PROJECT PHOENIX

SNAP!

A PICTURE OF THE AUSTRALIAN SEED SECTOR IN 2021

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Across all of our Project Phoenix activities and actions we pay respect to the Traditional Owners and Custodians of the lands and waters on which we work. We honour the resilience and continuing connection to country, culture and community of all Aboriginal and Torres Strait Islander people across Australia. We recognise the decisions we make today will impact the lives of generations to come.

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1 EXECUTIVE SUMMARY

1.1 Introduction

This desktop review of published reports on the Australian Seed Sector will form the introduction of the National Seed Strategy document. The review will allow for a deeper dive and consolidation of previous reports and papers. It will identify recurrent themes and new perspectives on solutions to longstanding issues. Identifying ongoing issues and themes within the sector will enable extra attention to be applied to understand why change within the sector has been difficult. The review will also identify barriers to scaling up restoration efforts to the scale required for bushfire recovery. Providing context for the recommendations on future directions is an important aspect of the review.

This report provides a review of the published reports on the Australian native seed and plant supply sector. The issues and barriers within the sector are outlined, and suggestions to inform seed-based restoration and conservation are provided.

1.2 Issues

Few issues were encountered in the development of this report. However, there are a couple of limitations to the report. Firstly, the short timeline (October–December) precluded any external consultation. Secondly, while this report reviews published reports, there may be unpublished information that was not captured during the review.

Many of the issues presented in this report were raised 10–20 years ago, yet they still seem to be relevant today. To address these issues and implement change, several key tasks are listed below:

- Coordinated and long-term restoration planning across the whole of Australia.
  - A 10 to 20-year plan for each region would allow ongoing work for seed collectors, lowering their financial risk and allowing them to collect during the good years and store for the future.
  - Regional planning would mean that there would be less onus on individual community groups and landowners to plan restoration and select appropriate species.
- Coordinated seed collection, testing, storage and dissemination at a regional level.
  - Restoration seed banks may need to be established in key locations to ensure appropriate storage conditions.
  - Regional audits of seed collection capacity and infrastructure would be required, and then strategically improved.
- Coordinated research programs embedded into restoration programs, along with coordinated restoration monitoring and evaluation.
  - This would determine if goals are met while also providing information for adaptive management to inform future restoration planning. Research programs could be simple, for instance, trailing two seeding rates, or complex, such as assessing provenancing strategies.

To oversee these tasks, a person (i.e. Commissioner/national coordinator) or entity (national industry body) should be appointed, to be an advocate for restoration and the seed industry, as well as providing training and opportunities for networking.

1.3 Outcomes

The key output is a written report reviewing published reports on the Australian Seed Sector. This review has led to a better understanding of the issues and barriers in the Australian Seed Sector, and a number of recommendations have been developed that can be used to underpin a National Seed Strategy.

This review identified the following issues in the native seed sector: supply and demand, licensing and permissions, location of the seed source, infrastructure for seed processing, storage, treatment and end use, seed quality testing and recording, seed germination, monitoring reporting and adaptive management, the cost of seed, funding, developing and accessing research and information on seeds and restoration, education and training, coordination and communication, scaling up, and implementing change.

Opportunities for seed use in fire management, such as fire preparedness, indigenous land management, threatened species, climate change and people are also outlined.

1.4 Evidence

The data sources include:

- peer-reviewed literature from journals such as *Restoration Ecology* and *Australian Journal of Botany*
- reports, such as the Australian Native Seed Sector Survey and National prioritisation of Australian plants affected by the 2019–2020 bushfire season
- online newspaper articles such as from 'The Conversation'
- national guidelines, including the *FloraBank Guidelines*, *Germplasm Guidelines* and *Translocation Guidelines*
- books, such as *Australian seeds — a guide to their collection, identification and biology*
- international strategy documents, such as The United Nations Decade on Ecosystem Restoration Strategy, National Seed Strategy for Rehabilitation and Restoration (USA)
- websites, such as www.landcareaustralia.org.au, www.ser.org, www.seedbankpartnership.org.au

1.5 Recommendations

1. Fire response

- Understanding:
  – how different plant species respond to fire (which are killed, and which survive; which are triggered to germinate or flower; which have the capacity to resprout)
  – how fire intensity, interval, severity and season affect plant species and
  – the effect of the interaction between fire and other factors (e.g. drought, disturbance) on plant species

  will help inform restoration strategies for each species and in each location.

2. Restoration approaches

- Knowing which approach to restoration is needed in each degraded environment is critical to determining whether or not seed is needed.

3. Seeds in the context of restoration

- Seed supply for restoration needs to be considered within the broader context of restoration, which includes, amongst other items, restoration planning, funding and monitoring. Having a holistic view not only of the supply chain, but other factors that influence it will lead to better on-ground outcomes.

4. Stakeholders

- Compiling a comprehensive database of all those involved in the seed sector could help lead to better cohesion and communication.
- There is no one industry body which represents the sector. However, the Australian Seed Bank Partnership is a consortium that represents a number of seed banks, NGOs and research organisations.

5. Supply and demand

- A strategy is needed to: increase the quantity of seed available for restoration; increase the numbers of species available so that restoration can be biodiverse; and smooth out demand so that there is less fluctuation, thereby providing ongoing employment for collectors and better price certainty for purchasers.
- Seed Production Areas are one option for improving seed availability.
- In addition, improving methods of seed-based restoration to increase seedling emergence and survival will increase seed use efficiency and therefore lower seed requirements.

6. Licensing and permissions

- Licensing applications must be clear and straightforward to complete, assessed within a reasonable time frame and collect aggregated data about collection in each jurisdiction.
- Licensing agencies could implement a short, online assessment to ensure that collectors understand the licensing conditions and their obligations to harvest in a responsible and sustainable manner.
- Purchasers should check to ensure that their seed was obtained legally.
- A regional assessment could be undertaken to identify suitable areas for seed collection, and allow restricted access to licenced collectors.

7. Seed sourcing

- Restoration plans must consider where the seeds will come from.
- This is important not only for direct seeding, but also when purchasing plants grown from seed. They must indicate whether seed will be sourced locally or non-locally (or both).
- They must consider whether the source populations are likely to be adapted to current and future environmental conditions. Increasing genetic diversity of collections may benefit restoration.

8. Infrastructure

- An assessment is needed of current infrastructure capacity (including seed processing facilities, drying facilities, storage facilities, Seed Production Areas, nurseries and direct seeding equipment), who owns it (public or private), and where it is.
- In addition, an investigation is required into what infrastructure is needed where and by whom.
- Restoration seed banks could be established in key areas.

9. Seed quality

- A behavioural change and education program to inform sellers and buyers of the necessity of seed testing, how to perform basic and advanced tests, and which tests to request, needs to be implemented in Australia to ensure buyer confidence and improve restoration success.

10. Seed germination

- Feedback from end-users of seed is needed to identify species for which research on germination is required. This research can be undertaken using in situ and ex situ trials.
- Seed enhancement technology is an emerging area of research in native seeds and has potential to improve restoration success.
- A propagation manual of Australian plants, listing germination conditions would be of benefit to the industry.

11. Monitoring, reporting, adaptive management

- Monitoring should be performed to determine whether or not the goals, aims and objectives are achieved. Simply reporting what the activities were (e.g. number of hectares seeded, number of trees planted) is not enough; the results need to be monitored, analysed and then reported (e.g. % survival after 1 and 5 years, number of species per hectare, average number of plants per square metre).
- Standardised monitoring protocols will enable data to be compared across sites and between years.

12. Cost of seed

- Encouraging purchasers to pay the true cost of seed may rely on other factors such as implementing quality testing and better allocation for funding for seed-based restoration.

13. Funding

- Funding timelines need to be in sync with restoration timelines, particularly given that restoration activities like seed collection, nursery propagation and planting are seasonal.
- Funding should be for more than 5 years to allow for adequate planning, seed collection and monitoring. It would also allow for more stable seed markets, ensuring support for businesses, workforces, training and improvement of quality (Hancock *et al.* 2020).
- Also, several decades of investment is required for restoration which does not match the 3–5 year funding cycles (Broadhurst *et al.* 2015).
- We need an intergenerational view to restore our biodiversity (Broadhurst *et al.* 2015).

14. Research and information

- Ensuring people have access to information by providing good quality publications at low or no cost will improve on the ground outcomes.
- A central repository for information may be useful. Providing an annual forum may assist two-way knowledge sharing.
- Conferences and forums need to be low cost, at a convenient time of the year, and in an accessible place and inclusive of practitioners. Funding may need to be provided to offset registration costs.
- Identifying knowledge gaps and addressing these through research will be needed for a restoration strategy. Networked and embedded experiments can be used to address knowledge gaps. Several important research questions are listed.

15. Education and training

- Provide low-cost, frequent training programs, possibly online.
- Possibly encourage training when licences or grants are applied for.
- Collate a centralised list of all training opportunities at all levels.
- Seed purchasers also require training.

16. Coordination and communication

- An industry body to represent the seed sector is now needed.
- Opportunities to communicate between different parts of the sector will benefit the whole industry.

17. Scaling up

- Plans for seed collection and storage, and implementation of seed-based restoration need to be able to be achieved at large-scale. A combination of changes is required to up-scale restoration, as there is no single solution.

18. Implementing change

- Change needs to be implemented by forming an industry body to understand the motivations of stakeholders, and communicate with them, as well as changing regulations.

19. Fire preparedness

- Use fire forecasting to direct future seed collecting efforts.
- Restore ecological communities to slow climate change.
- Plan to protect biodiversity assets.
- Trial the effectiveness of restoration to prevent, slow the spread or lower the intensity of fires.

20. Indigenous land management

- Engage indigenous people to help heal the land after catastrophic fires.

21. Threatened species

- Soil and canopy seed banks of the most imperilled species need to recover before seed collection is undertaken, except in urgent cases.
- Ecological restoration may provide additional habitat for threatened animals, and the prioritisation list could direct restoration to areas and with plant species which would benefit these animals.

22. Climate change

- Protection, restoration and assisted migration may be options to enable the persistence of species affected by climate change.

23. People

- Sharing resources may assist with the fire recovery efforts.
- Recovery planning could be undertaken at a national, state and regional level, to assist individual landowners.
- Building strong relationships between stakeholders will be critical for recovery and preparedness for any future fires.

2 INTRODUCTION

2.1 The 2019/2020 fires in Australia

The bushfire season of 2019/2020 was catastrophic. A combination of high temperatures and low rainfall led to record high fire danger, and the fires burned over 24 million hectares across the country (Royal Commission into National Natural Disaster Arrangements 2020). Between 90 and 153 listed and/or endemic plant species had over 90% of their range burned (Gallagher 2020). This loss of habitat is likely to lead to increased extinction risk of many species.

Australians were flooded with images of injured fauna and blackened trees, and these images galvanised a huge public response, both financial and in terms of pressure on politicians to act. While much of the financial aid went to people and fauna, it is the ecological communities in which the fauna live that also require funding and management. Raising the profile of the importance of habitat of threatened species will be critical to garner public support for restoration.

This review aims to highlight some of the issues and barriers to restoration of plant communities following the fires, in particular seed-based restoration, and can be used to inform restoration strategies.

Although this particular fire season was unprecedented in terms of land area affected, fire is in fact part of a natural sequence in many parts of the Australian landscape. Plant communities are not static — plants grow, flower, set seed and die, and some of these life events are affected by fire. For instance, some plant species spend part of the year (**annuals**) or many years (**fire ephemerals**) as seeds in the **soil seed bank**, during which time plants are not seen in the above ground vegetation. For fire ephemerals, as well as other species, fire can trigger seed germination, resulting in seedlings emerging from the ashes. These species may be comparatively short lived, germinating immediately after fire, flowering and setting seed quickly, then dying, while their seeds await the next fire. For other plants, fire triggers flowering (e.g. *Xanthorrhoea* spp.), or causes plants to release seeds from their fruits (e.g. *Banksia* spp.).

Of course, fire kills many species of plants. But other species can survive fire and are able to resprout. The effect of fire on plants depends on the **fire severity** and **fire interval** (or frequency), **fire severity** and **fire season**, as well as interactions between fire and drought or disturbance (Auld 2020). High intensity fires are more likely to result in plant deaths than low intensity fires. Too frequent fire intervals, that is, fires that happen too close together, for example, every 3–5 years rather than every 10–15 years, may kill young plants before they are resistant to fire, or kill plants before they flower and set seed. Hence, some species need long unburnt periods in order to flower or mature enough so that they are able to survive fire (e.g. those with epicormic buds).

These fire-related traits are not well understood in many of Australia's plant species, and the relationship between plants and time since fire needs to be better researched. Then, we will be able to understand ideal fire intervals, **recruitment strategies** of plants, and how to better restore them using seeds.

Understanding:

- how different plant species respond to fire (which are killed, and which survive; which are triggered to germinate or flower; which have the capacity to resprout),
- how fire intensity, interval, severity and season affect plant species, and
- the effect of the interaction between fire and other factors (e.g. drought, disturbance) on plant species,

will help inform restoration strategies for each species and in each location.

2.2 Why seed is needed for the fire recovery effort

Given that many Australian ecosystems are adapted to fire, why is seed needed for the fire recovery efforts? In some areas, seed may not be needed, just protecting areas from further disturbance, and not clearing burned plants which may resprout or provide habitat may be all that is required (Commander and Zimmer 2020). In some cases, weed control is essential to prevent competition, but the addition of seed or plants is not needed. However, in other areas, ecosystems may have already been degraded, and the natural recovery processes may not be able to operate. For instance, if areas have been subject to ongoing drought, too frequent fires, degradation from overgrazing or competition from invasive species, then the soil seed bank may have been depleted and plants may not be resilient enough to resprout. Also, in highly fragmented environments, such as in agricultural and urban regions, plants may not be able to recolonise from their surroundings. Hence, intervention is required.

Interventions lie along a continuum of restorative practices, from reducing impacts to full recovery (**Figure 1**). While the restorative continuum contains a range of restorative practices, through this report, for simplicity, we have chosen to use the term 'restoration' to describe any action on this continuum. Approaches to restoration can include natural regeneration, assisted regeneration or reconstruction (Approaches to restoration include natural regeneration, assisted regeneration and reconstruction. A combination of these approaches may be used.

Table 1), and combinations of these approaches are often required (Gann *et al.* 2019). The reconstruction approach generally requires reintroduction of plants. Reintroduction can be via seeds, or by using seeds (or cutting material) to produce plants. In some cases, plants can be transplanted (i.e. dug up and then replanted).

FIGURE 1. THE RESTORATIVE CONTINUUM (MODIFIED FROM GANN ET AL. (2019))

Approaches to restoration include natural regeneration, assisted regeneration and reconstruction. A combination of these approaches may be used.

