Seed Storage for Conservation of Australian Forest Genetic Resources

Report to South East Forestry Hub

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Acknowledgement of Country

CSIRO acknowledges the Traditional Owners of the lands, seas and waters, of the area that we live and work on across Australia and pays its respects to Elders past and present. CSIRO recognises that Aboriginal and Torres Strait Islander peoples have made, and will continue to make, extraordinary contributions to Australian life including in cultural, economic, and scientific domains.

Cover image: refrigerated, containerised seed storage at Sustainable Timber Tasmania’s seed centre, Perth, Tasmania

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Acronyms

Acronym	Meaning
ALA	Atlas of Living Australia
ASBP	Australian Seed Bank Partnership
ATSC	CSIRO Australian Tree Seed Centre
AVSB	Australian Virtual Seed Bank
BGANZ	Botanic Gardens Australia and New Zealand
CSO	Clonal seed orchard
DEECA	Department of Environment, Energy and Climate Action (Victoria)
EPBC	Environment Protection and Biodiversity Conservation Act 1999 (Cth)
FGR	Forest genetic resource
FPC	Forest Products Commission (WA)
GWW	Great Western Woodlands
IBRA	Interim Biogeographic Regionalisation for Australia
MAR	Mean annual rainfall
NSB	The National Seed Bank
NVIS	National Vegetation Information System
SEFH	South East Forestry Hub
SPA	Seed production area
SSO	Seedling seed orchard
STT	Sustainable Timber Tasmania
STZ	Seed transfer zone
TC	Tissue culture
TSCC	Tasmanian Seed Conservation Centre (Royal Tasmanian Botanical Gardens)

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Executive summary

Australia's forests are under increasing pressure from climate change effects including drought and increased fire frequency which are exacerbated by land clearing, infrastructure development, urban expansion, water extraction, and the spread of weeds, pests, and diseases. Although these challenges are recognised, and many positive actions are underway, forest genetic resources (FGR) remain vulnerable. Seed is a critical resource for conserving native forests, yet despite Australia's strong network of seed banks and skilled staff, rapid environmental change and past management practices have left forests exposed to biodiversity loss. There is a growing need for seed collections that better represent Australia's FGR, particularly in forest types most at risk—such as wet sclerophyll obligate seeders, rainforests, and alpine forests—where multiple stressors interact.

This study, guided by terms of reference from the South East Forestry Hub (Appendix A), and developed with strong participation from key stakeholders (Appendix B), assessed current and future seed collection and storage capacity. Australia has high-quality seed bank infrastructure for both bulk storage of obligate seeders in the east and smaller collections of threatened species nationwide. However, improvements are needed, and a more coordinated national approach to FGR conservation presents a significant opportunity.

Bulk collections and storage for obligate seeder eucalypts

Obligate seeder eucalypts are killed by fire but regenerate when heat triggers seed release. If a second fire occurs before the trees reach reproductive maturity, reseeding is required or the stand will be lost. In south-eastern Australia, the most at-risk obligate seeders include alpine ash (*Eucalyptus delegatensis*) and mountain ash (*E. regnans*). These forests cover vast areas, requiring large seed reserves.

Bulk seed stores in Tasmania, Victoria and NSW were designed to support regeneration of multiple-use forests, including areas harvested for timber. They were not intended to meet the demands of large-scale post-fire revegetation across tenures including National Parks and reserves, or private land, even though these contain extensive obligate seeder forests. The ACT has no seed reserves or storage facilities to support post-fire recovery. In Victoria, some facilities need refurbishment, and current storage capacity and collection programs are insufficient to meet reseeding needs after multiple large fires across all land tenures.

Most ash seed is collected from multiple-use State Forests rather than reserves, because bulk seed collection causes temporary tree damage currently considered unacceptable in protected areas. As a result, unique genetic diversity within reserves is not represented in storage, leaving these populations vulnerable. However, given climate-driven risks, the trade-off between short-term collection impacts and the permanent loss of FGR should be reconsidered in light of evidence showing collection impacts are localised and brief, with landscape-scale benefits.

A coordinated, cross-border approach to obligate seeder seed collection, storage and deployment is needed to protect ash forests. This will require upgrading existing facilities, expanding capacity, and growing the specialised workforce that supports seed operations. It will also require new government policy to enable collaboration across tenures; the absence of policy for seed collection and deployment in reserve systems is currently a major barrier to conserving these high-value ecosystems.

Numerous obligate seeder eucalypts occur in the Great Western Woodlands (GWW) of southwest Western Australia. Although this ecosystem is less studied than the eastern ash forests, it faces similar risks from increasing fire frequency and intensity. Only small quantities of seed from these species are held in conservation seedbanks, and this is unlikely to support large-scale restoration after widespread fires with short intervals. A detailed risk assessment of GWW obligate seeders and their seedbank representation is needed.

Non-obligate seeders

For non-obligate seeders or obligate seeders with soil seed banks—such as many *Acacia* species—smaller seed volumes are adequate and can be used efficiently through tubestock production. However, the sheer diversity of species and communities requiring protection, many with multiple subpopulations, makes comprehensive representation challenging. Because collections are dispersed across states and institutions, it is difficult to assess whether priority FGR are adequately conserved.

Several of Australia's smaller conservation seedbanks have good infrastructure and expertise, with some capable of long-term storage. However, several others have limited capacity to collect, store and maintain additional accessions, with constraints on both storage space and staff.

The Australian Virtual Seed Bank (AVSB) aggregates data from several collections and shows that while many threatened species appear in one or more seedbanks, provenance-level representation is often lacking. This may partly reflect incomplete data uploads— for example, major collections such as the CSIRO Australian Tree Seed Centre (ATSC), which specialises in range-wide FGR collections, are not included. It is likely that seedbanks responsible for broad taxonomic coverage hold, on average, only shallow representation of individual species.

Engaging with the Australian Seed Bank Partnership (ASBP) and AVSB to help build a better picture of holdings of FGR across collections is a recommended activity.

Rainforests

Rainforests have been assessed as being particularly susceptible to biodiversity loss from climate change stressors including drought, fire and disease. They are rich in tree species, many of which produce recalcitrant seed that is very difficult to store. Biotechnologies including tissue culture and cryostorage are alternative ways to store rainforest FGR. Although there are good cryostorage facilities in NSW, Victoria and WA, facilities are absent in the Northern Territory and Tasmania, where unique monsoonal and temperate rainforests are found, respectively. These technologies and storage facilities require considerable specialised expertise to operate. Either a wider network of state-based facilities or a national facility is required.

Alternatives to wild seed collection

Cultivated seed production would be a viable alternative to wild seed collection for threatened species and potentially for production of bulk seed from obligate seeders. The opportunity to establish seed production areas on private property, in collaboration with Traditional Owners and as plantings embedded into larger revegetation and carbon sequestration plantings are significant opportunities.

Training and expertise

Retention and development of skills related to FGR conservation will be vital for developing an enhanced network of seed banks that cover both the bulk storage and deployment for obligate seeders and the smaller collections of very diverse tree species that can be stored in smaller volumes. Retention of skills that currently reside in the private sector related to collection and deployment of obligate seeder species is a high priority. Harvesting seed from very tall trees, high volume processing, and coordination and delivery of aerial seeding services are all highly specialised services currently delivered by the private sector under state coordination. As native forest harvesting has now ceased in Victoria, and the annual need for supplementary collection and sowing of seed to harvested stands is currently not required, it is important that these skills are maintained. Training initiatives and coordination of work programs across states and tenures are possible ways to achieve this.

Coordination and policy development

Coordination is a key aspect to addressing the issues described above. Coordination of seed collection and storage across state borders and land tenures is required for the eastern state obligate seeder programs. Policy development is required to support this coordination, to clarify the roles and responsibilities of different organisations working across tenures. Collection and deployment of seed and/or seedlings within the state reserve systems is currently highly restricted, and this may lead to negative outcomes in the event of forest loss to fire, drought, disease or other stressors. Further coordination among seed banks, forest managers and restoration practitioners is required for all species.

The Australian Government, through Parks Australia currently supports a secretariat for the Australian Seed Bank Partnership (ASBP) to coordinate Australia's network of conservation seedbanks. Upgrade of the functionality and data depth of the Australian Virtual Seed Bank (AVSB) which is hosted by the Atlas of Living Australia (ALA) for the ASBP, would be beneficial, as a management tool, and to better understand which species are adequately conserved. Other organisations with a national remit that might play a role include Forestry Australia, the Forestry Hub network and CSIRO.

