e.g. no spatial or climatic pattern).

BLOCK: 'Blocking' is a method often employed in experimental design that allows the arrangement of experimental units (e.g. a set plots of each treatment) into groups or 'blocks' to help account for spatial environmental variation occurring across experimental sites (e.g. gradient of soil water content, or wind exposure from ridgetop to lower slopes). This procedure reduces the unexplained ('residual') variation in the response variable (e.g. height, survival) by attributing part of the total variation to differences arising between blocks, thus providing more precision to test differences between treatments (e.g. species/provenance. Blocks can be constructed through 'randomised complete block' and 'incomplete block' designs whereby each block replicate contains one plot of each treatment or a partial set of treatments, respectively.

CONTROL (TREATMENT): An experimental 'control' is often used as a reference point to compare against different levels of the experimental treatments. The control receives no treatment but is identical to the other treatments in all other respects. In embedded experiments the control could involve, for example, a standard planting method (for comparison with a new planting method), or a local provenance or species (for comparison with alternative provenances or species).

CO-PRODUCTION: Collaboration among managers, researchers, and other stakeholders, who, after identifying specific decisions to be informed by science, jointly define the scope and context of the problem, research questions, methods, and outputs, make scientific inferences, and develop strategies for the appropriate use of science.

DATA SHARING: Making data available so it can be freely used by others.

ECOLOGICAL RENOVATION: Ecological management and nature conservation actions that actively allow for environmental change (typically climate change), whilst where feasible supporting aspirations to conserve many historical values of ecosystems as expected for both nature conservation management and ecological restoration.

ECOLOGICAL RESTORATION: The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.

ECOSYSTEM SERVICES: The direct and indirect contributions of ecosystems to human wellbeing. They include production of clean soil, water, and air; moderation of climate and disease; nutrient cycling and pollination; provisioning of a range of goods useful to humans; and potential for the satisfaction of aesthetic, recreation, and other human values. These are commonly referred to as supporting, regulating, provisioning, and cultural services. Restoration goals may specifically refer to the reinstatement of particular ecosystem services or amelioration of the quality and flow of one or more services.

EDGE EFFECTS: Changes in population or community structures that occur at the boundary of two or more habitats.

EXPERIMENT: Experiments are a means of testing hypotheses. When most people think of an experiment, they think of manipulative experiments in which we manipulate a variable and measure the outcome, but an experiment can also be a comparison of two situations where a variable is present or absent (e.g. weeds versus no weeds).

EXPERIMENTAL DATA: Data measured or recorded from experimental plots or to monitor conditions during an experiment (e.g. measurements of plant height, soil nutrients, species richness, rainfall or fire intensity).

EXPERIMENTAL DESIGN: A set of procedures used to systematically test a hypothesis.

EXPERIMENTAL SITE: The site where the experiment is being established. The size and shape of the experimental site depends on the treatment combinations, replication, plot size and the nature of the available sites (among other things). The experimental site can be replicated to test whether similar findings can be found in similar or different sites, however the sites should be separated to ensure they are independent of each other (see 'Pseudoreplication'). It may be expected that a treatment may have different outcomes depending on the experimental site, for example, the application of irrigation may not improve plant survival in wet experimental sites, while it has a large effect in dry sites.

EXPERIMENTAL UNIT: The 'experimental unit' is the smallest unit to which treatments are applied. For example, in an embedded experiment, the experimental unit could be an individual plant OR the plot (see 'Plot') to be monitored for treatment effects.

FACTOR: A 'factor' refers to the type of manipulation applied in an experiment, that has two or more 'levels' (e.g. two levels of fertiliser application; one of which may be the 'Control Treatment' where with no fertiliser or a standard fertiliser amount). For example, in a comparison of four plant species and two sowing depths — species is a factor that has four levels, sowing depth is a factor with two levels, and an individual treatment comprises a specific species x sowing depth combination.