TABLE 1. APPROACHES TO RESTORATION

APPROACH	ACTIONS	EXAMPLES	PLANT RECOVERY
Natural regeneration	Remove the cause of degradation	Removing inappropriate grazing or inappropriate fire regimes	Germination from soil seed bank, resprouting, natural dispersal
Assisted regeneration	Remove the cause of degradation and active intervention to correct damage and trigger recovery	All of the above, plus soil remediation, installing habitat features, invasive species control	Germination from soil seed bank, resprouting, natural dispersal
Reconstruction	Remove the cause of degradation, active intervention to correct damage and trigger recovery, and reintroduce most of the biota	All of the above, with reintroduction likely	Species reintroduction, augmentation or reinforcement through seeding and planting

Knowing which approach to restoration is needed in each degraded environment is critical to determining whether or not seed is needed.

2.3 Aim of this review

The purpose of the overall project is to increase native seed and plant supply in preparation for the restoration of bushfire-affected areas and conservation of other valuable habitat. This report will review published reports on the Australian native seed and plant supply sector by outlining the issues and barriers, and providing suggestions to inform preparation of restoration and conservation. The information could be used to contribute to a national restoration strategy. The main problems are summarised in **bold**, and the suggestions for a national strategy are indicated by the icon.

3 METHODOLOGY

A literature review was conducted using Google Scholar to identify relevant publications. A search was also performed on the author's personal EndNote library (referencing software). The reference section of selected articles was used to find additional papers and Google Scholar was used to find cited articles. A literature search was performed through the Department of Biodiversity, Conservation and Attractions (WA) online library. Through this process, a list of over 160 papers was compiled (see Appendix 3 — Bibliography).

4 SEEDS USED IN RESTORATION

4.1 Seeds in the context of restoration

The process of restoration generally starts with identifying which site(s) are to be restored, and ends when the goals of restoration have been met (**Figure 2**). This process can take many years from beginning to end. For instance, proposal development to planting can take 1½ to 2½ years (Dillon *et al.* 2018), and then sites may be monitored for many years. Some projects will not have an end point as sites will be continued to be managed for as long as there are people willing to do so (such as volunteer groups or landowners) or funding is available. Restoration timelines can depend on approval processes, whether or not seed has already been collected, and how long plant propagation takes (if using seeds to grow plants).

While some projects may aim to purchase ready grown seedlings, thus saving time by not collecting their own seed or pre-ordering seedlings, this runs the risk of having insufficient plants or the wrong species available. Some activities are seasonal such as collection, seeding and planting, so if the opportunity to do these activities at the right time of year is missed, then the project may need to wait until the following year, leading to project delays of up to 12 months. Poorly-timed projects can also lead to restoration failure, for instance if plants are planted at the correct time of the year, but were propagated too early or too late, and therefore were either not mature enough or rootbound at time of planting. The monitoring phase of restoration may take several years, and depends on the project goals.

Seed supply for restoration needs to be considered within the broader context of restoration, which includes, amongst other items, restoration planning, funding and monitoring. Having a holistic view of not only the supply chain, but other factors that influence it will lead to better on-ground outcomes.

FIGURE 2. THE PROCESS OF RESTORATION PROJECTS INVOLVING SEEDS

Identify site to be restored

↓

Assess site and identify restoration approaches

↓

Make a restoration plan, including targets, goals and objectives

↓

Identify funding

↓

Make a target species list and select location for seed source

↓

Obtain licences for seed collection

↓

Collect, process, test, dry and store seed

↓

Prepare site

↓

Pre-treat seed (if needed), sow in field, or sow in nursery then plant

↓

Monitor emergence and/or survival

↓

Assess and report against targets, goals and objectives

↓

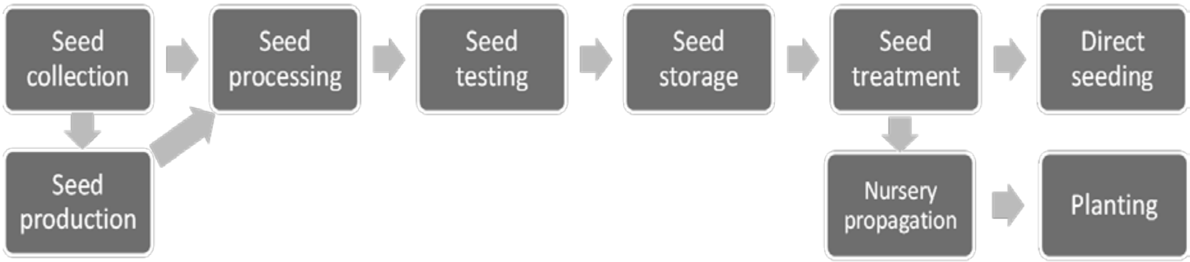
Do further actions if targets, goals and objectives are not met

4.2 The seed supply chain

The seed supply chain starts with seed collection (**Figure 3**), which is underpinned by an understanding of the ecosystem to be restored, which informs the restoration plan and then the seed sourcing plan (Cross *et al.* 2020) used to inform species selection. Collected seed may be used directly for restoration or may be used in Seed Production Areas to increase the volume of seeds. Once collected, seed is then processed (or cleaned) to remove it from the fruits, remove non-seed material (e.g. leaves, chaff) and remove empty (unfilled) seeds.

Then, seed may be tested to determine various parameters such as weight, purity (proportion of seed to non-seed material), viability (whether or not a seed is alive), and germination (Frischie *et al.* 2020). Seed is then dried and stored, with the storage conditions dependant on how long it is expected that the seed will be stored (De Vitis *et al.* 2020). Seed may be treated to increase germination (Commander *et al.* 2020; Kildisheva *et al.* 2020) prior to use. Finally, seeds can be used in either direct seeding or to grow seedlings in a nursery which are later planted (Shaw *et al.* 2020). Seed may change hands (through sale and purchase, or between organisations) at any point in the supply chain.

FIGURE 3. THE SEED SUPPLY CHAIN OUTLINING THE STEPS FROM COLLECTION TO USE



5 KEY STAKEHOLDERS

The key stakeholders in the native seed sector can be grouped into seed suppliers[1] (e.g. collectors, Seed Production Area (SPA) growers, sellers) and seed purchasers (e.g. buyers, distributers and other end-users), although some stakeholders fit into both categories (e.g. if they collect seed and implement restoration) (Hancock *et al.* 2020). There are also others associated with the sector, such as researchers, policy and licensing officers, environmental regulators and funding bodies. These stakeholders may include (e.g. see Hagger *et al.* 2017; Hancock *et al.* 2020):

- businesses
- catchment management authorities
- community groups
- government agencies (including botanic gardens and national parks)
- individuals
- indigenous groups
- landholders and land managers
- local government
- local land services
- natural resource management bodies

[1] http://anpsa.org.au/seedsupp.html

- non-government organisations
- not-for-profit organisations
- nurseries
- other commercial enterprises
- research institutions
- universities
- volunteers.

Seed collectors are generally small businesses with a small workforce, and most seed purchasers are local or state government (Hancock *et al.* 2020), however a few mining companies require large volumes of seeds (Koch 2007; Merritt and Dixon 2011). While individuals and organisations may belong to various professional societies (ANPC, SERA, AABR, ECA, RIAWA, ESA), there is no one industry body which represents them as a whole. Some organisations may belong to an umbrella group, such as Landcare Australia, which is made up of 6,000 Landcare, Coastcare, Bushcare, 'Friends of' and other community environmental care groups across Australia[2] (Robins 2018), and the Australian Seed Bank Partnership **(Box 1)**. The 56 regional natural resource management (NRM) organisations[3] such as Local Land Services (NSW), Landscape Boards (SA) and Catchment Management Authorities (Vic) may be represented by a state body (e.g. NRM WA).[4] There is also no organisation for registration of practitioners, such as for other professions, like the Medical Board (registration for medical practitioners) or Architect Registration Board. There are, however, non-mandatory certification programs, such as the Society for Restoration Ecology Certified Ecological Restoration Practitioner (CERP) program.[5] Currently, there are 15 certified practitioners in Australia (as at 5/11/2020).

The disparate nature of the sector and the lack of mandatory formal training or certification may be contributing factors to some of the sector issues. However, given the diversity of roles which people and organisations have within the sector, standardising training or implementing certification may be challenging.

[2] https://landcareaustralia.org.au/about/
[3] http://www.nrm.gov.au/regional/regional-nrm-organisations
[4] http://www.nrmwa.org.au/
[5] https://www.ser.org/general/custom.asp?page=Certification#:~:text=Certified%20Ecological%20Restoration%20Practitioner%20Program%20SER%27s%20ecological%20restoration,the%20world.%20Two%20levels%20of%20certification%20are%20offered%3A

Box 1 — The Australian Seed Bank Partnership

The Australian Seed Bank Partnership (ASBP) is a group of 12 organisations, including Botanic Gardens, government departments and NGOs, who have an interest in or expertise in seed banking, and a number of associate organisations. It is governed by the Council of Heads of Australian Botanic Gardens Inc. (CHABG).

It's mission is a national effort to conserve Australia's native plant diversity through collaborative and sustainable seed collecting, banking, research and knowledge sharing. The goals of the ASBP are to: collect and store seeds in seed banks as long-term insurance against loss of plant diversity; conduct research to improve conservation and restoration outcomes from seed banking; develop national standards to improve capacity to enable conservation and restoration of biodiverse and resilient ecosystems; share knowledge; and secure and strategically manage resources to support the work of the ASBP.

The ASBP evolved from the Australian Seed Conservation and Research (AuSCar) network, which was a series of partnerships between Australian states and territories and the international Millennium Seed Bank Project, now known as the Millennium Seed Bank Partnership (MSBP).

ASBP Partners:

- Australian Network for Plant Conservation Inc. (ANPC)
- Australian PlantBank, The Royal Botanic Gardens and Domain Trust (RBGDT)
- Brisbane Botanic Gardens Conservation Seed Bank, Brisbane City Council (BBG)
- George Brown Darwin Botanic Gardens, Parks and Wildlife Commission of the Northern Territory (GBDBG)
- Greening Australia (GA)
- Millennium Seed Bank Partnership, Royal Botanic Gardens, Kew (RBG Kew)
- National Seed Bank, Australian National Botanic Gardens, Parks Australia (ANBG)
- South Australian Seed Conservation Centre, Botanic Gardens and State Herbarium, South Australia (BGSH)
- Tasmanian Seed Conservation Centre, Royal Tasmanian Botanical Gardens (RTBG)
- The Victorian Conservation Seedbank, Royal Botanic Gardens Victoria (RBGV)
- The Western Australian Seed Centre, Kings Park, Botanic Gardens and Parks Authority (BGPA)
- The Western Australian Seed Centre, Kensington, Department of Biodiversity, Conservation and Attractions, Western Australia (DBCA)

Compiling a comprehensive database of all those involved in the seed sector could help lead to better cohesion and communication. There is no one industry body which represents the sector, however, the Australian Seed Bank Partnership is a consortium which represents a number of seed banks, NGOs and research organisations.

6 ISSUES IN THE NATIVE SEED SECTOR

6.1 Opportunities to address issues in a restoration strategy

Two main categories of issues in the native seed sector are evident — those directly associated with the restoration process, and those which underpin the process (**Figure 2**). For instance, seed supply and demand, licensing, sourcing seed, infrastructure for processing and storage, testing and purchasing are all steps in the restoration process (**Figure 2**). Developing and accessing information, training, coordination and scaling up are all issues that relate to many aspects of restoration and support the process.

6.2 Supply and demand

There is not going to be enough seed from enough species to be able to do seed-based restoration in Australia.

Seed supply and demand issues are currently hampering the restoration sector. These issues can be grouped into three main themes: quantity, diversity and fluctuation/inconsistency of supply and demand.

6.2.1 Quantity

The quantity of seed able to be supplied is unlikely to meet the demand of landscape-scale restoration. Seed is mostly sourced from the wild (Broadhurst *et al.* 2015), rather than from cultivated areas (termed Seed Production Areas, or SPAs). However, wild harvesting will not be able to meet future demand (Hancock *et al.* 2020). Overall volumes of seed available for restoration are low, meaning that the industry may not have the capacity to deliver large volumes of seed if they are required. The volumes of seed required can be substantial, for instance, Murray Local Land Services (NSW) has used up to 1,500kg of seed per year (Broadhurst *et al.* 2015). In the mining areas of the Pilbara (WA), land to be restored exceeds 20,000 ha, and with a seeding rate of 7kg/ha, that represents 140 thousand kilograms of seed required (Merritt and Dixon 2011).

Hancock *et al.* (2020) recently identified that seed supply was the most important issue facing the seed industry, and also pointed out that low seed availability affects the ability to respond rapidly to natural disasters. The issue of lack of supply was raised 20 years ago (Mortlock 2000), and it appears that the issue has not been resolved (Broadhurst *et al.* 2015). Thus, there is still a poor understanding of supply and demand in the native seed sector.

6.2.2 Diversity

Australia is a biodiverse country, with over 21,000 plant taxa. Certainly, not all of these species are required for restoration. In general, though, there is a lack of seed available from a broad range of species (Hancock *et al.* 2020). This shortage may hamper the ability to do biodiverse restoration, or the ability to source species which fulfil a particular service (e.g. food/habitat for threatened species). To overcome the lack of diversity available, all of the target species required could be identified in the early stages of restoration planning, with these species then collected over a number of years, rather than leaving collection to chance. Encouraging adequate species diversity in restoration could be done through funding applications or regulatory conditions.

6.2.3 Fluctuation

Seed availability fluctuates annually. In the wild, seed availability may follow a 'boom and bust' cycle (Broadhurst *et al.* 2015), whereby in some years, large volumes are available (such as after good rainfall, or for species such as fire ephemerals which set seed in the years following fire, then disappear from the above ground vegetation). In other years, such as following drought or immediately after fire, seed availability may be scarce. Hence, seed availability does not correspond to funding cycles and project timelines (Broadhurst *et al.* 2015) as well as requirements for post-fire restoration, announcements about government initiatives, etc.

Seed can be purchased from a catalogue of a seed collector,[6] in which case, seeds, which have been collected opportunistically, are stored for purchase at a later date. There may or may not be any information about the collection location or seed quality. Alternatively, seed of particular species can be collected for specific projects,[7] in which case advance notice is required. Hence, seed collectors who collect when seed is available, without being contracted by a particular client who will purchase the seed, do so at great financial risk.