Working group and coordinator

The scope of work required to initiate and sustain a coordinated approach would be considerable, and this would require a dedicated coordinator. The coordinator could work to a steering committee comprising stakeholder representatives from a wider working group. Work of the steering committee would include development of a coordination plan with objectives, a timeline for achievement, and milestones with clear performance measures. Potential tasks of the working group, steering committee and coordinator could include projects to provide better clarity on current seed storage; development of objectives and policy for working across borders and tenures, with associated liaison and lobbying; identifying opportunities for sharing and coordination of resources; standardised collection and storage standards and protocols; and identifying research priorities.

Funding

The coordinated approach would require funding which might most appropriately be invested by the Commonwealth, given the national benefit that it would provide. There would need to be considerable in-kind funding in the form of stakeholder engagement with the process from those states involved in the working group. Engagement with philanthropic and corporate funders might augment government funding in some circumstances.

South East Forestry Hub Case Study

The SEFH experiences many of the issues and opportunities that are present elsewhere in Australia. The SEFH contains most of NSW's extensive *E. delegatensis* forest, much of the *E. fraxinoides* and *E. dendromorpha*, and the entire populations of two threatened ash species with highly restricted distributions, all of which are obligate seeders. The newly created Forestry Corporation ash seed store at Eden provides good insurance against loss of *E. delegatensis* and *E. fraxinoides* on the multiple use forest estate in NSW but does not hold sufficient to broadcast sow following large fires in the reserve system. A larger store or stores would be required. Establishment of cultivated seed production capacity is advocated for the threatened species with relatively small distributions. Coordination among agencies within NSW and across the ACT and Victorian borders, development of policies that allow collection and deployment of seed within reserves and construction of a significantly larger seed store(s), with more human resources, would be required to address the issues.

The SEFH is home to around 90 threatened tree species, in addition to species subject to widespread dieback. While several of these species are represented in the conservation-oriented seedbanks within the SEFH (ATSC and National Seed Bank - NSB) and also the Australian PlantBank at Mt Annan, it is not clear how comprehensive the collections are, and whether they contain adequate genetic diversity to adequately deal with widespread losses due to climate change or other stressors. A stocktake of FGR across the relevant collections would help underpin conservation strategies for these species.

1 Why do we need to collect and store seed of trees?

Recent climate events, including the catastrophic bushfires of the 2019/20 Black Summer, have highlighted the vulnerability of Australia's forest ecosystems and their genetic resources (FGR). Other slower acting, but potentially devastating, phenomena such as extensive eucalypt dieback are also of grave concern. The distribution of forest types and species has always been dynamic. However, the pace of climate change, clearing for agriculture and urban expansion, and other stressors, have outstripped the ability of forests, which have long generational intervals, to adapt and respond. Seed-based re-establishment has been demonstrably effective at restoring and maintaining species, populations and forests at both small and large scales in Australia (e.g. Fagg et al. 2013; Bassett et al. 2024). The importance of maintaining a robust seed storage system is therefore crucial for the recovery and conservation of forest species affected by such events. Effective seed storage ensures the availability of high-quality FGR for future restoration efforts and can mitigate the loss of biodiversity.

Loss of Australian biodiversity assets to climate change and other threats is both highly likely and unacceptable: preventative interventions must be made (Cresswell et al. 2021). Tackling climate change is a global challenge that will take decades to address and longer for some remediation effects to be realised (MacDougall et al. 2020). Meanwhile, it is possible to preserve biodiversity assets through a variety of actions that include collecting and storing germplasm that represents the genetic diversity of species and populations. This concept is well understood in the fields of agriculture (Dempewolf et al. 2023) and animal husbandry (FAO 2007), where major undertakings have been made to preserve the genetic diversity of key breeds and that of remaining wild relatives of the crops and animals that the global human population relies upon as food sources. While numerous Australian forest tree species are now global fibre crop staples (with a planted estate of around 30 million hectares, *Eucalyptus* is the most widely planted hardwood genus in the world; *Acacia* and *Casuarina* are regionally important crops), they are also critical and defining structural elements in Australian ecosystems. The motivation for collecting and storing germplasm of Australian forest genetic resources (FGR) to be used as a repository of genetic diversity is prudent and critically important act of stewardship in the face of climate change and other current threats to our forest ecosystems.

2 Threats to forests and trees

Australia's forests are under threat from a variety of stressors (Table 1). Of these, items 1 – 4 are directly climate related. Threats 5-7 are indirectly related to climate. While threats 8 and 9 are not climate related, their effects can interact with climate-related threats to place further pressure on forests and trees – for example small forest fragments created by clearing for agriculture may be further impacted by drought, leading to localised population collapse. Some of these threats are slow acting (e.g. subtle changes to reproductive success and growth due to climate change) while others can have immediate and catastrophic effects (impacts of bushfires and flooding). Many forest and woodland species are well adapted to some of these stressors and can readily recover without human intervention. However, in other cases, having seed stocks in hand will facilitate and enable recovery (e.g. Ferguson 2011). Responding to these different types of threats will require different strategies, and each will place different demands on the seed collection and storage strategy.

Table 1 Threats to Australia's forests

Potential threat	Comment
1. Heat	Climate change is predicted to drive significant warming throughout Australia
2. Drought	Much of southern Australia is likely to become drier in scenarios to 2050 and 2080
3. Fire	Higher temperatures and lower rainfall are likely to increase the frequency and severity of forest fires in southern Australia. Fire regimes have changed due to landscape-level vegetation change since European settlement and more frequent drought in recent decades.
4. Rainfall seasonality	Rainfall in southern Australia is predicted to become more summer dominant. Some forest species are strongly adapted to winter-dominant rainfall patterns. Rain falling in hotter months tends to be less effective for deep-rooted perennials because of evaporation and uptake by actively growing shallow-rooted plants. Such rainfall can also reduce flowering events, resulting in lower seed availability.
5. Flooding regime	Lower rainfall and water extraction and its infrastructure have the potential to significantly impact the reproductive process of riverine forests and those of adjacent floodplains. In some areas, increased rainfall intensity and volume may lead to flooding resulting in erosion and, potentially, loss of species not adapted to this.
6. Disease	Climate change and global trade both contribute to newly emerging pest and disease threats. Examples include phytophthora, a well-established threatening fungal disease; myrtle rust is an emerging threat that entered Australia in 2010.
7. Weed ingress	Weeds can significantly compete with native forests species for niche and resources including water, nutrients and light.
8. Urban expansion	Clearing for urban development and infrastructure leads to loss of forests and fragmentation of larger patches of forest.
9. Agricultural practices	Clearing for agriculture leads to forest fragmentation and loss. Stock browsing may inhibit regeneration. Altered soil structure and nutrient content may have direct and indirect effects on forests and woodland. Removal of deep-rooted perennials and replacement with crops or pasture results in dryland salinity in some regions

Slower-acting stressors, such as dieback caused or exacerbated by the chronic effects of climate change, coupled with other stressors, might be dealt with over a period of years. This exerts a lesser demand on seed storage facilities. More-efficient use of seed through planting of tubestock or pelletised direct seeding (Cremer 1966; Lieurance et al. 2024) are other possibilities. On the other hand, post-fire recovery of some forest types and species may require a rapid response using direct sowing of large volumes of seed. Some species need to be established in this way, at a large scale, and in the winter immediately following the (usually) summer fire season, while the newly burnt seedbed is receptive (e.g. Bassett et al. 2015).

2.1 Climate change

The effects of climate change are global, and while the predictions for Australia are variable, temperatures are expected to continue to rise until 2050 and beyond in all regions. Australia's climate has already warmed by an average of 1.51 ± 0.23°C since national records began in 1910 (CSIRO and Bureau of Meteorology 2024). This is coupled with the high likelihood of a decrease in cool season rainfall across much of southern and eastern Australia. Rainfall seasonality is predicted to shift from winter-dominant in the most southerly areas towards increasing summer dominance. Meanwhile, the tropics may be subject to higher, and higher-intensity, rainfall. Another key prediction, with major implications for Australian forests, linked to the warming and drying climate, is the likely increase in the number of dangerous fire weather days and a longer fire season for much of southern and eastern Australia (Figure 1).