FULL FACTORIAL EXPERIMENT: A 'full factorial experiment' tests all combinations and levels of each factor in the experiment. For example, factor 1 with levels 1 and 2 combined with factor 2 levels A and B gives four different combinations (1 + A, 1 + B, 2 + A, 2+ B = four treatments). When the two factors have multiple levels, the total number of treatments becomes large quite quickly (e.g. Factor 1 (8 species) X factor 2 (3 sowing depths) = 24 treatment combinations). The advantage of conducting a full factorial experiment is that the effect of the factors, along with the interaction between factors, can be determined in a statistical analysis.

LEVELS: The possible values of a factor in an experiment. For example, an experiment might use four plant species which would be four levels or might sow seed at two depths which would be two levels.

METADATA: Data that provides information on other data, i.e. it is data about data. For example, a photo taken on a mobile phone automatically will have metadata such as date, time and location to each photo.

MONITORING: The systematic collection of data or information over time, often at regular intervals, but also opportunistically. Targeted monitoring focuses on the specific questions the experiment was established to investigate. Surveillance monitoring is designed to detect change over time and involves gathering long-term data on performance of single or multiple trials.

NATURAL REGENERATION: Germination, birth, or other recruitment of biota (including plants, animals, and microbiota) that does not involve human intervention, whether arising from colonisation, dispersal, or in situ processes.

NUISANCE VARIABLES: Even with the best experimental design there are a number of other nuisance variables that can influence the outcomes of an embedded experiment. Commonly, this includes variability in the temperature or rainfall, which can be logged directly at the planting site or acquired from the Bureau of Meteorology (BOM, weather station or modelled). Other factors such as weed or pest loads can be monitored and incorporated into the statistical analyses as nuisance variables or co-variables to facilitate the detection of treatment effects.

PLOT: A spatial unit whose size is determined by organisms or ecosystems under study (e.g. 25 m × 25 m for woodland trees or 10 x 10 m for grasslands). In terrestrial ecology, a plot is typically a contiguous group of plants or patch of vegetation that has the same treatment applied to it. For example, a plot could comprise plants from the same provenances or plants that have had the same management practices (e.g. fertiliser rate) applied to them. Experimentation with grasses and small plants, for example, often utilise plots. Importantly replicated plots of different treatments should be randomly distributed within blocks or across the experimental site.

POWER: Statistical power is the likelihood that a study will detect an effect of the treatments when there is an effect there to be detected.

PREDICTOR VARIABLES: Variables that are used to explain/predict variation in response variables with statistics. Also called explanatory variables.

PROVENANCE: Refers to the location where a plant lives or from where seed has been collected.

PSEUDOREPLICATION: Where observations that are not independent of each other are treated as replicates in the statistical analysis. This often happens when multiple samples are taken from a single plant or plot, or multiple 'plots' are located within a single treatment area. Examples include placing plots within one fire scar rather than separate fire scars when investigating outcomes of burning, or treating individuals or sub-plots measured from the same plot as replicates. Independence may also be compromised when there is insufficient distance between plots, such that trees in one plot may behave similarly to, or interact with, trees in another plot because they are growing nearby. (For more examples see Hurlbert SH. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs. 54: 187–211.)

RANDOMISATION: A method to allocate treatments to an experimental unit based on chance alone. This might be achieved, for example, by writing treatment names (including controls) on separate scraps of paper, then drawing them out of a hat for allocation to an experimental unit, or using a random numbers table/generator. For larger experiments, algorithms implemented on computers can be used to perform the randomisation. Randomisation is a critical aspect of any experimental design as it minimises the likelihood of experimental bias and hence drawing false conclusions.

RECOVERY: The process by which an ecosystem regains its composition, structure, and function relative to the levels identified for the reference ecosystem. In restoration, recovery is usually assisted by restoration activities — and recovery can be described as partial or full.

REFERENCE ECOSYSTEM: A representation of a native ecosystem that is the target of ecological restoration (as distinct from a reference site). A reference ecosystem usually represents an intact version of the ecosystem complete with its flora, fauna, and other biota, abiotic elements, functions, processes, and successional states that might have existed on the restoration site had degradation not occurred, and adjusted to accommodate changed or predicted environmental conditions.