Collectors who collect seed opportunistically also need to store the seed for an undefined period of time, which is an added cost (Broadhurst *et al.* 2015). In fact, there is limited capacity for large-scale storage of seed for restoration in Australia, compared with other parts of the world, in which restoration seed stores have the capacity for hundreds of tons of seed (Gibson-Roy 2018; Merritt and Dixon 2011). Hence, even if large volumes of seeds could be collected, they may not be able to be stored under appropriate conditions to ensure the seed remains viable until required.

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[6] https://www.nindethana.net.au/seed-list-html.aspx; https://www.seedingvictoria.com.au/cb_pages/buy_seed.php
[7] e.g. https://www.tranen.com.au/services/seed/seed-sales/

This fluctuation in supply, coupled with inconsistent demand, and insufficient diversity of species available is a major issue requiring resolution.

One option to address the issue of low supply is the use of Seed Production Areas (SPAs) (otherwise known as seed farming) (Gibson-Roy and Delpratt 2013; Hancock *et al.* 2020; Logie 2020; Merritt and Dixon 2011; Mortlock 1999a; Nevill *et al.* 2016; Standards Reference Group SERA 2017). SPAs are sites used for the production of bulk quantities of high quality seed of known origin, quality, free of any undesirable hybridity and with appropriate genetic diversity for replanting or direct seeding onto restoration and rehabilitation sites (Standards Reference Group SERA 2017).

The benefits of SPAs are that they can greatly increase the supply of seed, reduce the pressure on collecting from wild populations, reduce collecting costs as plants are all in one location, and may be harvested all at once. However, not all species are suitable to be grown in SPAs, and careful selection of species is required to ensure that there is a market for the species and that it is required for use or is likely to be purchased. SPAs also require land, infrastructure costs and maintenance costs. Considering various factors such as genetic diversity of the source material, and avoiding unintentional consequences like trait selection are essential. There are four key areas which need to be explored prior to development and management:

1. understand species biology
2. understand reproductive ecology
3. capture and maintain genetically appropriate source material
4. determine societal expectations and economics of production (Nevill *et al.* 2016).

Improving seed use efficiency is one method of reducing seed demand. For instance, if an improvement in site preparation or seed pre-treatments results in an increase in seedling emergence, then less seed is required to meet the targets, therefore lowering the costs of restoration (Merritt and Dixon 2011). Improving efficiency can be undertaken using well-designed field trials (Miller *et al.* 2016).

A strategy is needed to increase the quantity of seed available for restoration; increase the numbers of species available so that restoration can be biodiverse; and smooth out demand so that there is less fluctuation, thereby providing ongoing employment for collectors and better price certainty for purchasers. Seed Production Areas (SPAs) are one option for improving seed availability. In addition, improving methods of seed-based restoration to increase seedling emergence and survival will increase seed use efficiency and therefore lower seed requirements.

6.2 Licensing and permissions

If licences are too difficult to obtain, collectors are not aware of the need for a licence, or purchasers do not require it, then there is a risk of non-compliance with legislative requirements.

If seed is collected without a licence, there is no mechanism for state/territory governments to track the amount of seed collected, and from where it is collected, leading to the potential of overharvesting and therefore detrimental effects on the population.

Without access to locations with good quality and genetically diverse seed, collectors may be restricted to sourcing seed of poor quality and low genetic diversity.

State and federal legislation defines which activities need approval, which can be done without approval, and which are prohibited. Different types of approvals may be required for seed collecting (Nally *et al.* 2018). Seed collectors may need to obtain a collection licence from a regulatory authority, and also gain permission from the landowner or Traditional Owner on whose land they are collecting. Transporting seeds interstate may require an approval. Collection of threatened species may need additional approvals.

Seed collectors have raised concerns about the difficulties of obtaining collection permits (Hancock *et al.* 2020). They are also concerned about restrictions on seed sourcing locations and harvesting quantities. Collectors would like two-way communication with regulators to be improved and to receive better information from licensing agencies.

While the majority of collectors have collection licences, not all do. Also, not all purchasers either require collectors to be licenced, or are unsure if licences are required (Hancock *et al.* 2020). This lack of compliance could have detrimental effects on plant populations due to overharvesting, if there is no regulation on the number of collectors or maximum harvest from one location. It has been recommended to review licensing regulations to improve compliance and ensure that licence conditions are clear (Hancock *et al.* 2020).

Collecting seed from as many plants as is practicable within a population to increase genetic diversity is likely to have benefits in restoration. Unfortunately, if collectors are restricted by licensing conditions, or are unable to obtain access to land with large populations of plants, they only be able to collect from small populations, or from few plants, which may result in a collection with less genetic diversity.

In Australia, most seeds are collected on private property, followed by public reserves and roadsides. Much less is collected from state and national parks. It is unknown how much, if any seed is collected on travelling stock routes and Crown land. Vegetation on private property, small reserves and roadsides is likely to be fragmented, and there is a risk of overharvesting. Potentially, allowing licenced and well-monitored seed collectors access to large, relatively intact areas of vegetation may result in better quality collections (Hancock *et al.* 2020).

To improve collection standards, licensing could involve mandatory training, involving either an accredited course, such as AHCNAR305 — Collect native seed,[8] or each jurisdiction could develop a short online training course. For instance, to obtain a driver's licence, applicants need to complete training and pass a test; a similar system could be implemented for seed licensing to ensure that applicants are familiar with the conditions of the licence.

Licences for selling seed are not required, and there are no mandatory standards for seed supply (although there are optional standards in Western Australia).[9] An accreditation system for nurseries through the nursery industry, exists — the Nursery Industry Accreditation Scheme (NIASA) is a national scheme for production nurseries,[10] and has a Certified Nursery Professional program[11] and Best Practice Guidelines.

Licensing applications must be clear and straightforward to complete, be assessed within a reasonable time frame, and collect aggregated data about collection in each jurisdiction.

Licensing agencies could implement a short, online assessment to ensure that collectors understand the licensing conditions and their obligations to harvest in a responsible and sustainable manner.

Purchasers should check to ensure that their seed was obtained legally.

A regional assessment could be undertaken to identify suitable areas for seed collection, and allow restricted access to licenced collectors.

6.4 Location of the seed source

Choosing the location(s) from which to source seed can be a difficult decision for restoration practitioners. They need to take into account adaptation and diversity, while also considering the practicality of availability of areas from which to collect. The potential negative consequences of inappropriate seed sourcing include inbreeding depression (reduction in fitness due to mating of closely-related individuals), outbreeding depression (reduction in fitness due to mating of individuals adapted to different environmental conditions) and maladaptation (not adapted to the environment). Some seed merchants do not provide information on the collection location, thereby making it impossible for end-users to select their seed source.

Historically, recommendations have advised that seed (and also plant material for vegetative propagation) should be sourced from the local area, i.e. within a defined geographical range, termed 'local provenance' (Hancock *et al.* 2020). The reasons for collecting locally are because plants are likely to have evolved to suit the local conditions and to avoid possible negative

8 https://training.gov.au/Training/Details/AHCNAR305
9 http://riawa.com.au/wordpress/?page_id=1059
10 https://www.greenlifeindustry.com.au/Category?Action=View&Category_id=125#
11 https://www.greenlifeindustry.com.au/Category?Action=View&Category_id=156

consequences in restoration. These negative consequences include seed not being adapted to the local environment (maladaptation) and the resulting offspring being less fit (due to outbreeding depression) and hybridization.

The definition of the geographic range of what is considered 'local' varies widely, from 5–20km (Hancock and Hughes 2012) or within the same catchment (Cooper *et al.* 2018). Local provenance can also be defined as genetically-informed geographic distance, for instance 'sourced from the estimated pollination and dispersal range of the species' (Cooper *et al.* 2018). The extent of a provenance can be determined using genetic methods.

Seed collections with higher genetic diversity are potentially likely to benefit restoration, compared with collections with low genetic diversity. Genetic diversity of seed collections may confer resilience to populations, allowing them the potential to respond to environmental change. Whether or not the 'local provenance' is genetically diverse depends on the landscape context.

Seed collected from large populations within large, uninterrupted areas may have more genetic diversity than seeds collected from small, fragmented populations. Not only could seed from fragmented populations have low genetic diversity, it could be inbred, which may limit adaptive potential (Broadhurst *et al.* 2008). Also, in areas with small, isolated or fragmented remnant vegetation, it may be difficult to source enough seed for restoration (Mortlock 2000).

Alternative provenancing strategies have been developed to address some of the potential negative consequences associated with small, isolated or fragmented populations, and to increase the potential to adapt to future climate change. These strategies include admixture provenancing (using a wide variety of populations across the species' range in equal proportions), composite provenancing (again, using a wide variety of populations, but proportionally more from near the restoration site, and less from further away), climate-adjusted provenancing (sourcing from populations in the direction of the climatic change) and predictive provenancing (sourcing from a population in projected climatic conditions) (Prober *et al.* 2015).

If these alternative provenancing strategies are selected, seeds must be able to germinate, and plants must grow and reproduce in the current climate, otherwise the populations will not persist until the climate changes. Also, other environmental factors such as soil type (which influences available moisture) and canopy cover influence plant survival, so although climate predictions may identify locations which match the future climate, other environmental variables may not match.

As the climate changes, restoration practitioners are starting to look to these alternative seed sourcing strategies, rather than local provenance. Anecdotal evidence, such as poor seedling survival or tree deaths has sometimes been attributed to climate change. However, the causes of these plant deaths may not be known, and may be due to any number of reasons other than climate. Perhaps the ecosystem is degraded, and therefore not resilient or self-sustaining. If canopy cover has been reduced, for instance, the local microclimate may be warmer leading to plant deaths. Perhaps some species have a naturally high rate of seedling deaths. Perhaps the population numbers are so low that there is very low genetic diversity. It is wise to investigate the causes of seedling/tree deaths so that the cause can be addressed, and if it is then concluded that plants are not adapted to the changed climate, common garden or reciprocal transplant trials could be undertaken to select a location for a seed source.

Very little empirical testing of these alternative provenancing strategies has been carried out, and those tests that have been undertaken are usually on individual species, and not on an ecosystem scale. Also, comparatively few species have undergone genetic testing to delineate provenances.

Hence, it is critical that alternative seed sourcing strategies are undertaken under experimental conditions, with exceptionally rigorous records kept on seed source, and systems put in place to track seed lots from source to seedling. Then, appropriate monitoring needs to be undertaken to test the health and survival of the seedlings and consequently assess the performance of the different seed lots. Such a field trial is likely to require more financial resources than local sourcing of seed, however the results will be invaluable. Embedding experiments such as these into restoration projects at multiple sites may enable a better understanding about the use of provenance strategies (Broadhurst *et al.* 2017).

Practical considerations also need to be considered when sourcing seeds. Strategies need to take into account legislation, as states and territories have different rules regarding seed movement across borders. Decisions about seed sourcing become challenging if end users purchase seed from a catalogue of what a seed collector has in storage. They may not be able to choose from where the seed has been sourced, and in many cases, may not be told where it was collected from. In those cases, commissioning the collection of the target species from the desired locations may be advisable.

Restoration plans must consider where the seeds will come from. This is important not only for direct seeding, but also when purchasing plants grown from seed or cuttings. Plans must indicate whether seed will be sourced locally or non-locally (or both). They must consider whether the source populations are likely to be adapted to current and future environmental conditions. Increasing genetic diversity of collections may benefit restoration.

6.5 Infrastructure for processing, storage, treatment and end use

Lack of the right infrastructure in the right places could limit restoration ability. Without the right infrastructure, seed processing may not be optimised, seeds could lose viability in storage, and seeds could be wasted by sub-optimal nursery or direct seeding practices. Many regional seed banks have closed, limiting Australia's capacity to scale up restoration, or respond quickly to demand.

Different types of infrastructure and equipment are required for different parts of the seed supply chain (De Vitis *et al.* 2020; Gibson-Roy 2018). Infrastructure may be co-located, for example, to undertake processing, testing, storage and pre-treatment all in the one place, or these phases may be separate. Sometimes, facilities can be shared between users, for instance at some botanic gardens, processing, drying and storage facilities are shared between botanic gardens' staff, research staff and a friends (volunteer) group. In that case, they all belong to the same organisation, but are using seed for different purposes. Some seed suppliers allow customers to store their seeds in the supplier's seed storage facility for an annual fee.[12]

Processing facilities require sheds, areas for drying seeds and equipment such as sieves and seed separators. Testing facilities house microscopes and dissecting equipment. Seed storage facilities (seed banks) may have room temperature (23°C), cool (15°C), refrigerated (4°C) or freezer (-18°C) storage areas, and may have controlled humidity rooms (15% RH) to dry seeds prior to storage.

As opposed to conservation seed banks, which may house small quantities of thousands of species, restoration seed banks need to be large enough to store large quantities of seed for landscape-scale restoration, perhaps in the order of tons (Merritt *et al.* 2011). Seed pre-treatment equipment ranges from facilities to boil water, to flash flaming, priming or pelleting. Nursery facilities may be required for growing seedlings, or direct seeding machinery may be needed. Electronic infrastructure required are spreadsheets and databases for maintaining records about seed collections, contents of seed stores, details of implementation and monitoring data.

Seed banks with appropriate conditions are important for housing seed between collection and use to maintain seed viability (i.e. keep seeds alive). Collectors stockpile seed when the demand is low, perhaps due to poor planting conditions or lack of funding — another consequence of market unpredictability (Hancock *et al.* 2020). They also stockpile seed from speculative seed collection (i.e. collections that are not commissioned).

Despite the importance of seed banks and other infrastructure, seed markets in Australia do not yet support the larger infrastructure that is available in the USA (Gibson-Roy 2018; Hancock *et al.* 2020). Seed pricing may be partly responsible, with collectors indicating that if fair payment was made for seed, then more resources could be allocated to improving infrastructure.

[12] https://www.tranen.com.au/services/seed/seed-bank/

There is also some discontent from private operators as they do not have access to public funding for infrastructure, whereas other sectors of the industry can access funds (Hancock *et al.* 2020). A lack of infrastructure for seed storage may limit the amount of seed that can be stored at one time, thereby limiting the ability for large-scale restoration. It may also limit the time for which it can be stored, as room temperature (~23°C) storage is only suitable for the short-term (<5 years). To our knowledge, there has not been a recent investigation of the types of infrastructure available, and their locations across Australia. If this was investigated, it could identify the types of infrastructure needed, and areas in which it is required. Then, strategic investment could be made.

Merritt *et al.* (2011) propose the concept of a 'restoration seed bank', which is a facility not only to store collected native seed, but also to provide seed production, training and knowledge sharing. It should be connected to community and industry restoration programs. These restoration seed banks could also be a hub for traditional ecological knowledge, bushfood research and production, and other types of economic botany, like plants for medicinal use. Parts of the facility could be hired out to local groups or organisations who would benefit from access.