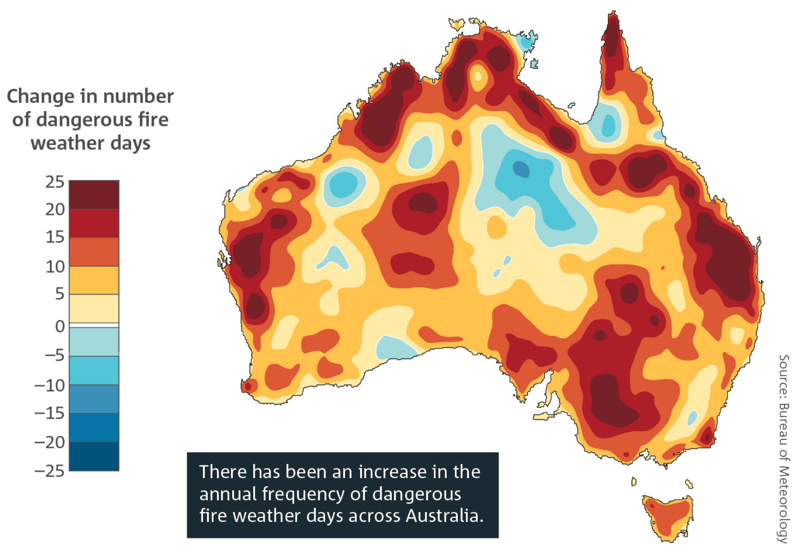


Figure 1 Increase in number of dangerous fire weather days (CSIRO and Bureau of Meteorology 2024)

These climate changes will have numerous effects on trees and forests. Table 2 outlines some of the critical forest process that will be affected.

Table 2 Disruptive effects of climate change

Effect	Selected references
Lower growth rates due to heat stress and lower water availability (possibly somewhat offset by the 'CO_2 fertilization effect')	Bowman et al. (2016)
Decline and mortality (dieback) due to drought and/or heat stress, either because of shorter extreme events or chronic degradation of stands and forest communities leading to dieback	Nolan et al. (2021); Keppel et al. (2023); Butt et al. (2013)
Lack of germination due to poor imbibement and/or unsatisfactory stratification due to warmer and drier winter conditions in alpine areas	Mok et al. (2012); Fagg et al. (2013)
Disrupted flowering and seeding processes leading to lower seed yields	Rawal et al. (2015); Bassett et al. (2024)
Changed dynamics of pests and diseases due to warmer temperatures and/or a shift towards summer-dominant rainfall	Keenan (2017); Pinkard et al. (2014); Booth et al. (2015)
Erosion and damage to soils due to high intensity rainfall	Zhu et al. (2020)
More-frequent and more-widespread bushfires	(Collins et al. 2022); Godfree et al. (2021); Ferguson (2011); Collins et al. (2022)
Drying of wet sclerophyll and rainforests allowing ingress of fire and drought induced mortality	Godfree et al. (2021); Gordon et al. (2025)

2.2 Fire

Fire has always had a major influence on Australian vegetation communities. Climate change, bringing higher temperatures, protracted drought, and other climatic changes such as incidence of dry lighting and more frequent fires, has been identified as a significant threatening process across a wide range of ecosystems from temperate to monsoonal forests (Godfree et al. 2021; CSIRO and Bureau of Meteorology 2024). Forest fire regimes have changed significantly since European settlement (Gill and Williams 1996). The landscape mosaic has changed dramatically, ignition sources have diversified, and indigenous burning practices have ceased throughout much of southern Australia. These changes have been implicated in loss of biodiversity through a variety of interconnected causes (Department of Agriculture Water and Environment 2022).

Wet sclerophyll forests of Tasmania, Victoria and NSW are under threat from fire as demonstrated by the catastrophic 2019-2020 bushfires (Godfree et al. 2021). Although these forest types are dependent on burning for regeneration, fires are tending to become more intense and more frequent, due to climate change, during the last fifty years. Obligate seeding species are particularly threatened. Obligate seeders are species that have no or limited ability to respond to fires by resprouting from lignotuberous or epicormic growth (Nicolle 2006). Post-fire regeneration is initiated when woody structures (e.g. capsules in eucalypts) in the tree canopy open and drop seed in the period after the fire. This seed germinates and replaces the lost stands (Figure 2). **Box 1** provides more information on obligate seeders.

Figure 2 Ten-year-old regrowth of the obligate seeder, *E. regnans* under a fire-killed mature stand near Marysville following Victoria's 2009 Black Saturday bushfires. Heavy seed crops ensured a large seed fall event, resulting in the dense regrowth. As of 2019, this regrowth was still at risk due to immaturity. (Image: O. Bassett, Forest Solutions)

Although rainforests are nearly always situated in landscape refugia that have historically been relatively free from fire, recent fire events following protracted drought have resulted in significant incursions, for example the 2019-2020 bushfires impacted 400 ha or 13% of the Queensland Gondwana rainforests (State of Queensland 2025). Rainforests, and mesic forests that contain a mix of dry sclerophyll and rainforest components, are not well adapted to post-fire recovery. Fire may result in ecological type change, with a shift towards more fire-adapted species and an overall loss of biodiversity (Paroissien et al. 2025).

Increasing fire frequency has resulted in ever-decreasing areas of old-growth alpine snow gum (the *E. pauciflora* species complex) forests (Morgan et al. 2024). Although *E. pauciflora* is typically not killed by fire and resprouts from a lignotuber, fire may exacerbate other causes of dieback (see next section) which includes the impacts of insect attack and drought.

Box 1. What is an obligate seeder?

Obligate seeders are species that are killed by fire and depend exclusively on seed for regeneration. Species with alternative regeneration strategies include the resprouters, that rely solely on resprouting from epicormic stem shoots or basal lignotubers following fire, and facultative seeders, that can either respond by resprouting or regenerate from seed. Most Australian eucalypts are facultative resprouters. Among the best-known Australian obligate seeders are the majestic eastern Australian ash eucalypt species including alpine ash (*E. delegatensis*), mountain ash (*E. regnans*), and six others (Table 4). However, another major group of Western Australian woodland eucalypts, including the gimlets and mallets, also comprises numerous (78) obligate seeders. These eucalypts all rely on canopy-stored seed; i.e. seed is retained in capsules in the crown. Soon after the fire event, the seed is released from the crowns of the fire-killed trees. If the seed bed is receptive and conditions in the following months are conducive, the seed will germinate and the population regenerates. Eucalypt seed will not usually survive more than 3-6 months, with only a very small proportion surviving longer than a year, and a long-term soil seed bank is not formed (Sebire and Fagg 2009; Bassett et al. 2024).

Other species, including many acacias, are also obligate seeders, however they rely on a soil seed bank: many acacias have a highly robust seed coat that can survive, sometimes for decades, in the soil. The heat from a fire initiates the germination process by cracking the seedcoat allowing it to imbibe water and germinate.

Box 1 Figure A *Eucalyptus fraxinoides* is an obligate seeder native to NSW and Victoria. It is killed by fire and relies on a canopy-borne seed crop for regeneration [photo: ATSC]

Climate change significantly threatens obligate seeders, especially those with a long interval between germination and reproductive maturity. Both *E. delegatensis* and *E. regnans* have a long generational interval of between 15 and 20 years for stands to reliably produce sufficient seed to regenerate effectively (Doherty et al. 2017; Doherty et al. 2023). As fire frequency and intensity are both generally increasing, there is a risk that regenerating stands will burn again before they have produced seed (Bassett et al. 2024). This is a lesser risk for some other obligate seeder species that have shorter time to reproductive maturity – for example many acacias (Williams et al. 2024). Exacerbating this threat, a warmer climate brings the risk of ineffective stratification (for example *E. delegatensis subsp. delegatensis* requires at least four weeks of exposure to snow during winter to overcome dormancy (Poynter et al. 2009) and inadequate rainfall for germinated seedlings to establish. Later in the stand lifecycle, drought effects may also lead to sparse, non-existent or poor-quality flowering and seed crops. These effects, combined, lead to a phenomenon termed 'interval squeeze' (Enright et al. 2015). If regeneration fails, a vegetation 'type change' will occur (Bowman et al. 2014)[1]. This may be a change to other tree species in mixed-species stands or even reversion to non-forest vegetation in some cases (Fairman et al. 2016).

What are the implications for seed collection and storage?
The need for significant seed stocks of the eucalypt obligate seeders has been identified: if seed is not available in the months immediately following a fire, then local populations may be lost if the burnt area is extensive. It is important to collect and store significant volumes of the obligate seeder species, not only representative of the species, but also of a wide selection of provenances.

[1] An upcoming publication (Bassett et al. in preparation) is set to revise the meaning of this term to refer to significant change to ash forest structure and will introduce a new term 'state change' that refers to reversion to non-ash species or non-forest (O. Bassett pers. comm.)