REFERENCE SITE: An extant intact site that has attributes and a successional phase similar to the restoration project site and that is used to inform the reference model. Ideally, the reference model would include information from multiple suitable reference sites.

REHABILITATION: Management actions that aim to reinstate a level of ecosystem functioning on degraded sites, where the goal is renewed and ongoing provision of ecosystem services rather than the biodiversity and integrity of a designated native reference ecosystem.

REINTRODUCTION: Returning biota to an area where it previously occurred.

REMEDIATION: A management activity, such as the removal or detoxification of contaminants or excess nutrients from soil and water, that aims to remove sources of degradation.

REPLICATION: The number of copies of treatment and control experimental units. In other words, a replicate comprises a single set of all of the treatment combinations to be compared in an experiment. Replication is the repetition of this set (i.e. creating multiple replicates) across an experimental site. Replication is fundamental for estimating the 'within treatment variation', which in turn provides the basis for statistical tests that compare it with variation between treatments. A logical expectation is that, if a treatment makes a difference to the outcome of interest, the variation between treatments would be greater than the variation within treatments. This statistical test becomes more powerful as more replicates are available for estimating the within and between treatment variation.

RESPONSE VARIABLES: Variables that are expected (hypothesised) to change in response to the treatments applied to the experimental units. It is important to clearly identify the response variables that will be measured (specifying when, what, and where measurements will be taken). If, for example, plant survival and growth are the desired response variables then it is important to obtain a baseline shortly after the time of planting to compare to another point in time (or series of time points). Here it will be important to consider how long the treatment effects will take to reveal themselves and when the effects may be greatest (e.g. following summer extremes). Given temporal variability it may be best to take measurements at multiple points in time. In this case each plant is the experimental unit, which will be measured for survival, defined as the presence of green leaves (although more quantitative measures could be taken, such as, the percentage of growing tips with green leaves), and growth, measured as plant height from the ground to the top of the canopy (although basal diameter or leaf area may also be informative). While the response variable could be simply the measurement taken at any point in time, it may be more informative to estimate the change in survival or growth between defined points in time (e.g. spring/summer).

RESTORATION ACTIVITIES: Any action, intervention, or treatment intended to promote the recovery of an ecosystem or component of an ecosystem, such as soil and substrate amendments, control of invasive species, habitat conditioning, species reintroductions and population reinforcements.

RESTORATIVE CONTINUUM: A spectrum of activities that directly or indirectly support or attain at least some recovery of ecosystem attributes that have been lost or impaired.

REVEGETATION: Establishment, by any means, of plants on sites (including terrestrial, freshwater, and marine areas) that may or may not involve local or native species.

STATISTICALLY SIGNIFICANT DIFFERENCE: The level of evidence supporting a hypothesised treatment effect or difference is described as 'statistically significant' when the differences between treatment means are considered unlikely to have occurred by chance alone. Rather, it is likely to have been caused by the treatment effect imposed. A significant main effect is usually declared at a P-value less than 0.05, 0.01 or 0.001 (i.e. an effect is considered significant if there is less than 5%, 1%, or 0.1% probability that the effect was observed by chance alone, respectively). Statistically significant differences should then be considered in the context of the size of the effect, to ensure there is a biologically meaningful response.

TREATMENT: In an experimental context, the term 'treatment' refers to type of experimental manipulation or situation that is being compared, e.g. a plant species or provenance, a method for sowing seeds or controlling weeds, a burning or grazing treatment, a soil amelioration technique, and/or various combinations of these factors to make up specific treatment combinations. A treatment has two or more factor levels (see 'Factor'), one of which is sometimes called the control (see 'Control (treatment)').

Appendix 2.

A common set of attributes

Collecting a common set of information at the site and plot level provides the ability to collate experimental and monitoring data from across a network of experimental sites to develop a database that can be interrogated to address overarching questions at local, regional, and national levels. The table below provides an example of potential common attributes or data for each experimental site drawn from Chapter 5. Some of the information is related to the Darwin Core information. Information recorded at each site can be integers (numbers), text, dates or binomial (yes or no). See Jellinek and Bailey 2020 for a more detailed set of attributes.