> An assessment is needed of current infrastructure capacity (including seed processing facilities, drying facilities, storage facilities, Seed Production Areas, nurseries and direct seeding equipment), who owns it (public or private), and where it is. In addition, an investigation is required into what infrastructure is needed. Restoration seed banks could be established in key areas.

6.6 Seed quality: Testing and recording

'Without a seed testing report, it cannot be determined whether planting failure is attributable to poor seed or to other causes, such as inadequate site preparation, poor sowing technique or adverse weather conditions.' (Hancock *et al.* 2020)

Seed quality testing involves assessing the purity (composition by weight of the pure clean seed of a species expressed as a percentage of the mass of the whole sample), seed fill (percentage of seed that contains an embryo) and seed viability (percentage of live seed) of a seed lot. Native seed is not routinely tested, and there are no mandatory standards for seed quality. This issue leads to two problems: firstly, purchasers are buying a product of unknown quality, which may or may not be poor value for money; and, secondly, if quality is unknown, the cause of restoration failures are unknown.

The main reasons for not testing are:

- no in-house testing facilities
- independent laboratory testing too difficult or expensive to access
- not demanded by the purchaser (Hancock *et al*. 2020).

Given the diversity of species in Australia, seed testing can be challenging, because internal seed morphology (i.e. what the seed looks like inside) differs between species, and testing requires training and experience. Despite the current lack of national standards for seed quality and testing, there are, however, international standards (Pedrini and Dixon 2020) and standards in Western Australia.[13] The second edition of the *FloraBank Guidelines* will have guidelines for seed quality testing (Commander in prep).

The International Seed Testing Association (ISTA) has developed International Rules for Seed Testing[14] (ISTA 2020) which cover generic testing rules, and also methods for over 1,000 species (mostly agricultural and horticultural species (Milivojević *et al.* 2018)). ISTA also has an accreditation program.[15] However, only six laboratories are ISTA certified,[16] and it is not indicated whether they specialise in agricultural or native seeds.

ISTA has a wild species working group[17] to develop seed testing methods for wild species, and the Forest Tree and Shrub (FTS) Seed Committee.[18] There are not currently any Australians in either group, and the FTS committee is actively seeking Australian representation.

RIAWA has developed non-mandatory standards[19] and an accreditation system[20] for use in Western Australia. Currently, six corporate entities, one trader/broker and one individual are accredited.

They list the main advantages for buyers:[21]

- *'Confidence that the seed being purchased has been collected sustainably and is of specified quality,*
- *ability to compare "apples with apples" in terms of prices and quality offered from different suppliers,*
- *access to a list of accredited seed suppliers and collectors on the RIAWA website.'*

And the main advantages for collectors/suppliers:

- *'Industry recognition of quality to help differentiate your products and services,*
- *ability to differentiate product quality by seed grade,*
- *promoted on the list of accredited seed suppliers and collectors on the RIAWA website.'*

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13 http://riawa.com.au/wordpress/wp-content/uploads/2019/10/01-RIAWA-Seed-Standards-191021.pdf
14 https://www.seedtest.org/en/international-rules-for-seed-testing-_content---1--1083.html
15 https://www.seedtest.org/en/accreditation-_content---1--1012.html
16 https://www.seedtest.org/en/memberlaboratories-step2.html (5/11/2020)
17 https://www.seedtest.org/en/tcom-wsg.html
18 https://www.seedtest.org/en/tcom-fts.html
19 http://riawa.com.au/wordpress/?p=2276
20 http://riawa.com.au/wordpress/?page_id=1059
21 http://riawa.com.au/wordpress/?page_id=1059

To overcome some of the barriers to testing, training programs could be provided to collectors and buyers, particularly outlining the simple tests which can be performed with limited facilities or inexpensive equipment. Larger seed banks could hire out facilities for others to use. Sellers could be encouraged to supply, and purchasers encouraged to request, seed quality information.

A behavioural change and education program to inform sellers and buyers of the necessity of seed testing, how to perform basic and advanced tests, and which tests to request, needs to be implemented in Australia to ensure buyer confidence and improve restoration success.

6.7 Seed germination

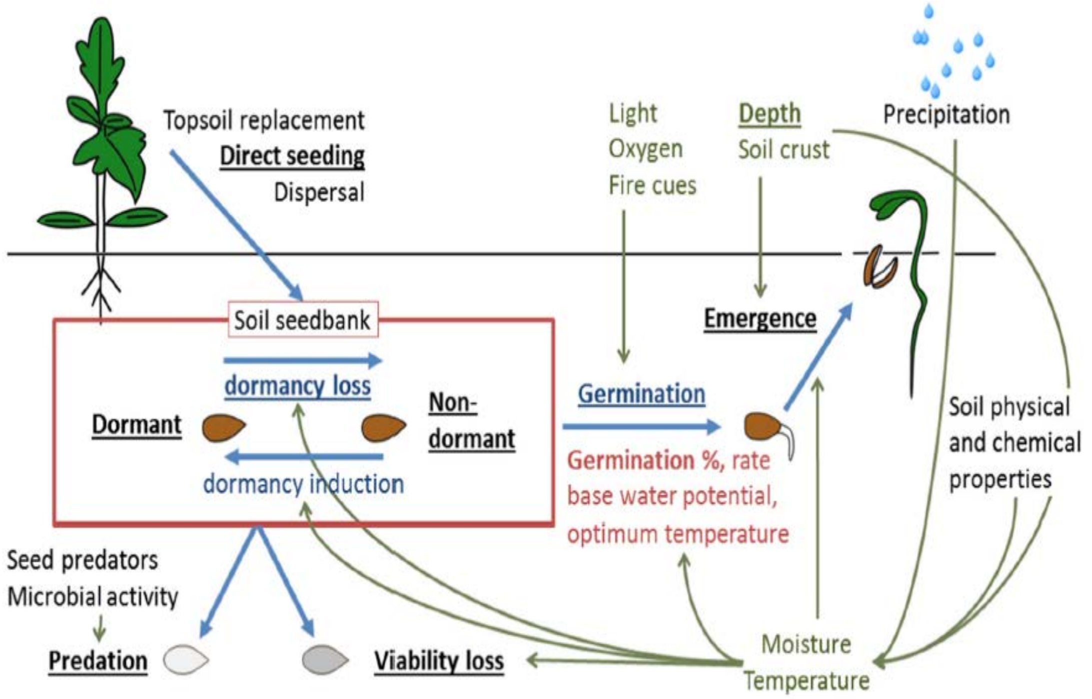
Lack of knowledge of the conditions required by seeds to germinate can limit the success of both nursery propagation and direct seeding. It can also result in poor seed use efficiency and wasted resources.

Seeds require specific light, temperature, moisture and oxygen conditions to germinate. Seeds which are alive, but unable to germinate when provided with optimal conditions otherwise suitable for germination, are considered dormant. Lack of knowledge of the conditions required to overcome seed dormancy may result in low germination at the time of sowing, and low seeding establishment from broadcast seed, are two factors limiting restoration outcomes (Merritt *et al.* 2011; Merritt *et al.* 2004).

To increase germination, seed treatments can be developed. For instance, germination of seeds of 18 Australian species required for restoration ranged from 1 to 27%, and after seeds were treated to overcome dormancy, germination increased to 41–100% under ex situ conditions (Turner *et al.* 2013). Pre-treating seeds to overcome dormancy also increases germination in the field (Commander *et al.* 2020). Seed enhancement technologies such as priming, coating and pelleting also have the potential to improve field establishment (Erickson *et al.* 2017; Pedrini *et al.* 2020), but these techniques are still emerging and being refined for Australian species.

Treating seeds to improve germination and modifying soil conditions to improve emergence can improve seed use efficiency, lowering the amount of seed needed, and lowering restoration costs. However, seed treatments and optimal germination conditions are not known for all species, and this could be the focus of future research. Both in situ and ex situ trials can be used to address these problems and provide solutions (**Figure 4**).

FIGURE 4. THE COMPLEX INTERACTIONS INFLUENCING DORMANCY LOSS, GERMINATION AND EMERGENCE UNDER *IN SITU* CONDITIONS



This conceptual model shows demographic and life-stage transitions (blue) that influence seedling recruitment based on seed traits (red) and environmental filters (green). In situ burial trials can be used to quantified dormancy loss, predation and viability loss. In situ seed sowing trials can be used to quantify emergence. Ex situ germination trials can be used to quantify the maximum germination %. Taken from Commander *et al.* (2020).

Feedback from end-users of seed is required to identify species for which research on germination is required. This research can be undertaken using in situ and ex situ trials.

Seed enhancement technology is an emerging area of research in native seeds and has potential to improve restoration success.

A propagation manual of Australian plants listing germination conditions would be of benefit to the industry.

6.8 Monitoring, reporting, adaptive management

Without rigorous monitoring and reporting back to stakeholders and funding bodies, whether or not the restoration achieved the goals is not known. This can result in wasted funds if the same mistakes are repeated time and time again.

A restoration project does not end when a seed or plant is put into the ground. The project needs to be monitored to generate knowledge, answer questions, apply adaptive management and provide evidence to stakeholders (Gann *et al.* 2019). Most importantly, monitoring needs to measure progress towards the goals and objectives of the project, and when or if they have been achieved.

However, monitoring of restoration projects more commonly involves recording inputs, such as work plan actions and visual observations, than outcomes, like repeatable surveys and the use of indicators, unless motivated by scientific research (Hagger *et al.* 2017). Projects should design monitoring programs so that the results can be evaluated against the objectives set out in the restoration plan, such as outlined in Gann *et al.* (2019). If standardised methods were used for monitoring, and results were collated annually, then the results of projects could be compared across the country (e.g. see Silcock *et al.* (2019). An example of a national monitoring program is the monitoring, evaluation, reporting and improvement (MERI) framework, which collects information from Regional Land Partnerships projects.[22]

Barriers to long-term monitoring are likely to be short-term funding (see also section 6.10), and perhaps also training. Designing monitoring programs may be beyond the level of expertise of some groups, however, TERN for example, provides methods for standardised surveys.[23] Another reason for the lack of appropriate monitoring is that it may not be required under funding conditions.

The bushfire recovery efforts are an excellent opportunity to perform long-term and large-scale ecological monitoring, to better understand Australia's environment, how it naturally recovers from fire, and which of our interventions best support the recovery.

Monitoring should be performed to determine whether or not the goals, aims and objectives are achieved. Simply reporting what the activities were (e.g. number of hectares seeded, number of trees planted) is not enough; the results need to be monitored, analysed and then reported (e.g. % survival after 1 and 5 years, number of species per hectare, average number of plants per square metre). Standardised monitoring protocols will enable data to be compared across sites and between years.

[22] Regional Land Partnerships MERI framework | National Landcare Program (nrm.gov.au); National Landcare Programme Monitoring and Reporting Plan | National Landcare Program (nrm.gov.au)
[23] https://www.tern.org.au/tern-observatory/tern-ecosystem-surveillance/

6.9 The cost of seed

The cost of native seed fluctuates, partly due to fluctuations in supply and demand, making project budgeting challenging. Purchasers are unwilling to pay the 'true cost' for seeds, meaning that seeds may be under-priced and collectors leave the marketplace. Without quality information, it is difficult for the purchaser to compare seed lots from different suppliers and to ascertain value for money.

Native seed pricing depends on a number of factors such as location, ease of collection, ease of cleaning and processing and whether the plants are common or uncommon (pers. com. Martin Driver). If a species is common and easy to collect and process, it is likely to be substantially cheaper than a species that is uncommon and difficult to collect and process. Seed is usually sold on a per kilogram basis, not at a cost per seed. Sometimes, a day rate is quoted for seed collection if it is to be done in a specific area for a particular client. Seed may be purchased as individual seed lots or as a seed mix. Seed mixes are then applied at a standard rate, e.g. 7kg per ha, and may or may not include a filler. Seed testing is an added cost if it is undertaken.

The traditional supply and demand curve does not work in the seed industry. This fundamental economic principle states that as demand goes up, then supply and prices rise (and vice versa), whereas if supply goes up, the demand and prices will fall. However, as previously stated, supply is dependent on environmental factors such as rainfall, and is unable to respond to demand.

Seed collection efforts could increase responding to demand, but as stated, demand already outweighs supply. Also, the main driver of demand is state and Commonwealth programs (Broadhurst *et al.* 2015), hence there is limited competition, which keeps prices low. Many seed supply companies state that prices are subject to change without notice, or that prices vary according to supply and demand.[24]

Hancock *et al. (*2020) found that consumers are unwilling to pay the 'true cost' for seeds. In addition, seed purchasers know that not paying the true cost is a risk to the sector. They may either be unwilling or unable (due to limited funding) to pay an appropriate amount. Volunteers may also be negatively affecting pricing, as some groups are able to access seed at a lower cost than others, and if volunteers collect seed then there is lower demand from suppliers.

The cost of seed may or may not take into account seed quality (see section 6.6). Also, seed quality information may not be made available at sale. Hence, it is difficult to compare prices between suppliers. In Western Australia, RIAWA has developed an accreditation system where suppliers can indicate the level of quality they are supplying using the seed grading, and charge more for a better quality product (see section 6.6).

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[24] e.g. http://www.ausseed.com.au/terms-of-trade/; https://www.seedingvictoria.com.au/cb_pages/buy_seed.php https://www.tranen.com.au/services/seed/seed-sales/; https://www.nindethana.net.au/information/ordering-information.aspx

The grades are:[25]

- Conservation Grade, A+ Grade — Commercial Plus
- A Grade — Standard Commercial
- B Grade — Minimum Commercial
- C Grade — Seeding Grade.

This system is not used nationally.

Encouraging purchasers to pay the true cost of seed may rely on other factors such as implementing quality testing and better allocation for funding for seed-based restoration.

6.10 Funding

Short-term funding is leading to poorly-planned and monitored restoration.

As restoration is undertaken by a variety of stakeholders, it is funded in a variety of ways. Commercial organisations such as resource companies may be required to fund and undertake restoration as a condition of project approval (Kragt *et al.* 2019). Land restored as an offset is funded by a developer, and may be implemented by a third party (Maron and Louis 2018). NGOs may fund restoration through private donors (e.g. Bush Heritage Australia, Gondwana Link).[26] Restoration by state government agencies may be funded by the state.

However, restoration by community groups, local government, not-for-profits, regional NRM groups and landholders may be funded by the federal government (e.g. Environment Restoration Fund,[27] the National Landcare Program[28]) or state governments (e.g. Community Stewardship Grant[29] in WA). There are also non-government grants, such as National Tree Day,[30] funded by donations from business and individuals.