2.3 Dieback

Dieback is a term that describes the decline and eventual death of plants due to various stressors (Figure 3). These include drought, pathogens, insect attack, changed nutrient and fire regimes and combinations of these. As noted in the section above, wildfire may interact with these stressors, heightening the impacts.

Fungal dieback is commonly caused by species from the *Phytophthora* genus, particularly the introduced species *P. cinnamomi*. It affects a broad spectrum of native plant families including Proteaceae (e.g. *Banksia*, *Hakea*) and Myrtaceae (e.g. eucalypts) as well as other native and non-natives. Its impacts have been particularly serious in Western Australia (Shearer et al. 2007). *Austropuccinia psidii* (myrtle rust), another fungal pathogen that entered Australia in 2010, threatens members of the family Myrtaceae, with several genera being highly susceptible. Dalziell et al. (2025) have recommended 'biobanking', including seed storage, as a conservation approach to guard against loss of highly susceptible taxa in Western Australia.

Figure 3 Dieback on a fragment of native forest on a rural property near Jericho, Tasmania

The causes of dieback can be hard to pinpoint in some cases, but climate change is often implicated (Ross and Brack 2015, 2017). Severe drought leading to hydraulic insufficiency and carbon starvation has led to extensive canopy browning and dieback of eucalypt forests in the past: this phenomenon was documented in the 2019-20 drought (Losso et al. 2022). Other causes include changed fire regimes due to clearing and management (Jurskis and and Turner 2002), soil nutrient status, and altered insect pest population dynamics (Bush 2018; Lynch et al. 2017; Brookhouse et al. 2024).

Table 3 gives some specific examples of widespread dieback.

Table 3 Examples of widespread dieback

Dieback occurrence	Description	References
E. viminalis in the Monaro Tablelands of NSW	Since the 2000s *E. viminalis* dieback in the Monaro plains agricultural area in south-eastern NSW has been extensive. Based on a systematic road survey, the affected area is estimated to cover around 2000 km^2, with almost all *E. viminalis* within that area either dead or severely affected. Insects (*Gonipterus* sp.) and other causes have been postulated. Some seed collection from remaining trees has been undertaken by the ATSC.	Ross and Brack (2015); Jurskis and and Turner (2002)
E. pauciflora dieback in the Australian Alps	Significant dieback of high-elevation *E. pauciflora* and *E. lacrimans* stands on the Kosciuszko massif, have been associated with boring insect infestation which appear to be interactive with climate and proximity to human development.	Brookhouse et al. (2024); Morgan et al. (2024)
Eucalypt dieback in the Midlands of Tasmania	Dieback of dryland eucalypts has been extensive in the Midlands of Tasmania. Soil attributes, grazing history and lack of recruitment are all factors leading to remnant woodland decline in this heavily cleared agricultural area.	Davidson et al. (2007); Bailey (2023)
Jarrah dieback south-west Western Australia	Jarrah (*E. marginata*) dieback has been caused by factors including acute and chronic drought, waterlogging and infection by *Phytophthora,* a soil pathogen introduced to WA from SE Asia in the early 1900s. The latter broad-spectrum pathogen has also impacted *Banksia*, *Hakea* and many other plant taxa.	Matusick et al. (2018); Davison (2018); Matusick et al. (2023)

2.4 Other stressors

Other anthropogenic pressures are placing many forest types and species under pressure additional to that caused by climate change (Fensham et al. 2020). Extensive clearing in the past has left woodlands of the sheep-wheat belt in a highly fragmented state, however the net forested area in Australia has been quite stable between about 130 and 135 Mha for several decades, with a slow increase since 2008 (ABARES 2023).

Altered water regimes are caused by climate change (rainfall amounts, intensity and seasonality) as well as other factors including agriculture clearing (loss of deep-rooted perennial vegetation causing altered recharge and discharge balances (Stirzaker et al. 2002)), and water infrastructure and extraction for agricultural and urban use. Aspects of this topic are explored later in **Box 3**.

Weeds are another significant problem that can lead to competition for site resources and in some cases can lead to poor regeneration (Bassett et al. 2024; Butcher et al. 2005; Coutts-Smith and Downey 2006).

3 Which forest types are most threatened?

Climate change will impact all Australian forest ecosystems to a greater or lesser extent. The other threats listed in Table 1 have the capacity to exacerbate these effects. Despite the almost universal impacts, some forest types have been identified as particularly vulnerable and/or dealing with the threats will place high demands on available seedstocks. Perhaps the highest profile of these in southeastern Australia is the threat to the iconic ash eucalypt forests located throughout Tasmania, Victoria and New South Wales. However, these are not the only obligate seeder forests and species. An extensive Mediterranean climate obligate seeder eucalypt ecosystem exists in southwestern Western Australia and several other tree species throughout the rest of Australia's forests are obligate seeders. Obligate seeder forests will only regenerate from seeds, and if these are not available, due to increased fire frequency or other causes, seed-based interventions may be required.

Other ecotypes that have been singled out as vulnerable include alpine forests and rainforests. Both have already been observed to be suffering from climate-related mortality and/or are demonstrably struggling to regenerate following fires. Rainforests are particularly challenging to rehabilitate using seed because of the very wide range of species, many of which have seed that is very difficult to store, germinate and establish in heavily disturbed ecosystems.

Woodland ecosystems and species that occur on the fringes of urban areas have suffered severe fragmentation from clearing during the last two centuries. Dieback, related to drought and other stressors, and ongoing clearing, continue to threaten the woodlands. Species with naturally restricted distributions are particularly vulnerable. Even widespread species may suffer localised degradation and local population loss. Overall, the need to collect and store seed of these species is a very significant challenge that should be addressed as a matter of urgency.

The following sections describe these forest types in more detail.

3.1 Obligate seeding eucalypts - the ash forests

The wet sclerophyll forests of NSW, Victoria and Tasmania contain diverse canopy tree taxa including significant proportions of obligate seeder species and non-obligate seeders. Some of the key species and near relatives are given in Table 4. The most extensive obligate seeder species are *E. delegatensis* (alpine ash) and *E. regnans* (mountain ash). Some authors refer to other species including *E. obliqua* and *E. fastigata,* which are facultative seeders (**Box 1**), as members of the ash group (see Table 4) while others consider only *E. delegatensis* and *E. regnans* to be "ash", at least in the Victorian context (e.g. Fairman 2023). It should be noted that *E. delegatensis* subsp. *tasmaniensis* differs from the mainland subspecies because it can recover either by epicormic resprouting post-fire or from seed (Rodriguez-Cubillo et al. 2020). Figure 4 shows the location of the main eastern state obligate seeder eucalypts.

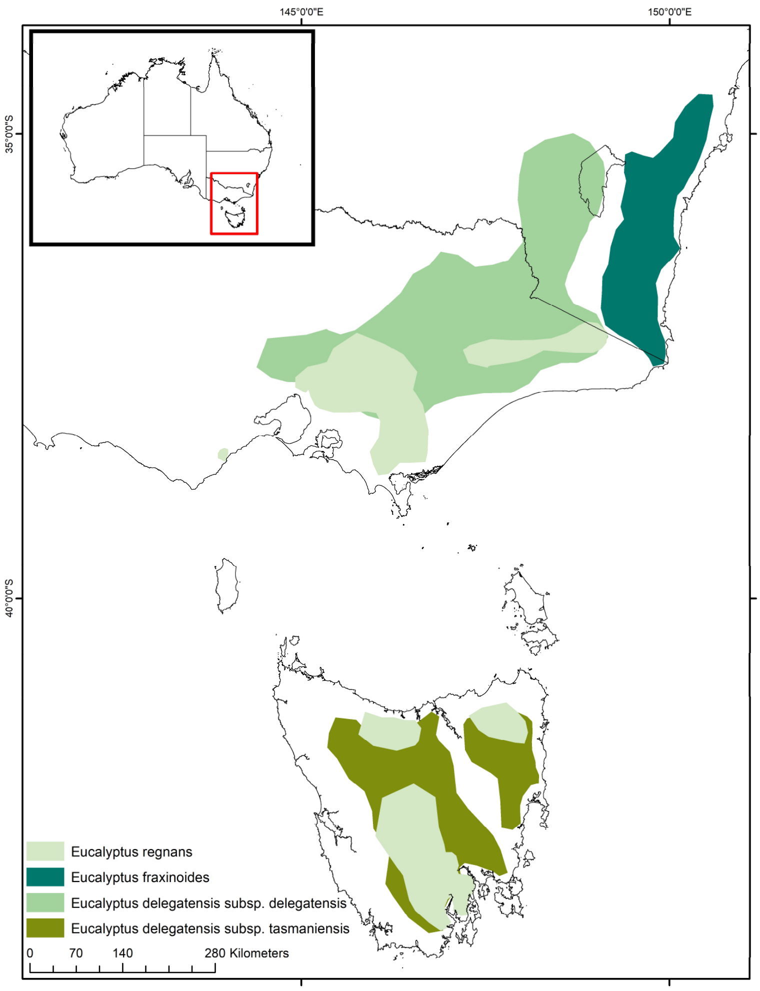


Figure 4 Approximate distributions of three of the key obligate seeder species *E. delegatensis, E. regnans* and *E. fraxinoides* (bounding polygons surround points of natural occurrence recorded in the Atlas of Living Australia (www.ala.org.au). Populations may not be continuous within these regions, and while *E. regnans* and *E. delegatensis* spp. co-occur within these broadly-defined areas, they may occupy specific niches on-ground.