ATTRIBUTE OR DATA NAME	DESCRIPTION	DARWIN CORE LINK	ATTRIBUTE OR DATA TYPE
Project ID	• Unique identifier for each assessment or monitoring project	http://rs.tdwg.org/dwc/terms/datasetID	Integer
Project name	• A name to identify a project. Projects are structured data, typically survey based with one or more surveys grouped together	http://rs.tdwg.org/dwc/terms/datasetName	Integer
Project description	• A description of the Project Name. • Example: 'Revegetation data recorded from 50 x 4 m quadrats at the Coorong and Lower Lakes Landcare Restoration project 2018–2020'	http://rs.tdwg.org/dwc/terms/catalogNumber	Text
Observer name	• The name of the person undertaking the monitoring	http://rs.tdwg.org/dwc/terms/recordedBy	Text
Site ID	• A unique identifier for each site surveyed. A site could be a discreet restoration area, or for example a property.		Integer
Site name	• The name for the set of location information. To define a site name it is important to give clear information. If you are monitoring a series of sites then use that in the Site Name field, e.g. Site 1a.	http://rs.tdwg.org/dwc/terms/verbatimLocality	Text
Site location	• Describe 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

ATTRIBUTE OR DATA NAME	DESCRIPTION	DARWIN CORE LINK	ATTRIBUTE OR DATA TYPE
Coordinate system	• From a defined list, indicate the type of coordinates used to record the site coordinates. • Only include one of the following coordinate types: – latlong, to identify latitude/ longitude DMS (degrees minutes seconds); – decdegrees, to identify latitude/ longitude DD (decimal degrees); or – eastnorthl, 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. E.g. GDA94, WGS84, AGD66	http://rs.tdwg.org/dwc/terms/verbatimCoordinates	Text
X coordinate	• A numeric representation 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 coordinates given in the Northing or Latitude related with the type of coordinates used	http://rs.tdwg.org/dwc/terms/verbatimCoordinates	Text or Integer
Survey ID	• A unique identifier of the survey	http://rs.tdwg.org/dwc/terms/eventID	Integer
Survey 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
Date	• The single date or the start date when a survey occurred. E.g. dd/mm/yyyy	http://rs.tdwg.org/dwc/terms/verbatimEventDate	Date
Survey method	• A description of the sampling methods. E.g. 50 x 4 m quadrat or 2 ha 20 min bird survey	http://rs.tdwg.org/dwc/terms/samplingProtocol	Text
Survey effort	• A description of the time spent surveying or the area surveyed	http://rs.tdwg.org/dwc/terms/samplingEffort	Text
Species name	• The scientific name of the species surveyed	http://rs.tdwg.org/dwc/terms/scientificName	Text
Common name	• The vernacular name of the species	http://rs.tdwg.org/dwc/terms/vernacularName	Text
Taxon ID	• A unique identifier for that species. This may differ between states.	http://rs.tdwg.org/dwc/terms/taxonID	Integer
Count	• The number of that species recorded in a given area	http://rs.tdwg.org/dwc/terms/individualCount	Number

ATTRIBUTE OR DATA NAME	DESCRIPTION	DARWIN CORE LINK	ATTRIBUTE OR DATA TYPE
Non-mandatory fields			
Height (mm)	• To measure the growth of a species		Number
DBH (mm)	• Diameter at breast height		Number
Survival	• To record if the species is alive or dead		Binary (Y/N)
Plant ID	• Unique number of a plant in a given plot		Integer
Provenance	• To record where the plant has come from		Text
Planting type	• To record if it was direct seeded or from tube stock		Text
Site preparation	• How was the site prepared (weed control, ripping, mounding)		Text
Topography	• Topography and aspect of the site		Text
Notes	• A field to write notes		Text

REFERENCES

Jellinek S, Bailey TG. 2020. Establishing Victoria's Ecological Infrastructure: A Guide to Creating Climate Future Plots. Greening Australia and the Victorian Department of Environment, Land, Water and Planning. Melbourne, Victoria. Version 2.1.