These grants generally have a short duration, ranging from 12 months (Community Stewardship small grants) to three years (Environment Restoration Fund) or five years (Regional Land Partnerships). The National Tree Day[31] funding is for just five months, as it provides grants to purchase seedlings which close on 19 February 2021 to plant as part of National Tree day on 1 August 2021. Short-term grants do not allow sufficient time for seed or seedlings to be sourced.

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25 http://riawa.com.au/wordpress/wp-content/uploads/2019/10/01-RIAWA-Seed-Standards-191021.pdf
26 http://www.gondwanalink.org/aboutus/funding.aspx
27 https://www.environment.gov.au/environment-restoration-fund
28 http://www.nrm.gov.au/national-landcare-program
29 https://www.wa.gov.au/service/community-services/grants-and-subsidies/apply-community-stewardship-grant
30 https://treeday.planetark.org/about/
31 https://treeday.planetark.org/about/

In Western Australia, Community Stewardship Grants are generally announced in November/December,[32] when the seed collection season has already commenced. Cut-offs for orders for contract growing of seedlings are in November, for planting in the following winter.[33] This means there is insufficient time for seed to be sourced from specific locations (unless it happens to be held in a seed bank), and there is likely to be insufficient time for the right species from the right locations to be grown for the project. Annual funding also does not allow time for monitoring.

Three-year projects may have more lead time for seed sourcing and propagation, however, if that takes a year, again, there is not much time for monitoring to determine the success or otherwise of the project. The most successful restoration projects have a duration of many decades (e.g. SERA Award for Restoration Excellence Winner 2018, Lord Howe Island Board, who have been conducting restoration since the 1980s).[34]

Funding timelines need to correspond with restoration timelines, particularly given that restoration activities like seed collection, nursery propagation and planting are seasonal. Funding should be provided for more than 5 years, to allow for adequate planning, seed collection and monitoring. It would also allow for more stable seed markets, ensuring support for businesses, workforces, training and improvement of quality (Hancock *et al.* 2020).

Also, several decades of investment is required for restoration, which does not match the 3–5 year funding cycles (Broadhurst *et al.* 2015). We need an intergenerational view to restore our biodiversity (Broadhurst *et al.* 2015). A national restoration strategy providing a clear direction for restoration across the country would provide vision and direction for funding and projects, rather than small, ad hoc grants allocated on a one-off basis.

[32] https://www.wa.gov.au/sites/default/files/2020-11/2020%20-%20Successful%20Community%20Stewardship%20Grants.pdf; https://www.mediastatements.wa.gov.au/Pages/McGowan/2020/12/Grants-boost-community-effort-to-care-for-States-natural-assets.aspx
[33] https://www.plantrite.com.au/our-plants/revegetation-tubestock/
[34] https://www.seraustralasia.org/case-studies/2019/1/8/lord-howe-island-new-south-wales-australia

6.11 Developing and accessing research and information on seeds and restoration

Some sectors of the industry may have difficulty in accessing information. Knowledge gaps in seed ecology and restoration ecology limit the success of restoration. If conferences fail to reach practitioners, then information presented at conferences will not lead to improvements in restoration projects.

By sharing information about seeds and restoration, the industry can learn from participants to improve outcomes. Understanding where knowledge is held, how people access it and the knowledge gaps will help improve access and strategic research.

Written information about seed and restoration can be found in:

- books (Sweedman and Merritt 2006)
- papers within scientific journals (e.g. *Restoration Ecology* (RE),[35] *Seed Science Research* (SSR),[36] *Ecological Management and Restoration* (EMR))[37]
- websites of professional societies (International Network for Seed-based Restoration (INSR), Australian Association of Bush Regenerators (AABR), Australian Network for Plant Conservation (ANPC))
- online databases (Australian Seed Bank Partnership,[38] Seed Information Database)[39]
- society bulletins (*Australasian Plant Conservation*,[40] *Australian Plants Journal*)[41]
- technical sheets[42]
- guidelines (Commander *et al.* 2018; Offord and Meagher 2009)
- reputable online news source (e.g. The Conversation).[43]

Another consequence of the lack of a national organisation that represents the native seed industry is that there is no single repository for collating information about native seeds. There are several barriers to people accessing this information. One barrier might be cost. Books, both print and e-books can be expensive, although some can be downloaded or previewed for free.

Scientific journal articles often cost money to download (e.g. between $7 and $42 for EMR articles), unless the reader belongs to a library with a subscription, has paid for a subscription (e.g. $110 for EMR), or received a subscription or discounted subscription as a benefit of a

[35] https://onlinelibrary.wiley.com/journal/1526100x
[36] https://www.cambridge.org/core/journals/seed-science-research
[37] https://onlinelibrary.wiley.com/journal/14428903
[38] https://asbp.ala.org.au/
[39] http://data.kew.org/sid/
[40] https://www.anpc.asn.au/apc/
[41] http://www.anpsa.org.au/pubs.html
[42] http://brahmsonline.kew.org/msbp/Training/Resources
[43] https://theconversation.com/au

society membership. Articles which are open access sometimes require payment from the author, which may be a barrier for authors to publish. In some instances, an entire issue is provided as open access (e.g. Cross *et al.* 2020). Another method of overcoming this barrier is to publish information on freely-accessible websites, however, this information may not be subject to a review process and hence may be incorrect, potentially leading to negative environmental outcomes.

Another barrier may be writing style or assumed prior knowledge. Certain publications may have a specific target audience (e.g. research, practitioners, policy makers), and may use terminology with which the non-target audience is not familiar, making the publication difficult to understand. Different countries and states may use the same terminology in different ways. Yet another barrier may be that people simply do not know where to look, or do not have time to search and read through individual articles. Location may be a barrier, as those in remote areas may not have access to book shops through which to browse.

This is where free, online publications, written in plain English, are beneficial to the industry. They should synthesise the latest research and practice, and provide it in a format that end-users can understand, provide feedback to inform research and policy, and ensure that they improve on-ground outcomes.

Publications such as these require funding to ensure that they can be made available for free, and they require a collaboration between science communicators and those in the industry. The *FloraBank Guidelines* (Commander in prep; Mortlock 1999b) is a good example of a free, online publication that aims to share information and improve practice.

Identifying knowledge gaps is another area of importance as it can drive research. Knowledge gaps identified include a lack of information on flowering and seed set which leads to inappropriate collection timing, lack of knowledge on how to overcome seed dormancy, which prevents germination, and low seedling establishment from broadcast seed (Merritt and Dixon 2011). Research is needed in seed technology, seed production and genetic analysis (Merritt and Dixon 2011).

Importantly, research areas must be integrated (Merritt and Dixon 2011). Laboratory, glasshouse and field trials can all be used to answer research questions, as can surveys and expert elicitation. Experiments that are embedded in restoration projects are a beneficial opportunity for landowners and researchers, especially if they are well designed and replicated across many locations so that results can be pooled (Gellie *et al.* 2018). There are already some networked sites across Australia. The Terrestrial Ecosystem Research Network (TERN)[44] has an ecosystem surveillance platform to survey across a national network of sites. Although this network is for survey data, it could be adapted for monitoring of replicated experiments.

[44] https://www.tern.org.au/tern-observatory/tern-ecosystem-surveillance/

Miller *et al.* (2016) provide a number of research questions that can be used to design experiments to optimise restoration. These questions are categorised into five themes:

1. setting targets and planning for success
2. sourcing biological material
3. optimising establishment
4. facilitating growth and survival
5. restoring resilience, sustainability and landscape integration.

A selection of the questions is listed:

- What species and how many seeds, tubestock, and so on of each are required to meet final targets given developmental transition likelihoods?
- From where should biological material (typically seed) be sourced to minimise negative impacts for ecological restoration?
- For seed sourcing, is it better to mix genotypes (thereby increasing evolutionary potential) or match genotypes to local conditions (maximising local adaptation)?
- Might inbreeding or low genetic diversity within source population(s) impact on the success of ecological restoration?
- When does outbreeding depression impact on the success of ecological restoration in populations established from composite or admixture provenancing?
- How can spatio-temporal opportunities for efficient sourcing of large numbers of viable seeds from natural populations be predicted?
- What techniques are appropriate to increase production of viable seeds in natural populations?
- How can viable seed output be maximised in managed seed production facilities without compromising genetic diversity and integrity?
- What are the optimal storage requirements to maintain long-term viability of seeds?
- Can micropropagation techniques be adapted for efficient production of recalcitrant species required in restoration?
- What is the dormancy mode of seed of species required for restoration, and what approaches are required to overcome dormancy?
- What conditions are necessary for optimal germination of species required for restoration?
- What seed delivery techniques or seed enhancements could improve seed survival and germination and seedling establishment on site?
- What tubestock pre-planting treatments are required to optimise establishment and survival on planting?

- What scheduling or site manipulation is required to optimise seed germination and establishment of seedlings and tubestock?
- Are soil or substrate physical, hydrological, chemical, and biological attributes limiting and can they be manipulated to optimise plant growth and survival in restoration?

These questions can be used to inform experimental approaches.

Sharing knowledge can also be done face-to-face, such as at meetings, forums, workshops and conferences. One issue with conferences is that they do not always meet the needs of practitioners. Either the registration costs are too high, they are in inaccessible places or held at an inconvenient time of the year (Hancock *et al.* 2020). More efforts need to be made to reach on-ground practitioners. In addition, those who already attend conferences could seek out practitioner-focused forums at which to present.

The Australasian Seed Science Conference[45] (ASSC) organised by ASBP will be held in September 2021, and the 13th Australasian Plant Conservation Conference[46] (APCC13) **'**Seeds to recovery' will be held in April 2022. As well as providing information, these would be excellent forums in which to discuss information needs and access.

ASSC will cover the following themes:

- Seed biology and evolutionary ecology — Unlocking the challenges of germination, dormancy and seed ecology in a changing world.
- Seed sourcing and end-use — Considering genetic diversity, restoration and translocations as well as sector specific approaches to seed conservation and use.
- Seed and gene bank management — The ins and outs of managing ex situ seed banks and gene banks and the methods for maximising seed quality and longevity.
- Seeds in culture and society — Sharing stories and learning about cultural seed use, including collaborations between traditional use and ex situ seed banks and gene banks.

APCC13 'Seeds to Recovery' will cover the following sub-themes:

- seeds
- bushfire recovery
- conservation/threatened species and communities
- engaging people with conservation/restoration

[45] https://seedscience2021.com.au/
[46] https://www.anpc.asn.au/conferences/apcc13/

An annual forum (in-person or online) for the whole native seed industry may help share knowledge and identify knowledge gaps. It needs to be low cost, at a convenient time of the year, and in an accessible place. Although grant funding can often only be used for on-ground works, some grants are available for building community capacity, and perhaps these could be used to fund community group or landowner attendance at conferences.

Ensuring people have access to information by providing good quality publications at low or no cost will improve on the ground outcomes. A central repository for information may be useful. Providing an annual forum may assist two-way knowledge sharing.

Conferences and forums need to be low cost, at a convenient time of the year, and held in an accessible place and inclusive of practitioners. Funding may need to be provided to offset registration costs.

Identifying knowledge gaps and addressing these through research will be needed for a restoration strategy. Networked and embedded experiments can be used to address knowledge gaps. Several important research questions are listed.

6.12 Education and training

Many seed suppliers have not undertaken training, and there are no requirements for them to do so. A lack of training could lead to poor quality products and poor restoration outcomes.

The native seed survey report found that many seed suppliers have not undertaken training (Hancock *et al.* 2020). As mentioned in section 1.9, there is no training requirement to obtain a collecting licence. No licences are required to sell seed, and no mandatory standards are in place for seed supply. Education and training in seed collection and restoration is provided by TAFE, Universities, botanic gardens and professional associations.

Under the Australian Government training scheme (training.gov.au), units of competency offered include collecting native seed; Collect Native Seeds (AHCNAR305) is a unit of competency which can be completed within several certificates, including indigenous land management, natural area restoration and conservation and land management.[47] In addition, Certificates III and IV in Seed Testing are offered.

At least four universities offer programs in Restoration Ecology or a related field (Charles Sturt University; Curtin University; University of Melbourne; University of Western Australia) as well as ACS Distance Education, according to SER's Academic Program Directory.[48]

[47] https://training.gov.au/Training/Details/AHCNAR305
[48] https://www.ser-rrc.org/directory/academic/

Some botanic gardens host horticultural trainees, honours and postgraduate students[49] to provide training in native plants.

Various organisations run workshops on an as needs basis or online. ANPC runs training courses in seed collection, direct seeding, plant identification, translocation and provenance,[50] Apace (WA) runs collection, processing and propagation workshops,[51] and the Revegetation Industry Association of WA (RIAWA) is preparing an online course to complement its accreditation system.[52] As mentioned in section 5, SER's CERP program involves an e-learning course followed by an application outlining relevant experience. A program for those involved in the seed industry, similar to SER's CERP program, could be set up in Australia. It could be based on the *FloraBank Guidelines*, which is currently being updated.

Just as seed collectors require training, so to do seed purchasers. There currently don't appear to be any training courses targeted at seed purchasers in Australia, to assist them with restoration planning, seed and seedling procurement, budgets for seed, and how to write tenders for seed supply. The new FloraBank module which outlines tips for buying and selling seed[53] is a step in the right direction, but more is needed to support this sector of the industry.

> Provide low-cost, frequent training programs, possibly online. Encourage training when licences or grants are applied for. Collate a centralised list of all training opportunities at all levels. Seed purchasers also require training.

6.13 Coordination and communication

Lack of coordination of the sector by means of a representative body means that change is unlikely to be realised, including the benefits of collaboration and communication.

6.13.1 Industry body

Currently, a body to represent those in the native seed sector does not exist. This lack of representation may be partly responsible for some of the issues in this report, but importantly, it is also responsible for missed opportunities. By giving the sector a combined voice, and having a structure to bring stakeholders together and facilitate communication, it is possible that change may be enabled. Bush regenerators and land managers cited the lack of coordination as one of the main barriers (Cooper *et al.* 2018). Two Australian reviews have called for the formation of a National Industry Body (Broadhurst *et al.* 2015; Hancock *et al.* 2020). The vast majority of those in the seed industry who were surveyed by Hancock *et al.* (2020) are in favour of creating an industry body, although they had differing opinions on its structure.