Table 4 Eastern Australian obligate seeder and related eucalypts

Species (All subgenus *Eucalyptus* (*Monocalyptus*))	Reproductive mode
E. delegatensis subsp. *delegatensis*	Obligate seeder
E. delegatensis subsp. *tasmaniensis*	Epicormic sprouter
E. dendromorpha	Obligate seeder
E. fastigata	Epicormic sprouter
E. fraxinoides	Obligate seeder
E. obliqua	Epicormic/lignotuberous sprouter
E. oreades	Obligate seeder
E. paliformis	Obligate seeder
E. regnans	Obligate seeder
E. stenostoma	Obligate seeder
E. triflora	Obligate seeder

Table 5 gives consolidated area estimates for southern states ash-type forests (Bureau of Rural Sciences 2002; Forestry Tasmania 2010b; Bassett et al. 2024). Another recent analysis of *E. regnans* forest types in Victoria estimates approximately 290,000 ha (Fairman 2023). Precise estimation of ash forest areas is challenging because of their large extent across various land tenures, lack of spatial data on the fate of the forests (e.g. “type change”, or reversion to non-ash species or non-forest) following several high intensity fires, and the presence of mixed stands that comprise pure species, dominant ash species, and ash species as a minor canopy components. The extent of ash in Victoria’s reserve system is not known with certainty, as the data are model-based, with new stands being found following recent post-fire assessments (Bassett et al. 2015; Bassett et al. 2024; Bassett et al. 2021). Discrepancies between the various estimated totals at the species level may be due to data and acquisition methods rather than reflective of a substantial change in ash-type forest area. However, some documented cases of ecological type change have been documented (e.g., Bassett et al. 2015, 2021), with further studies in preparation, and in aggregate 25,000 ha may have been lost (O. Bassett unpublished preliminary data). Type change is also likely to have occurred in the ACT, as 66% of the *E. delegatensis* in Namadgi had burnt twice in the 18 years to 2020, and by 2023 about 37% of the community appeared to be in transition from dominance by *E. delegatensis* to dominance by non-obligate seeders (Office of the Commissioner for Sustainability and the Environment (ACT) 2023).

Box 2 focuses on the impacts of the 2019-20 megafires on the obligate-seeder *E. delegatensis* forests.

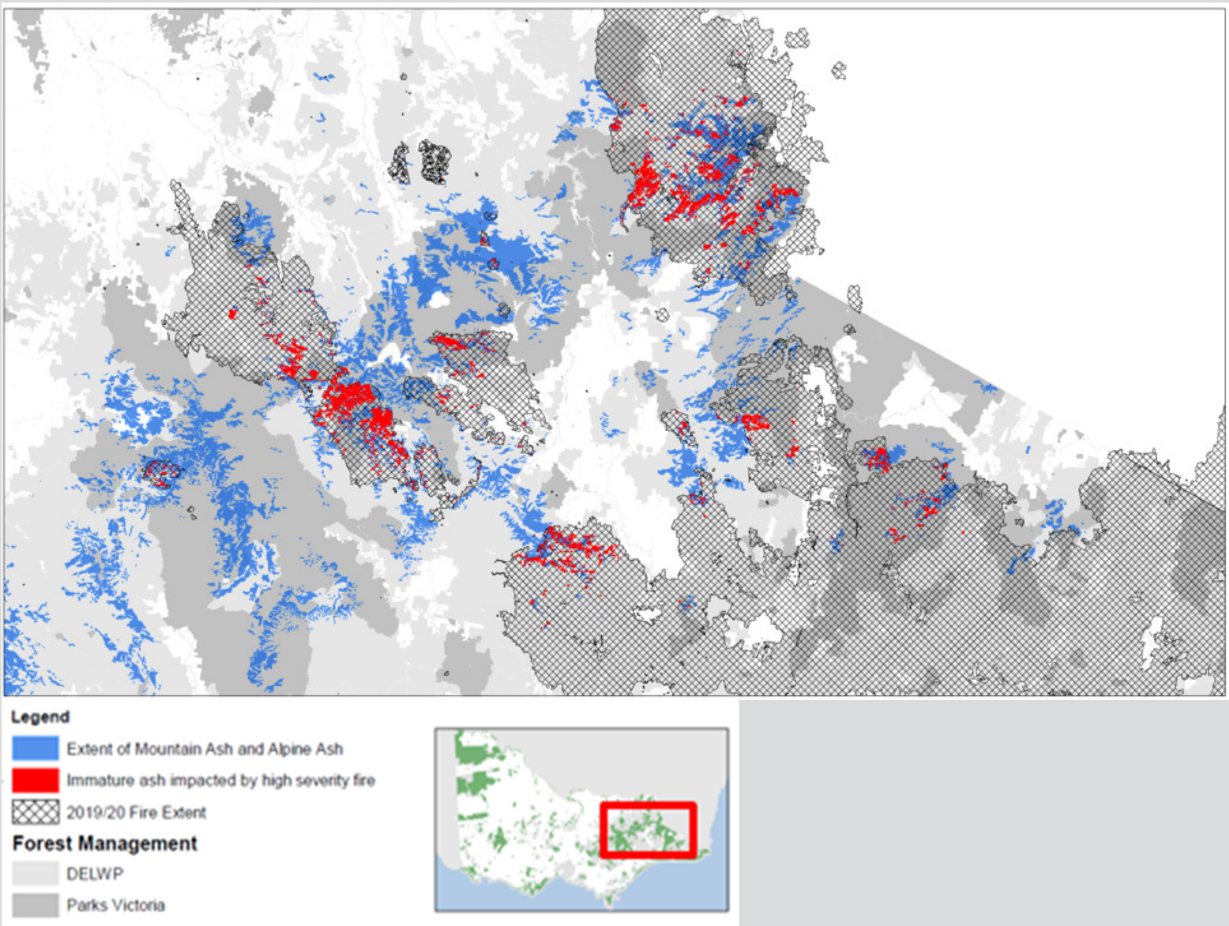
Table 5 Ash-type forests in eastern Australia by land tenure and area, adapted from Bureau of Rural Sciences (2002)

		Tenure						
State	Species	Multiple-use forests	Nature conservation reserve	Private	Other Crown land	Lease	No data	Total (ha)
NSW	*E. delegatensis*	19,949	91,591	27,060	8,447	0	0	147,047
	E. fastigata	63,451	99,097	34,042	2,914	Included in	0	199,504
	E. obliqua	20,532	23,664	6,769	539	Private	0	51,504
	TOTAL—NSW	103,932	214,352	67,871	11,900	0	0	398,054
VIC	*E. delegatensis*[1]	224,750	154,270	1010	120	0	0	380,150
	E. fastigata	36,303	16,894	749	44	0	0	53,990
	E. obliqua	401,553	210,420	223,139	19,441	6,449	0	861,001
	E. regnans	137,661	66,434	35,288	3,036	7,131	0	249,550
	TOTAL—VIC	800,267	448,018	260,186	22,641	13,580	0	1,544,691
TAS	*E. delegatensis*[2]	225,000	195,000	139,000	0	0	0	559,000
	E. obliqua	319,681	118,616	123,631	12,581	0	0	574,510
	E. regnans	55,744	10,018	4,975	1,381	0	0	72,118
	TOTAL—TAS	643,417	270,687	270,520	28,442	0	0	1,205,628
SA	*E. obliqua*	16	2,928	6,303	1,111	221	332	10,910
	TOTAL—SA	16	2,928	6,303	1,111	221	332	10,910
ACT	*E. delegatensis*	0	4,645	0	0	0	19	4,665
	E. fastigata	38	1,949	0	0	0	344	2,332
	TOTAL —ACT	38	6,595	0	0	0	363	6,996
Grand totals		1,547,670	942,580	604,880	64,094	13,801	695	3,166,279