[49] https://www.bgpa.wa.gov.au/about-us/information/education-and-training/higher-education
[50] https://www.anpc.asn.au/workshops/training/
[51] https://apacewa.org.au/community-2/training-education/
[52] https://prezi.com/i/n8iumcso_doh/riawa-newsletter-december-2020/
[53] https://www.anpc.asn.au/florabank/

Hancock *et al.* 2020 states:

'Establishing this body will require direct and in-kind resourcing from Federal, State and regional agencies. Over time, once the native seed market is stable and financially viable, a user-pays system may be more appropriate. This body would be responsible for:

- *advocating on behalf of the native seed sector on environmental program development, policies, and processes*
- *developing agreed standards of practice for the native seed sector for seed-related activities not already covered by existing guidelines such as guidance on suitable geographic/ecotype ranges or seed transfer zones or the use climate-ready strategies*
- *providing seed buyers with clarity around seed point-of-origin and sourcing practices including through an investigation of quality assurance systems developed in North America and Europe (e.g. capturing appropriate genetic diversity)*
- *assisting seed suppliers to meet market requirements for seed volumes, seed quality and species diversity*
- *in collaboration with and supported by agency-based biodiversity conservation, NRM and NLP strategies and programs, facilitate regionally-based forums for native seed providers and users*
- *delivering sector information, information sharing, and networking opportunities through conferences, workshops, forums and other forms of delivery*
- *overseeing the development of accredited (or similarly recognised) training in all aspects of native seed handling and end-use, including contracting and sale specifications.*
- *transitioning from a body funded from outside sources to one that is independently viable.'*

Within Australia, individuals in the seed sector may be associated with Greenlife Industry Australia[54] (the nursery industry), the Australian Seed Foundation or the Revegetation Industry Association if WA, but none of these organisations represents the whole sector.

Internationally, seed networks exist such as the Xingu Seed Network in Brazil, which involves over 30 organisations and 450 seed collector groups, who supply seed for restoration,[55] the Seeds of Success Program in the USA, which involves more than 65 collection teams (**Box 2**) and the International Network for Seed-Based Restoration[56] (INSR), which is a network within the Society for Ecological Restoration.

Initially, this proposed industry body could be a sub-group under the auspices of another organisation, like ASBP, SERA or ANPC. This industry body could have representatives from a number of organisations (Error! Reference source not found.). There could be state branches of the national industry body.

[54] https://www.greenlifeindustry.com.au/Category?Action=View&Category_id=769
[55] https://ser-insr.org/news/2017/9/15/xingu-seeds-network-in-brazil
[56] https://ser-insr.org/

TABLE 2. ORGANISATIONS FROM WHICH REPRESENTATIVES COULD BE SELECTED TO FORM AN INDUSTRY BODY

SECTOR	ORGANISATIONS
Government	Australian Government, Department of Agriculture, Water and the Environment (Environment Restoration Fund; National Landcare Program) Catchment Management Authorities (CMAs) (VIC) CSIRO Local Land Services (LLS) (NSW) Parks Australia State Government environment departments The Office of the Threatened Species Commissioner
Non-government / Not for profit	Australian Seed Bank Partnership (ASBP) Australian Wildlife Conservancy (AWC) Bush Heritage Australia (BHA) Council of Heads of Australian Botanic Gardens (CHBAG) Conservation Volunteers Australia (CVA) Landcare Australia NRM Regions Australia Planet Ark and National Tree Day The Nature Conservancy
Commercial	Commercial seed collectors Greening Australia (GA) Restoration practitioners
Professional Organisations /networks	Australian Association of Bush Regenerators (AABR) Australian Network for Plant Conservation (ANPC) Australasian Institute of Mining and Metallurgy (AusIMM) Australian Local Government Associations (ALGA) Australian Native Plants Society (Australia) (ANPSA) Botanic Gardens Association of Australia and New Zealand (BGANZ) Environmental Consultants Association (ECA) Ecological Society of Australia (ESA) Greenlife Industry Australia (formerly NGIA) National Indigenous Australians Agency (NIAA) RegenWA Revegetation Industry Association of WA (RIAWA) Society of Ecological Restoration Australasia (SERA)
University / Government funded	Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) Cooperative Research Centre for Transformations in Mining Economies (CRC TiME) Clean Air and Urban Landscapes (CAUL) Hub Threatened Species Recovery (TSR) Hub National Collaborative Research Infrastructure Strategy (NCRIS) Terrestrial Ecosystem Research Network (TERN) WA Biodiversity Science Institute (WABSI)
International organisations	International Network for Seed-based Restoration (INSR) International Union for the Conservation of Nature (IUCN) Society of Ecological Restoration (SER) UN Environment Program

One of the barriers to coordination is that different parts of the industry use different terms, which means that it is not immediately obvious that they are doing similar actions (e.g. seeding and planting) even if it is in different settings (mining, agricultural, urban environments), and that can lead to lack of communication. Terms such as landcare, bush regeneration, revegetation, regenerate, ecological restoration, mine rehabilitation, reclamation, tree planting, coastcare, natural resource management, rewilding, reforestation, translocation, are all likely to involve the use of native seeds.

These sectors may also have different communication forums, such as Ecological Society of Australia[57] (aimed at ecologists), Landcare Australia[58] (aimed at landcare groups) or Mine Closure[59] (aimed at the mining industry) conferences; hence there may be limited cross-talk and networking between sectors. Two upcoming conferences with seed themes that could involve all parts of the industry, and could be used to discuss industry coordination are ASSC and APCC13 (see section 6.11).

Botanic Gardens are poised to assist with the recovery efforts following the bushfires (Council of Heads of Australian Botanic Gardens Inc. 2020). Better communication between conservation seed banks and the restoration seed industry could also provide two-way benefits. Botanic Gardens, many of which house conservation seed banks,[60] are knowledge-hubs of skills such as native plant identification, propagation, seed bank management and scientific research (Hardwick *et al.* 2011). For instance, the Restoration Seed Bank Initiative was a partnership between a Botanic Garden (Kings Park and Botanic Garden), a University (the University of Western Australia) and a resource company (BHP) to develop knowledge and skills to achieve restoration (Turner *et al.* 2016).

Commissioner for Restoration

In addition to an industry body, another option to give the sector a voice is to appoint a **Commissioner for Restoration**, similar to the role of other Commissioners. The Threatened Species Commissioner has given a voice to threatened species, and works collaboratively with stakeholder groups to tackle issues.[61]

In Western Australia, there is a Soil and Land Conservation Commissioner, who 'is responsible for administering the Soil and Land Conservation Act 1945, includes preventing land degradation, promoting soil conservation and educating landholders and the general public about sound land management'.[62]

[57] https://www.ecolsoc.org.au/opportunities/attend-our-conference/
[58] https://landcareaustralia.org.au/national-landcare-conference-2020/
[59] https://papers.acg.uwa.edu.au/c/mc2019
[60] https://www.seedpartnership.org.au/
[61] http://environment.gov.au/biodiversity/threatened/commissioner/role
[62] https://www.mediastatements.wa.gov.au/Pages/McGowan/2020/09/New-Soil-and-Land-Conservation-Commissioner-appointed-to-drive-soil-health-and-landscape-repair.aspx

The Australian Capital Territory has a Commissioner for Sustainability and the Environment and Victoria has a Commissioner for Environmental Sustainability. Perhaps, in this UN Decade on Ecosystem Restoration,[63] it is timely for a Commissioner for Restoration to be appointed.

Box 2 — The Seeds of Success program in the US

Information from Seeds of Success (2018).

The Seeds of Success program[1] (SOS) aims to 'establish a national, high quality, accurately identified and well documented native plant species seed collection'. Each collection captures a unique population (a group of individuals living within the same collection site, continuous in range and generally uniform in appearance; one accession or collection). Collections can be used for conservation and to develop plant materials (i.e. through seed production). The goal of the plant development program to ensure a stable and economical supply of native plant materials for restoration after fire.

Originally, the SOS program was a cooperation between the Bureau of Land Management (BLM) and the Royal Botanic Gardens, Kew's Millennium Seed Bank (MSB). SOS has grown from 23 to over 65 collection teams from 2000 to 2018. The BLM leads the program, and employs a National Curator. As an aside, Australia also participated in the MSB project, and the partnership is now called the Australian Seed Bank Partnership (ASBP).

The SOS has developed a training course named 'Seed Collection for Restoration and Conservation'. They provide information on their website,[1] have an email list for discussion, and monthly collectors' conference calls. Annual reports summarising the collections must be completed.

Target species for collection depend on the region, and are developed with collectors, land managers, BLM staff, researchers, SOS National Coordinating Office and other stakeholders. In some parts of the USA, there are target species lists on an ecoregional level. An 'ecoregion' is defined by its environmental conditions, climate, landforms and soils. Ideal collections are from over 100 individuals and have >10,000 viable seeds. Collection protocols are provided.

After cleaning, testing and processing, seeds are stored in long-term storage (-20°C) or in a working collection (4°C). Three main organisations store the seed (the US Department of Agriculture, Agricultural Research Service; the National Center for Genetic Resources Preservation (NCGRP) in Fort Collins, Colorado; and the Western Regional Plant Introduction Station (WRPIS)).

[63] https://www.decadeonrestoration.org/

An industry body to represent the seed sector is now needed. Opportunities to communicate between different parts of the sector will benefit the whole industry.

6.14 Scaling up

Large-scale restoration, particularly of cleared or highly degraded areas, will require large volumes of seeds. There may not currently be capacity to source and store large volumes of seeds, nor the governance, policy, knowledge or investment to support scaling up.

The seed industry in Australia may not yet have the capacity to implement restoration at the scale required, particularly after the large-scale bushfires of 2019–20. The industry needs to be supported with a framework to enable scaling up, which includes addressing governance and land ownership, building capacity (technological and educational), applied science, ensuring that restoration is compatible with livelihoods and promoting investment (Perring *et al.* 2018).

At a national scale, prioritising both regions in which restoration will provide cost-effective results, and research needs (Menz *et al.* 2013), as well as a consistent framework for within-region planning and prioritisation, will enable allocation of limited resources (Pannell and Roberts 2010). In fact, national programs should use technical and socioeconomic information, set realistic targets, prioritise investments, choose appropriate policies, invest in long-term outcomes, incentivise environmental outcomes, link monitoring and evaluation to management, allow sufficient time for planning, and if not, they will be of little benefit (Pannell and Roberts 2010).

Stakeholder collaboration is also essential for large-scale restoration (Jellinek *et al.* 2019), given that large areas involve multiple landowners, and cross jurisdictional boundaries. Above all, communicating both the ecological and social benefits that restoration provides may increase stakeholder engagement and support (including individuals, corporations and governments). Integrating multiple motivations of stakeholders into project planning may deliver multiple benefits (Hagger *et al.* 2017; Jellinek *et al.* 2019).

Many of the recommendations in this report will assist with scaling up restoration. For instance, Seed Production Areas can greatly increase the volume of seed available for restoration (section 6.1). Improving infrastructure for seed storage, using restoration seed banks, or restoration knowledge hubs, which combine research, storage, and community and industry-based restoration, have the potential to increase capacity (section 6.4; Menz *et al.* 2013; Merritt and Dixon 2011).

Seed technology has the potential to make seeding cheaper and more efficient (section 6.6; Erickson *et al.* 2017; Pedrini *et al.* 2020). Education and training will be essential to share knowledge (section 6.11). Strategic research to address on-ground questions (Miller *et al.* 2016) such as how to increase seedling emergence will enable the industry to restore larger areas with less seed (section 6.10). Connecting small-scale projects together through an industry body (section 6.12) could result in economies of scale (Menz *et al.* 2013), if smaller projects share resources to better plan restoration, order seed and share equipment for implementation. It will only be through a combination of changes that Australia will be able to scale up its seed-based restoration.

Several large-scale restoration projects are currently being implemented in Australia, e.g. Gondwana Link (Bradby *et al.* 2016; Jonson 2010), Habitat 141,[64] Great Eastern Ranges,[65] Living Flinders[66] and Wild Eyre[67] projects, as well as restoration following resource extraction such as Alcoa (Koch 2007; Koch and Hobbs 2007) and BHP Iron Ore (Erickson *et al.* 2017).

Although these are not national projects, they are certainly aiming to restore at the landscape scale. Hence, their procedures and practices could be adopted at the national scale. One of the likely reasons for success of some of these projects is good long-term planning, and ongoing implementation over many years combined with continual improvement. In addition, structured seed collection and storage programs can ensure that sufficient seed is available for 3–5 years into the future (Erickson *et al.* 2017).

Plans for seed collection and storage, and implementation of seed-based restoration need to be able to be achieved at large-scale. A combination of changes is required to up-scale restoration, as there is no single solution. Scaling up will need to be supported with capacity building, policy and investment.

6.15 Implementing change

Many of the issues presented in this report were raised 10–20 years ago (Broadhurst *et al.* 2008; Merritt and Dixon 2011; Mortlock 2000) but yet they still seem to be relevant today. In fact, Hancock *et al.* (2020) mentions that sector members have highlighted that little action has been taken over the past two decades, and the lack of change was also noted in 2015 by Broadhurst *et al.* (2015). Reasons for this lack of change have not been determined. Perhaps individuals and organisations have not taken responsibility for making the changes recommended over the past two decades. Perhaps regulatory authorities have not mandated change.

[64] https://www.habitat141.org.au/
[65] https://ger.org.au/
[66] https://www.greeningaustralia.org.au/projects/living-flinders/#:~:text=Living%20Flinders%20is%20a%20large%20landscape%20restoration%20project,kilometres%20of%20South%20Australia%E2%80%99s%20iconic%20Southern%20Flinders%20Ranges.
[67] https://wildeyre.com.au/

How could change be implemented? The formation of an industry body could help to raise the profile of the issues, and speak on behalf of the industry (see section 6.13). It could also educate and empower individuals. A top-down approach from various levels of government would provide leadership. Governments can change funding timelines and criteria, as well as licensing conditions. Successful programs could be showcased to inspire organisations and individuals to raise their standard and empower them with knowledge in the absence of leadership. Training providers could collaborate to communicate consistent messages and encourage change.

In some instances, there will need to be change in one area, to enable change in another, for instance, increasing the price of seed could enable seed collectors and merchants to improve storage infrastructure and encourage seed testing. Then, once seed is tested, purchasers may not mind paying a bit more, to ensure that they have quality seed. But, if seed testing is mandatory without a corresponding price increase, perhaps the result will be that collectors leave the industry.

Importantly, the stakeholders need to understand what the change means to them, so communication is vital. If they understand the benefits, they are more likely to participate (Jellinek *et al.* 2019). The evidence of linking ecological restoration with human health is increasing, hence public health benefits could be promoted to motivate restoration (Breed *et al.* 2020).