1 Data updated from Bassett et al. (2024) 2 Data updated from Forestry Tasmania (2010b)

Box 2. The 2019-2020 bushfires – impacts on Victorian obligate seeder (ash) forests

The 2019-20 eastern Australian megafires were among the world's most extensive recorded fires, burning more than 8 Mha (Godfree et al. 2021). The fires burnt significant areas of obligate seeder forest in the ACT, NSW and Victoria. In Victoria, 88,000 ha of ash forests burnt, with about 25,600 ha of this reproductively immature and killed by high severity fire; not being able to naturally regenerate (Bassett et al. 2021; Bassett et al. in preparation). Following the fires, the largest native forest re-seeding program ever undertaken in Victoria was completed by the end of July 2020. VicForests, the body then responsible for commercial harvesting in Victoria's State forests, and the State forest manager (then DELWP, now DEECA) had available a total of 4.7 t of *E. delegatensis* seed in the four months following the fires. At the preferred resowing rate of around 1 kg/ha, this would have been sufficient to re-establish only 4700 ha. After post-fire rapid assessments and priority analysis of damaged forests, the best course of action was determined to be sowing 11,586 ha at an average rate of 400 g/ha (Bassett et al. 2021). Areas with the best chance of future survival were prioritised. This left 14,000 ha of forest gauged as unable to naturally-regenerate, including 8400 ha of receptive ash killed by the 2019/20 fire and about 5600 ha being either unreceptive or having already changed type following previous fires (Bassett et al. in preparation). The 14,000 ha was left unsown (Fairman et al. in preparation).



Box 2 Figure A Extent of the ash forest burn in Victoria resulting from the 2019-20 bushfire season [Source: https://www.communitybushfireconnection.com.au/recovery/regrowing-our-ash-forests/]

If more seed had been available, it could possibly have been used to either sow a greater area or sow at a more appropriate rate. However, availability of aircraft and personnel was already at capacity. Lack of seed was not the only constraint (Bassett et al. in preparation).

Were the interventions successful?

Limited monitoring of regeneration was carried out in the first year following sowing, indicating a successful establishment at ecological stocking rates (Fairman et al. in preparation). Favourable climatic conditions at the time assisted this result. Longer-term monitoring has not yet been undertaken, so ultimate success of the sowing operation is yet to be determined, Previous interventions have been successful (Bassett et al. 2015; Fagg et al. 2013). Monitoring of naturally-regenerated plots in NSW revealed adequate recruitment (Doherty et al. 2023). However, the un-sown areas will be at risk of vegetation type-change.

Box 2 Figure B Successfully regenerating *E. delegatensis* under a fire-killed stand near Corryong, Victoria [Image: Caitlin Cruikshank, DEECA]

Could the impact have been worse?
Victoria's seed stocks, and capacity to deploy these with cooperation of government and private sector consultants, averted a larger disaster. The impact could have been far worse if the prevailing climate conditions had been unsuitable for sowing and the establishment of natural and artificial regeneration. It would not have been possible to repeat-seed, or later sow these areas, as sowing in later years is not feasible following the first post-fire spring, as seed beds become unreceptive.

What are the follow-up actions and learnings?
In the years following the fires, native forest logging ceased on Victorian public land. VicForests role in management of the multiple use forests transitioned to DEECA. DEECA has continued the seed collection program post 2019/20 sowing to replenish seedstocks, achieving a store of about 12 tonnes by January 2026 (7 tonnes *E. delegatensis*, 5 tonnes *E. regnans* (Bill Paul, DEECA, pers. comm.). The response to the fires in the ash forests would have been more effective if more seed had been immediately available post-fire. High quality mapping, resource inventory and expertise available through VicForests, Parks, University of Melbourne and specialists in the private sector, allowed a large-scale rapid response that would not have been possible without these resources. Ensuring this capacity is maintained and grown in future is key to the ongoing survival of the Victorian ash forests. This capacity should be extended to obligate seeder forests across all land tenures and across state borders into the ACT and NSW.

Seed banking of species from the entire ash group would be a wise precautionary measure. If banking seed for broadcast sowing is not immediately practical, samples suitable for population rescue, particularly of the less widely distributed species, would be desirable. Although significant stocks of obligate seeder species are held in store in Tasmania and Victoria, examination of the AVSB database (see section 5.4) shows that only small collections of each of these species are being held by conservation seedbanks. It is not clear whether these small collections have captured sufficient genetic diversity to guard against biodiversity loss in the event of fires.

3.2 Other obligate seeders

Additional to eucalypts, many other genera of trees and shrubs are obligate seeders (**Box 1**). These include genera which rely on a soil seed bank (e.g. many *Acacia* species) and those that rely on canopy seed banks similar to the eucalypts. Recent studies have identified that the latter group are also likely to be threatened by increased fire frequency and intensity. Examples include *Banksia cunninghamii* (Muir et al. 2024), *Banksia spinulosa* (Whelan and Ayre 2022) and *Pomaderris bodalla* (Le Breton et al. 2023). A review of fire threats to a sample of five threatened ecological communities including rainforest, wet sclerophyll forest, heathland, grassy woodland and shrubland '*Bushfire impacts: how much seed will I need*?' (Pickup 2021), revealed that the proportion of obligate seeder species ranged widely, with 35 obligate seeding tree taxa identified in lowland rainforest of NSW. This study also estimates the number of seedlings that would be needed for enrichment plantings under various scenarios. It does not go on to make the difficult estimate of the volume of seed that would be required to support the required plant numbers, but it clear that it would be a major challenge to hold sufficient volumes in store to tackle widespread losses.

The Great Western Woodlands (GWW) in southwest Western Australia (Figure 5) are a very extensive (75,000–90,000 km^2) woodland ecosystem dominated by obligate seeder eucalypts (Gosper et al. 2018). Obligate seeder species from the *Banksia*, *Hakea* and other genera also reside in this region. The GWW are home to 78 obligate seeder eucalypts including salmon gum (*E. salmonophloia),* mallet (e.g. *E. astringens)* and gimlet (*E. salubris* and relatives) groups. The GWW are temperate dry sclerophyll forests receiving 400 to 700 mm MAR. Like their eastern States wet sclerophyll counterparts, the GWW obligate seeders are threatened by changing fire regimes, with fire intensity, extent and frequency likely to continue to increase, potentially threatening these woodlands. Research into the ecology of the GWW obligate seeders is relatively less developed than thoroughly researched species such as *E. delegatensis* and *E. regnans*, although work on ecosystem dynamics in response to fire is underway, with some information on generational interval gathered for some species (Gosper et al. 2018; Gosper et al. 2022; Gosper et al. 2024). Examination of AVSB records, which may not completely represent all collections, shows that small samples of several of the GWW obligate seeder eucalypts are held by various seedbanks. However, it is probable that more work should be done to secure seed samples that adequately represent the genetic diversity of this unique ecosystem.

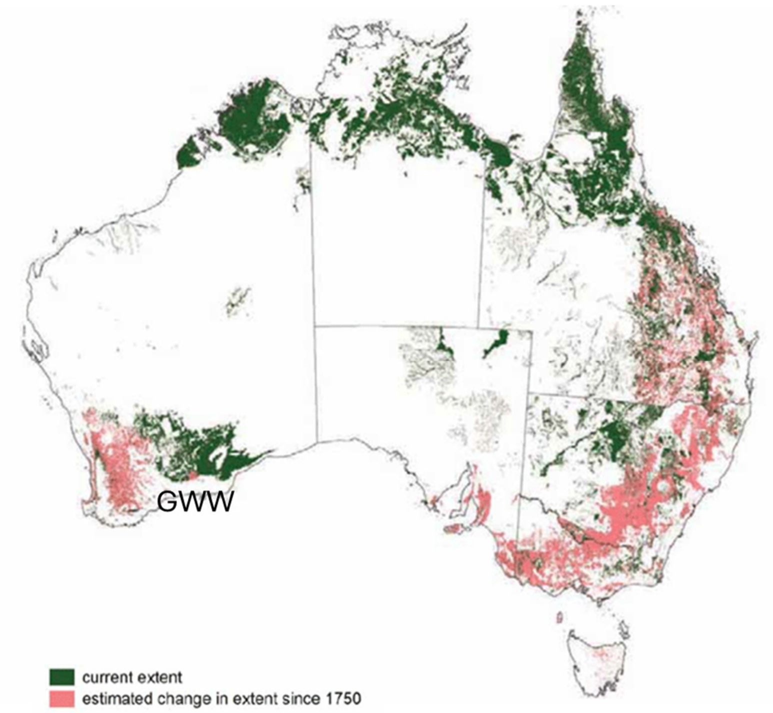


Figure 5 Previous and current extents of eucalypt woodland forest types in Australia, including the Great Western Woodlands (GWW) (Source www.anbg.gov.au/photo/vegetation/eucalypt-woodlands.html)