Understanding the existing motivations of each stakeholder could enable targeted communication to appeal to that motivation. Hagger *et al.* (2017) performed a survey to identify the motivations for ecological restoration — the end use of seeds. Most participants had a biotic motivation (increasing biodiversity), followed by pragmatic (improving water quality) and idealistic (social reasons) motivation, but motivations differed by region and landscape context. The survey didn't specifically include seed collectors or merchants, but did include private organisations, state government, community groups and landowners. Hence, socioecological approaches to initiating change are just as important as technological approaches.

In the mining industry, improvements in restoration have been driven by social pressure and regulation, and in some cases, by a company's desire to implement best practice and with support from management (Gardner and Bell 2007; Grant and Koch 2007; Jellinek *et al.* 2019; Stevens and Dixon 2017). The standards for restoration have increased, from, for example, in 1983, not quantifying any outcomes (e.g. 'carry out a continuous program of investigation and research…for the protection and management of the environment' (Shark Bay Solar Salt Industry Agreement Act 1983)) to, in 2009, mandating the return of 70% of the original species diversity of flora (Ministerial Statement 811).[68]

[68] https://www.epa.wa.gov.au/0811-koolanookablue-hills-direct-shipping-ore-mining-project-shires-morawa-and-perenjori

These increasing standards have driven change within the industry, and encouraged companies to engage with the research community, with one company supporting more than 150 honours, masters and PhD projects over 20 years (Gardner and Bell 2007; Grant and Koch 2007). Agreed standards of restoration / measurable condition targets are termed 'completion criteria' by the mining industry. They are specified in the conditions recommended in the Ministerial Statement, which is applied by the State Government Minister for Environment (in Western Australia, and other jurisdictions) (Kragt *et al.* 2019; Manero *et al.* 2020).

However, these conditions are sometimes perceived as being unachievable and may be inconsistent between projects; hence an improved framework is required to provide guidance on how to develop criteria that is both achievable and measurable (Kragt *et al.* 2019; Manero *et al.* 2020). Governments, therefore, have been part of the force driving increasing standards in restoration in the mining industry, and could encourage better restoration in other sectors through policy and the use of legislation, engagement with research, as well as clear, consistent regulatory guidelines for both restoration in mining and other land uses (e.g. see Stevens and Dixon 2017).

The United Nations Decade on Restoration Strategy document (UN Environment Programme 2020) outlines a pathway to implementation. Their nine actions could be utilised in Australia to implement change, and are:

- Empower a global movement
- Finance restoration on the ground
- Set the right incentives
- Celebrate leadership
- Invest in research
- Build up capacity
- Celebrate a culture of restoration
- Build up the next generation
- Listen and learn

> Change needs to be implemented by forming an industry body, understanding the motivations of, and communicating with stakeholders, and changing regulations.

Two key papers have proposed actions to address seed supply issues in Australia, and their recommendations have been summarised below (Table 3), alongside the goals and objectives of the USA National Seed Strategy.

Table 3. Actions to address seed supply issues in Australia and the goals and objectives of the USA National Seed Strategy

Theme	Hancock *et al.* (2020)	Broadhurst *et al.* (2015)	USA National Seed Strategy (Plant Conservation Alliance 2015)
Communication	Discussions among federal, state and regional government agencies with responsibilities for implementing large-scale national environmental programs, policies and procedures be initiated and thereafter conducted annually.		Ensure good communications: External Communications: Conduct Education and Outreach through the Plant Conservation Alliance Network Internal Communications: Distribute and Implement the Strategy Across Agencies, and Provide Feedback Mechanisms Report Progress, Recognise Achievements, and Revise Strategy
Coordination	Establishment of a national native seed industry body to represent and assist the sector (and government)	Establishment of a National Restoration Industry Body representing the broad range of stakeholders from small and local landholders and community groups to more 'industrialised' projects undertaken by NGOs and mining companies	
Education and training		Develop a highly skilled, energetic and experienced workforce with defined career paths.	Develop tools for land managers: Develop Training Programs for Practitioners, Producers, and Stakeholders Develop Native Seed Source Availability Data and Tools for Accessing the Data Integrate and Develop Science Delivery Tools to Support Restoration Project Development and Implementation Build on Ecological Assessments and Disturbance Data, and Provide Training that will Allow Managers to Anticipate Needs and Establish Spatially-Explicit Contingency Strategies

THEME	HANCOCK *ET AL.* (2020)	BROADHURST *ET AL.* (2015)	USA NATIONAL SEED STRATEGY (PLANT CONSERVATION ALLIANCE 2015)
Funding	The costs and benefits of short- versus long-term funding cycles be undertaken to determine if the shift to longer cycles by some jurisdictions warrants similar funding cycles at all levels of government. More consistent and sustained funding for biodiversity recovery is required from funding agencies	A change in length and security of funding for restoration in line with the realistic time frames over which change can be made in natural systems. A funding portfolio that supports longer term projects to maximise the benefits of investment and capture the lessons that can be learned over these time frames	
Infrastructure	Determine the scale of infrastructure investment required to develop and maintain a sector capable of meeting future demand.		
Funding	The costs and benefits of short- versus long-term funding cycles be undertaken to determine if the shift to longer cycles by some jurisdictions warrants similar funding cycles at all levels of government. More consistent and sustained funding for biodiversity recovery is required from funding agencies		
Recognition		Acknowledgement at a Commonwealth, State and Regional Natural Resource Management policy level of the critical importance of the native seed supply chain to all restoration outcomes.	
Research	Supporting research, especially that which includes and mobilises knowledge of the restoration sector. Ensuring that this knowledge is current and easily accessed.	Encourage research partnerships to help natural resource managers maximise the benefits of funding through effective monitoring and evaluation programs and adaptively manage their seed resources as well as restoration protocols. Improve knowledge and communication on native seed biology and technology.	Undertaking research and improving technologies for seed production and use: Characterize Genetic Variation to Delineate Seed Zones, and Provide Seed Transfer Guidelines for Current and Projected Future Environmental Conditions Conduct Species-Specific Research to Provide Seed Technology, Storage, and Production Protocols for Restoration Species

THEME	HANCOCK *ET AL.* (2020)	BROADHURST *ET AL.* (2015)	USA NATIONAL SEED STRATEGY (PLANT CONSERVATION ALLIANCE 2015)
			Conduct Research on Plant Establishment, Species Interactions, and Ecological Restoration Develop or Modify Monitoring Techniques, and Investigate Long-Term Restoration Impacts and Outcomes
Seed Production Areas (SPAs)	Integrate Federal, State and regional environmental strategies to support the development and operation of regional SPAs.	Develop strategically located SPAs and associated design standards and storage systems.	
Seed supply and demand	Improve forward planning and coordination of seed requirements for regional restoration programs. Investigate environmental programs, incentive schemes or legislative directives that are successfully operating in the USA and Europe to determine whether these would be appropriate in Australia.		Assess the seed needs of federal agencies and the capacity of private and federal producers: Assess the Seed Needs of Federal Agencies and the Capacity of Private and Federal Producers; and Tribes, States, Private Sector Seed Producers, Nurseries, and Other Partners Increase the Supply and Reliable Availability of Genetically Appropriate Seed
Seed testing and tracking	Establish minimum seed quality standards and a nationally consistent mechanism for native seed testing that provide affordable services for suppliers and purchasers. Price seed to reflect the full range of costs and standards obligations associated with the collection and/or production, processing, testing and storage to provide sustainability for seed suppliers. Develop a national seed database and tracking system for seed sales to assist sellers and buyers determine species and seed availability, allow for future auditing of seed-based restoration, and to provide data on supply and demand.	Establish Industry Standards to ensure that identified native seed supply issues are addressed at each level of NRM restoration funding delivery.	

7 SEED USE IN FIRE MANAGEMENT

7.1 Fire preparedness

In the future, if temperatures increase and rainfall is low, there will be an increase in fire danger. Climate scientists are able to predict fire danger, and have predicted fire danger to the end of the century. The risk of catastrophic fire can be factored into planning. Hence, this fire forecasting may be useful in directing future seed collecting efforts — if we know which areas are likely to burn in the near future, we can go in and sustainably collect seed before it burns, and then use that seed for restoration. Alternatively, we can increase the resilience of the areas by doing ecological restoration pre-fire, to lessen the impact of fire.

Given that changing climates may lead to an increased bushfire risk, it may also be prudent to develop ways to halt or lessen this change. While decreasing the burning of fossil fuels is commonly recommended to slow climate change, restoring ecological communities can also slow climate change.

While some efforts to slow climate change using plants has used 'tree planting' to absorb atmospheric carbon, ecological restoration — that is, restoring whole communities of plants and animals — is more likely to be effective, as these communities are more likely to be resilient and self-sustaining, meaning that they will not require as much human input, and will be more resilient to events such as fire and climate extremes.

Protection of key assets is done during fire management. These key assets are lives, property and infrastructure. However, biodiversity assets are also important to protect. One such example in the 2019/2020 fires was the protection of the Wollemi Pines. These ancient trees were protected by a collaboration between National Parks and Wildlife Service Remote Area Firefighting Team and NSW Government Department of Planning, Industry and Environment (NSW Department of Planning Industry and Environment 2020). In that way, more of our precious biodiversity assets should be identified now, so that if they are in threat from fire, they can be protected.

Restoration may be able to prevent fires. For instance, riparian restoration has been shown to improve the function and moisture holding capacity of waterways and wetlands, to provide barriers for fires.[69]

Also, restoring ecosystems can improve resilience, and resilient ecosystems are likely to recover from with less assistance compared with ecosystems that have lost their resilience.

[69] https://www.nationalgeographic.com/animals/2020/09/beavers-firefighters-wildfires-california-oregon/

Use fire forecasting to direct future seed collecting efforts.

Restore ecological communities to slow climate change.

Plan to protect biodiversity assets.

Trial the effectiveness of restoration to prevent, slow the spread or lower the intensity of fires.

7.2 Indigenous land management

Cultural burns, or indigenous fire regimes, have been suggested to combat the likelihood of catastrophic fires. Indigenous knowledge about the relationships between plant regeneration and fire could be better utilised for fire planning and restoration. In fact, the plant responses to cultural burns versus other types of fire is not well known and would require the collaboration of cross-cultural ecologists. Engaging indigenous people to help heal the land after catastrophic fire is an essential process, and would result in long-lasting benefits to indigenous and non-indigenous people, as well as the landscapes.

Engage indigenous people to help heal the land after catastrophic fires.

7.3 Threatened species

Following the 2019/20 fires, an assessment was made to determine which of Australia's plant species were most impacted and at risk of extinction, and prioritised a total of 486 taxa (Gallagher 2020). These taxa are Endangered, Critically Endangered, listed as high risk under two or more criteria, or had more than 80% of their range burnt. Germplasm (including seed) collection has been proposed as a management action for taxa listed under three of the prioritisation criteria, with the urgency of the action deemed as immediate. However, it is recommended that seed collection isn't undertaken until the soil (or canopy) seed bank has been replenished, except in urgent cases warranting ex situ conservation. Seeding and planting should only be undertaken if species do not recover, and need to follow national guidelines on translocation (Commander *et al.* 2018). Research may also be required for these species.

Threatened animal species too have been impacted, with 119 species requiring urgent management intervention (Legge *et al.* 2020). Management actions recommended are on-ground surveys, protecting unburnt areas, providing supplementary shelter, food and water, predator control and emergency salvage. Ecological restoration could also serve to increase the habitat available to these species. Determining the most important plants for these imperilled fauna species may direct research and restoration. Collaboration between plant and animal scientists would be beneficial to ensure that the plants on which these fauna depend are considered in restoration.

The Threatened Plant Index has recently been released.[70] The index shows monitoring data on 112 Australian threatened plant species. The effect of management interventions can be interrogated using the index. Data can be submitted by anyone collecting standardised data, thus, it has potential for those monitoring threatened species in fire affected areas, and those undertaking management actions.

Seed banks of the most imperilled species need to recover before seed collection is undertaken, except in urgent cases.

Ecological restoration may provide additional habitat for threatened plant animals, and the prioritisation list could direct restoration to areas and with plant species which would benefit these animals.

7.4 Climate change

With the changing climate, those responsible for managing threatened species are increasingly looking for ways to ensure that these species are able to survive in predicted future climates. Whereas some may be able to adapt and/or migrate, others may not be able to do so, especially if their genetic diversity is low (which may limit adaptation) or if they live in small **remnant** (disjunct) ecosystems. Protection and restoration of climate change refugia may be needed. In some cases, assisted migration may be an option to enable the continual survival of the species.

Protection, restoration and assisted migration may be options to enable the persistence of species affected by climate change.

7.5 People

One of the difficulties with bushfire recovery is that there are a number of stakeholders responsible for land within one ecosystem. These landowners may have access to different resources. For instance, a state government landowner may have access to ecologists to perform vegetation surveys.

A farmer might have a large unburnt area of remnant vegetation from which seed could be collected. A local government may have a volunteer group willing to assist vegetation surveys or seed collection. A regional botanic garden may not own any land, but has facilities and knowledge for cleaning, testing and storing seed. Commercial nurseries too may not own land, but have facilities and knowledge for plant propagation. So, while it may seem that a diversity of landowners may restrict recovery efforts, it's actually a **unique opportunity for them all to share resources** and work together.

[70] https://tsx.org.au/2020/12/01/welcome-australias/; https://tsx.org.au/visualising-the-index/2020-threatened-plant-index/

Duplication of efforts is a waste of resources, so recovery planning could be done at several levels — at a national or state level, some principles could be set out, and at a regional level, a detailed recovery/restoration plan could be developed, so that each individual landowner does not need to develop their own, but could tailor a regional plan to suit their circumstances. These regional plans may include a species list from which landowners could order seed, a list of species likely to require restoration by seed, targets such as density of key species or species diversity. It may also include the threats common to the region, and how to address them. Regional plans could all use a common format, but be developed for each region using stakeholder groups.

There is emerging evidence that involvement in ecological restoration activities may benefit mental health by reducing depression and increasing cortisol (Nabhan *et al.* 2020) and anecdotal evidence suggests it may help heal trauma caused by ecosystem degradation. Given the likely trauma experienced by people in communities affected by fire, involving these people in ecological restoration has the potential to provide mental health benefits.

Strong existing relationships between people and organisations were crucial to the disaster response. To be prepared for the next catastrophic fire, building these relationships between stakeholders within regions, and between experts in different regions, is critical. Cross-sector relationship building, for instance between ecologists and fire and emergency services. is essential.

Sharing resources may assist with the fire recovery efforts.

Recovery planning could be undertaken at a national, state and regional level, to assist individual landowners.

Building strong relationships between stakeholders will be critical for recovery and preparedness for any future fires.

8 ISSUES, SUGGESTIONS AND RECOMMENDATIONS

8.1 Seed and restoration strategy

A strategy on seeds for restoration needs to sit within a context of the broader issues in restoration. Hence, not only should interventions apply to the seed supply chain itself, but also thought needs to be put into factors that influence the supply chain. These external factors include motivations for restoration (e.g. from volunteer-led restoration to mandatory post-mine restoration), funding schemes that drive restoration (how much and for how long), coordination at regional, state and national levels, education and training, investment in research and access to information. Also, there need to be coordinated efforts at all levels of government (Broadhurst *et al.* 2015).

The key tasks to be implemented are (Error! Reference source not found.):

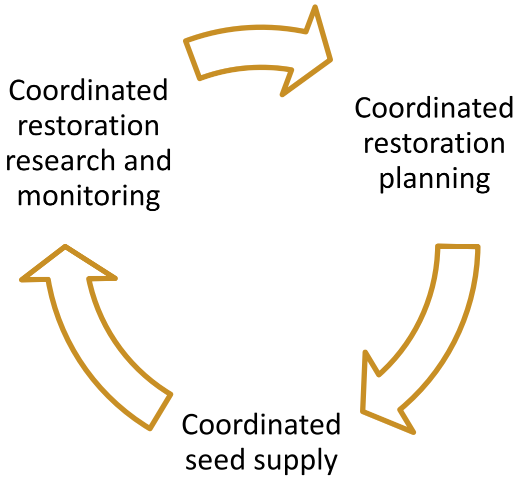
- Coordinated and long-term restoration planning across the whole of Australia.
  - A 10 to 20-year plan for each region would allow ongoing work for seed collectors, lowering their financial risk and allowing them to collect during the good years and store for the future.
  - Regional planning would mean that there would be less onus on individual community groups and landowners to plan restoration and select appropriate species.
- Coordinated seed collection, testing, storage and dissemination at a regional level.
  - Restoration seed banks may need to be established in key locations to ensure appropriate storage conditions and
  - Regional audits of seed collection capacity and infrastructure would be required, and then strategically improved.
- Coordinated research programs embedded into restoration programs, along with coordinated restoration monitoring and evaluation
  - This would: 1) determine if goals are met; and 2) provide information for adaptive management to inform future restoration planning. Research programs could be simple, for instance trialling two seeding rates, or complex, such as assessing provenancing strategies.

To oversee these tasks, a person (i.e. Commissioner/national coordinator) or entity (national industry body) should be appointed, to be an advocate for restoration and the seed industry, as well as providing training and opportunities for networking.

The result would be that standards of restoration could be raised across all stakeholders.

Coordinated planning should inform coordinated seed supply, which then supplies seed for implementation of restoration within a research framework, which is monitored, and evaluated, with results informing restoration planning (**Figure 5**).

FIGURE 5. COORDINATED PLANNING AND SUPPLY



8.2 Summary of recommendations

1. Fire response

- Understanding:
  - how different plant species respond to fire (which are killed, and which survive; which are triggered to germinate or flower; which have the capacity to resprout)
  - how fire intensity, interval, severity and season affect plant species and
  - the effect of the interaction between fire and other factors (e.g. drought, disturbance) on plant species

  will help inform restoration strategies for each species and in each location.

2. Restoration approaches

- Knowing which approach to restoration is needed in each degraded environment is critical to determining whether or not seed is needed.

3. Seeds in the context of restoration

- Seed supply for restoration needs to be considered within the broader context of restoration, which includes, amongst other items, restoration planning, funding and monitoring. Having a holistic view of not only the supply chain, but other factors that influence it will lead to better on-ground outcomes.

4. Stakeholders

- Compiling a comprehensive database of all those involved in the seed sector could lead to better cohesion and communication.
- There is no one industry body which represents the sector, however, the Australian Seed Bank Partnership is a consortium which represents a number of seed banks, NGOs and research organisations.

5. Supply and demand

- A strategy is needed to increase the quantity of seed available for restoration; increase the numbers of species available so that restoration can be biodiverse; and smooth out demand so that there is less fluctuation, thereby providing ongoing employment for collectors and better price certainty for purchasers.
- Seed Production Areas (SPAs) are one option for improving seed availability.
- In addition, improving methods of seed-based restoration to increase seedling emergence and survival will increase seed use efficiency and therefore lower seed requirements.

6. Licensing and permissions

- Licensing applications must be clear and straightforward to complete, be assessed within a reasonable time frame, and collect aggregated data about collection in each jurisdiction.
- Licensing agencies could implement a short, online assessment to ensure that collectors understand the licensing conditions and their obligations to harvest in a responsible and sustainable manner.
- Purchasers should check to ensure that their seed was obtained legally.
- A regional assessment could be undertaken to identify suitable areas for seed collection, and allow restricted access to licenced collectors.

7. Seed sourcing

- Restoration plans must consider where the seeds will come from.
- This is important not only for direct seeding, but also when purchasing plants grown from seed. They must indicate whether seed will be sourced locally or non-locally (or both).
- They must consider whether the source populations are likely to be adapted to current and future environmental conditions. Increasing genetic diversity of collections may benefit restoration.

8. Infrastructure

- An assessment is needed of current infrastructure capacity (including seed processing facilities, drying facilities, storage facilities, Seed Production Areas, nurseries and direct seeding equipment), who owns it (public or private), and where it is.
- In addition, an investigation is required into what infrastructure is needed where and by whom.
- Restoration seed banks could be established in key areas.

9. Seed quality

- A behavioural change and education program to inform buyers and sellers of the necessity of seed testing, how to perform basic and advanced tests, and which tests to request, needs to be implemented in Australia to ensure buyer confidence and improve restoration success.

10. Seed germination

- Feedback from end-users of seed is required to identify species for which research on germination is required. This research can be undertaken using in situ and ex situ trials.
- Seed enhancement technology is an emerging area of research in native seeds and has potential to improve restoration success.
- A propagation manual of Australian plants, listing germination conditions would be of benefit to the industry.

11. Monitoring, reporting, adaptive management

- Monitoring should be performed to determine whether or not the goals, aims and objectives are achieved. Simply reporting what the activities were (e.g. number of hectares seeded, number of trees planted) is not enough, the results need to be monitored, analysed and then reported (e.g. % survival after 1 and 5 years, number of species per hectare, average number of plants per square metre).
- Standardised monitoring protocols will enable data to be compared across sites and between years.

12. Cost of seed

- Encouraging purchasers to pay the true cost of seed may reply on other factors such as implementing quality testing and better allocation for funding for seed-based restoration.

13. Funding

- Funding timelines need to be in sync with restoration timelines, particularly given that restoration activities like seed collection, nursery propagation and planting are seasonal.
- Funding should be for more than 5 years, to allow for adequate planning, seed collection and monitoring. It would also allow for more stable seed markets, ensuring support for businesses, workforces, training and improvement of quality (Hancock *et al.* 2020).
- Also, several decades of investment is required for restoration, which does not match the 3–5 year funding cycles (Broadhurst *et al.* 2015).
- We need an intergenerational view to restore our biodiversity (Broadhurst *et al.* 2015).

14. Research and information

- Ensuring people have access to information by providing good quality publications at low or no cost will improve on the ground outcomes.
- A central repository for information may be useful. Providing an annual forum may assist two-way knowledge sharing.
- Conferences and forums need to be low cost, at a convenient time of the year, and in an accessible place and inclusive of practitioners. Funding may need to be provided to offset registration costs.
- Identifying knowledge gaps and addressing these through research will be needed for a restoration strategy. Networked and embedded experiments can be used to address knowledge gaps. Several important research questions are listed.

15. Education and training

- Provide low-cost, frequent training programs, possibly online.
- Possibly encourage training when licences or grants are applied for.
- Collate a centralised list of all training opportunities at all levels.
- Seed purchasers also require training.

16. Coordination and communication

- An industry body to represent the seed sector is now needed.
- Opportunities to communicate between different parts of the sector will benefit the whole industry.

17. Scaling up

- Plans for seed collection and storage, and implementation of seed-based restoration need to be able to be achieved at large-scale. A combination of changes is required to up-scale restoration, as there is no single solution.

18. Implementing change

- Change needs to be implemented by forming an industry body, understanding the motivations of, and communicating with stakeholders, and changing regulations.

19. Fire preparedness

- Use fire forecasting to direct future seed collecting efforts.
- Restore ecological communities to slow climate change.
- Plan to protect biodiversity assets.
- Trial the effectiveness of restoration to prevent, slow the spread or lower the intensity of fires.

20. Indigenous land management

- Engage indigenous people to help heal the land after catastrophic fires.

21. Threatened species

- Seed banks of the most imperilled species need to recover before seed collection is undertaken, except in urgent cases.
- Ecological restoration may provide additional habitat for threatened plant animals, and the prioritisation list could direct restoration to areas and with plant species which would benefit these animals.

22. Climate change

- Protection, restoration and assisted migration may be options to enable the persistence of species affected by climate change.

23. People

- Sharing resources may assist with the fire recovery efforts.
- Recovery planning could be undertaken at a national, state and regional level to assist individual landowners.
- Building strong relationships between stakeholders will be critical for recovery and preparedness for any future fires.

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APPENDIX 1 — GLOSSARY

Annual plant: a plant that completes its life cycle, from seed germination, to growth and reproduction, within one growing season.

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.

Ecological restoration: the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.

Ecoregion: areas within similar ecosystems with generally similar type, quality, and quantity of environmental resources. The SOS standard is to use Omernik Level III Ecoregions (http://www.epa.gov/wed/pages/ecoregions/level_iii.htm).

Ecosystem resilience: the degree, manner and pace of recovery of ecosystem properties after natural or human disturbance.

Extinction risk: IUCN Red List categories are intended to reflect the likelihood of a particular species going extinct under prevailing circumstances. A set of quantitative criteria is used to evaluate the extinction risk.

Fire ephemeral: a plant with a short life-cycle which recruits after fire.

Fire frequency: how often fires occur.

Fire interval: the time between fires.

Fire season: what time of year the fire is.

Fire severity: how hot the fire is (often fire intensity is used for this).

Fire spatial extent: how much area is burnt and how patchy this burnt area is.

Genetic diversity: the sum total of all genetic variation for a population, taxon or other taxonomic rank.

Germination: begins with water uptake by the seed and ends with the start of elongation by the embryonic axis, usually the radical. Germination is considered complete when the radical protrudes through its covering structures.

Natural regeneration: germination, birth, or other recruitment of biota including plants, animals and microbiota, that does not involve human intervention, whether arising from colonization, dispersal, or in situ processes.

Plant traits: morphological, anatomical, physiological or phenological features measurable at the individual level.

Priming: a water-based technique that allows controlled seed rehydration to trigger the metabolic processes normally activated during the early phase of germination ('pre-germinative metabolism'), but preventing the seed transition towards full germination.

Provenance (genetic): area identifying genetic distinction and usually though to represent genetic adaptation to local environmental conditions.

Reconstruction approach: a restoration approach where arrival of the appropriate biota is entirely or almost entirely dependent upon human agency as they cannot regenerate or recolonize within feasible time frames, even after expert assisted regeneration interventions.

Recruitment: production of a subsequent generation of organisms.

Recruitment strategies: strategies to produce a subsequent generation, e.g. seed, clonal reproduction.

Reintroduction: an attempt to establish a population at a site or habitat type where it no longer occurs (locally extinct).

Remnant vegetation: an area of vegetation that is left after the greater part of that vegetation community has been cleared.

Seed dormancy: a dormant seed (or other germination unit) is one that does not have the capacity to germinate in a specified period of time under any combination of normal physical environmental factors (temperature, light/dark, etc.) that otherwise is favourable for its germination, i.e. after the seed becomes non-dormant.

Seed Production Area (SPA): a spectrum of management approaches and intensities and system models aimed at increasing the amount, quality, and diversity of native seed for restoration.

Seed quality: the purity, seed fill and seed viability of a seed lot.

Soil seed bank: seeds stored within or on the soil.

APPENDIX 2 — ACRONYMS

AABR	Australian Association of Bush Regenerators
ALGA	Australian Local Government Associations
ANBG	Australian National Botanic Gardens, Parks Australia
ANPC	Australian Network for Plant Conservation
ANPSA	Australian Native Plants Society (Australia)
APCC13	13th Australasian Plant Conservation Conference
ASBP	Australian Seed Bank Partnership
ASSC	Australasian Seed Science Conference
AusIMM	Australasian Institute of Mining and Metallurgy
AWC	Australian Wildlife Conservancy
BBG	Brisbane Botanic Gardens Conservation Seed Bank, Brisbane City Council
BGANZ	Botanic Gardens Association of Australia and New Zealand
BGPA	Botanic Gardens and Parks Authority (WA)
BGSH	Botanic Gardens and State Herbarium, South Australia
BHA	Bush Heritage Australia
CAUL	Clean Air and Urban Landscapes Hub
CERP	Certified Ecological Restoration Practitioner (Society for Restoration Ecology)
CHBAG	Council of Heads of Australian Botanic Gardens
CMAs	Catchment Management Authorities (VIC)
CRC CARE	Cooperative Research Centre for Contamination Assessment and Remediation of the Environment
CRC TiME	Cooperative Research Centre for Transformations in Mining Economies
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CVA	Conservation Volunteers Australia
DAWE	Department of Agriculture, Water and the Environment
DBCA	Department of Biodiversity, Conservation and Attractions (WA)
ECA	Environmental Consultants Association
ESA	Ecological Society of Australia
GA	Greening Australia
GBDBG	George Brown Darwin Botanic Gardens, Parks and Wildlife Commission of the Northern Territory
GIA	Greenlife Industry Australia (formerly NGIA)
INSR	International Network for Seed-based Restoration
IUCN	International Union for the Conservation of Nature
LLS	Local Land Services (NSW)
MSBP	Millennium Seed Bank Partnership
NCRIS	National Collaborative Research Infrastructure Strategy
NIAA	National Indigenous Australians Agency
NRM	Natural Resource Management
RBG Kew	Royal Botanic Gardens, Kew
RBGDT	The Royal Botanic Gardens and Domain Trust

RBGV	Royal Botanic Gardens Victoria
RIAWA	Revegetation Industry Association of Western Australia
RTBG	Royal Tasmanian Botanical Gardens
SER	Society of Ecological Restoration
SERA	Society of Ecological Restoration Australasia
SPA	Seed Production Area (see Appendix 1 — Glossary)
TERN	Terrestrial Ecosystem Research Network
TSR	Threatened Species Recovery Hub
WABSI	Western Australian Biodiversity Science Institute

APPENDIX 3 — BIBLIOGRAPHY

The bibliography includes both the list of references which were directly referred to in the document, and also recommended reading of relevant literature which was not directly referred to.

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