3.3 Woodland species that have been extensively cleared

Clearing for pasture and agriculture has resulted in severe fragmentation of Australian grassy woodland ecosystems, in many of which only scattered remnant tree cover remains. Ongoing clearing, isolation, long-term impacts of historic gold mining, lack of recruitment due to stock browsing, impacts from agrichemicals, dryland salinity and changed fire regimes are in many cases leading to slow, ongoing decline of woodland remnants. These effects are often observed as 'dieback' (see Section 2.3). Modelling indicates that in the absence of active management, many of these remnants could be lost completely within 90 – 180 years (Gibbons et al. 2008). Collection of seed with sufficient genetic diversity from these remnants has been identified as an important conservation intervention (Broadhurst 2013). Except for the GWW in Western Australia, most of the eucalypt woodland species are not obligate seeders and the fragmented nature of the forests means that they can be effectively re-established using relatively small volumes of seed per unit area of restoration using tubestock, if protection from browsing/grazing is provided. Production of seed using dedicated cultivated seed stands is another good option for these species (see section 9.1). A challenge is to collect seed that is sufficiently genetically diverse from small remnants: these often comprise related trees and suffer from inbreeding effects. It may be necessary to produce seedlots based on several patches to ensure sufficient diversity.

The widespread clearing of woodlands in Australia makes them a prime target for restoration to provide ecosytem benefits including dryland salinity prevention and soil ameioration, habitat for wildlife, shelter for stock and carbon sequestration. Establishment of revegetaion at the required scale is typically carried out by direct seeding. This technique, like broadcast sowing of obligate seeder species, uses large amounts of seed, and reports of seed shortages of particular species are widespread. Ironically, harvesting large quantities of seed from remnant woodlands can place further pressure on their survival. The issues of seed supply and demand, and the need for better coordination and a transition from wild harvested seed to cultivated seed production areas (SPA) are documented in several recent studies (Hancock et al. 2020; Coelli et al. 2026; Van Moort et al. 2021).

3.4 Alpine forests

Climate change effects including warmer and wetter summers and drier winters with less snow cover have been implicated in dieback of Australian alpine species (Verrall et al. 2023). These impacts may be very difficult to combat. Increased incursion of fire into fragile alpine forests is an additional problem caused by protracted drought and increased fire intensity. In Tasmania, pencil pine (*Athrotaxis cupressoides)* was extensively burnt in 2016. The fires were ignited by dry lightning, the increased frequency of which has been attributed to climate change. Regeneration of this species is far from certain to occur because of its slow growth rates. The Tasmanian Seed Conservation Centre (TSCC) has commenced collecting and banking seed of this species to be used in response to future losses.

Dieback of *E. pauciflora* and closely-related *E. lacrimans* in the Australian alps has been associated with boring insect attack, although an interaction with human development and management of the region has also been identified (Brookhouse et al. 2024). ATSC and the ANU-led alpine dieback

‘Save Our Snow Gums’ project, as well as DEECA in Victoria, have all commenced collecting seed from these and other upland species potentially affected by climate impacts.

3.5 Rainforest species

Australia’s Gondwanan rainforest communities (Figure 6) are highly diverse, with many hundreds of tree species from a wide range of genera (e.g. Floyd 1989). A long-term study in the moist tropics found that average annual tree mortality risk has doubled over the last 35 years, implying a halving in life expectancy (Bauman et al. 2022). Godfree et al. (2021) concluded that rainforests are probably most susceptible to localised loss of biodiversity (species, populations) from widespread fires such as the 2019-20 megafires. Rainforest rehabilitation is difficult once canopy species have been lost, as many species require canopy shade and protection to establish. Moreover, seed of rainforest species is often non-orthodox (i.e. recalcitrant or intermediate) and very difficult to store. Strategies for collection, processing and short-term storage of non-orthodox seed are given by Sommerville et al. (2021b). Once rainforest canopies are substantially damaged by drought or fire ingress, rehabilitation is challenging, even more so than for other forest types.

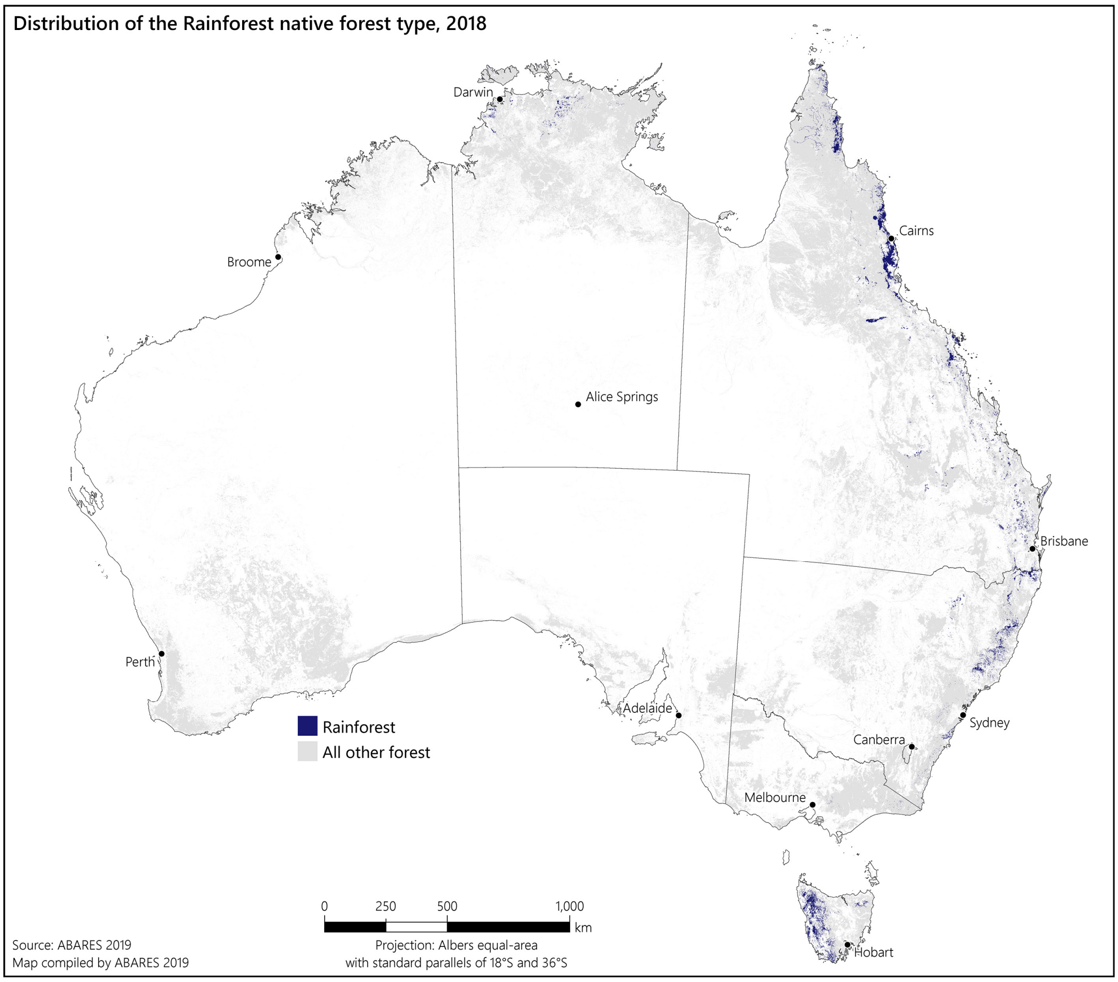


Figure 6 Extent of Australian rainforests (ABARES 2019)

3.6 Threatened species

There are over 1400 formally listed threatened plant species in Australia including numerous trees and shrubs. Each state has its own threatened species list and species may also be covered by the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act, Cth) list (www.dcceew.gov.au/environment/epbc). The Commonwealth Threatened Species Action Plan has a priority list of 30 plant species which includes several forest trees including *Acacia peuce*, *Banksia montana*, *Eucalyptus imlayensis*, *E. leprophloia* and *Macadamia jansenii*. Although most listed species have action plans for conservation, seed banking is variable among them, noting that lack of seed production has contributed to the threatened status in some species (e.g. *E. imlayensis*, see also **Box 4** on *E. benthamii*). Although the threatened species lists are useful for identifying species that should be prioritised for conservation through seed banking, there are many non-threatened species that include threatened provenances or subpopulations. This issue is addressed further in Section 4.1 and **Box 3**.

4 Climate change and provenance

4.1 The importance of provenance

Provenance refers to the geographic location of a particular wild tree stand. It is often assumed that different provenances within a species will be genetically distinct, although this is not always the case. This can be formally tested by growing trees of different provenances at a common site and testing for quantitative genetic differences in measured traits or by using molecular genetic (DNA/RNA) markers. If there are differences, the provenances can be more formally referred to as *subpopulations* of the species. Major subpopulation differentiation might give rise to a species being divided into subspecies. When carrying out seed collections to underpin conservation efforts, it is important to sample a given species widely rather than only collecting from one or a few provenances. For example, for *E. camaldulensis*, Australia's most widespread eucalypt species, the ATSC has collected seed from around 280 provenances, each provenance being represented by a sample of 10 – 50 individual trees (see also **Box 3**). Variation among provenances is more likely to occur if the species is geographically widespread, although it can also occur within short distances, especially due to altitudinal variation in steep terrain. Wide-ranging collections are important both to conserve genes that confer unique trait variation in specific populations and so that if seed needs to be deployed in a conservation intervention, a well-adapted provenance is available.

4.2 Seed transfer zones

In Europe and North America, where species often span countries and considerable distances, seed transfer zones (STZ) have been defined for some of the major production forestry species and other vegetation types (Ying and Yanchuk 2006; Pedlar et al. 2021). These zones delimit boundaries that may be defined by spatial and/or altitudinal variation, and form the basis for rules, some of which are actively enforced, for transfer of FGR. The STZ rules avoid maladaptation and preserve the genetic character of forests. A review of STZ in Australia identified non-enforceable zones in NSW, Tasmania, South Australia and Western Australia (Hancock and Encinas-Viso 2021). STZ boundaries in Tasmania are based on University of Tasmania research and operationalised by STT (Figure 7 - left). However, STT prefers to reestablish harvested stands using seed collected from that stand where possible. Seed zones have also been defined for obligate seeder eucalypts in southern NSW, based on research from Edith Cowan University, and applied by Forestry Corporation (Figure 7 – right). In Victoria, where ash seed is frequently transferred over long distances for bushfire recovery, seed transfer guidelines are provided in Native Forest Silviculture Guideline No.2 (Bassett et al. 2026), with STZs based on bioregions and reference to known historic genetic refugia. A hierarchy of transfer priorities is followed to achieve the best match between sown and seed collection sites.

The definition and implementation of STZs is complicated in Australia because of the multiple tenures that they might span and the numerous stakeholder groups that are involved. Apart from delimiting the biological boundaries of STZs, social input from stakeholders including government, private owners and Traditional Owners will be required. There will not necessarily be a single best course of action in defining STZs, and management decisions will need to incorporate a variety of stakeholder views.

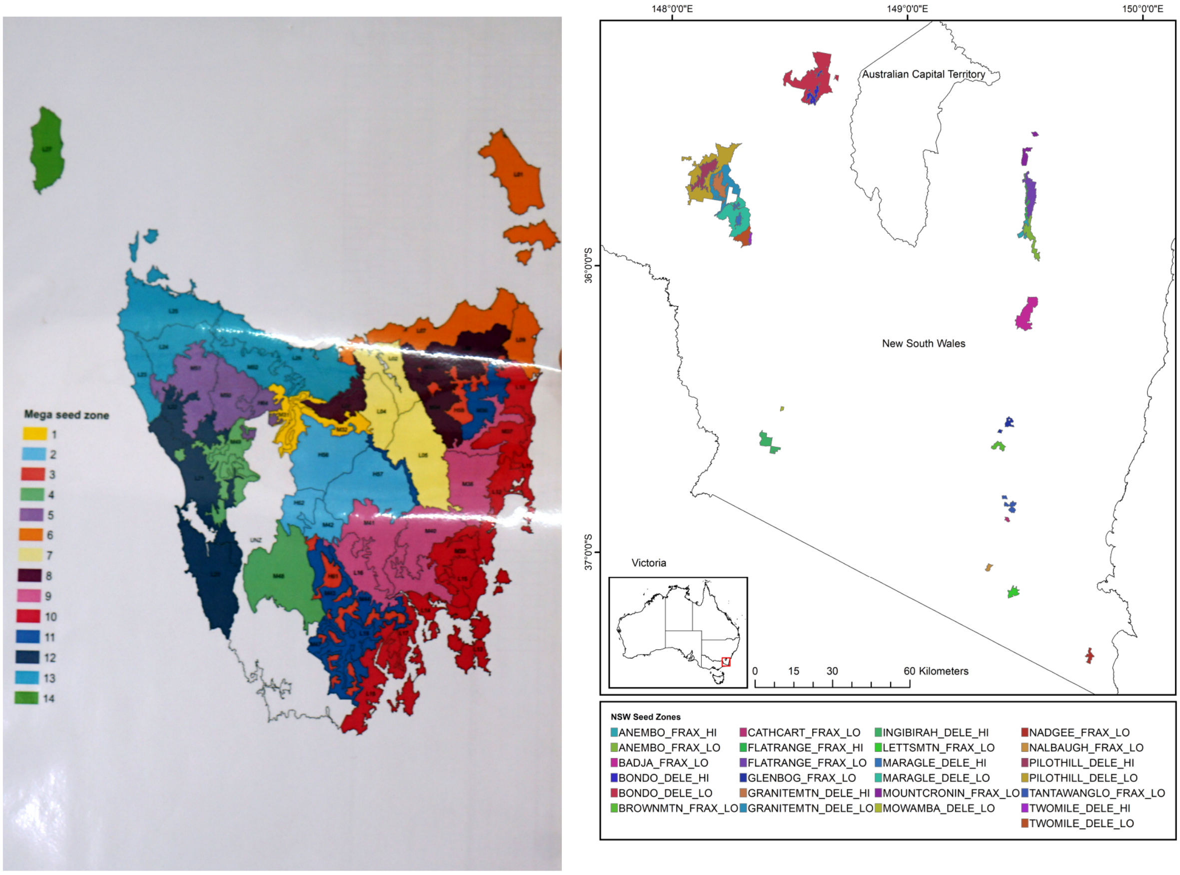


Figure 7 LEFT Tasmanian has 14 mega seed zones replacing the former 61 seed zones. The zones were defined based on University of Tasmania and STT research; **RIGHT** Seed zones in southern NSW for *E. delegatensis* and *E. fraxinoides* based on research conducted by Edith Cowan University in association with Forestry Corporation

4.3 Climate adjusted provenance selection

As the effects of climate change on adaptation of forest trees have become apparent, the concept of climate-adjusted provenance selection has evolved. The underlying principle is that germplasm from a site whose current climate is analogous to the projected future climate of the planting site is selected (Prober et al. 2015; Breed et al. 2018). Practically, in southern Australia, this means germplasm from hotter, drier climates is selected in the hope that it will be better adapted to future climate. This has started to replace the widespread policy of preferentially using local provenances to carry out revegetation works. However, the climate plasticity of many of Australia's forest tree species is not known, and it is therefore not a certainty that climate adjusted provenance selection is a necessity in all cases. Extensive introduction of eucalypt and acacia species outside of their niches has demonstrated that they may be adaptable to a wider range of climates than that of the natural range would suggest (Booth 2017). The practice of climate adjusted provenance selection may therefore (i) increase the chance of ongoing presence of a particular species that might be lost to climate maladaptation, OR; (ii) contribute to the genetic pollution, decline or loss of local subpopulations. Unfortunately, the rate of climate change is so rapid relative to the very long life cycle of many forest trees, it is very difficult to assess the long-term consequences of such interventions. Harrison (2021) has outlined an innovative strategy for mixing local and non-local provenances using the Midlands of Tasmania as a case study region: forests and woodlands of this upland region are already suffering from the effects of warming climate (Figure 1). This area is the subject of current research using both field-based trials and molecular genetics to assess whether or not particular provenances of a species show significant population differences that might indicate differing adaptive potential.

4.4 What does provenance mean for seed collection and storage?

Long-term preservation of FGR involves ensuring that sufficient genetic diversity to cope with adaptive stressors is available. Seed collections should ideally be made from each subpopulation of a species to represent unique adaptive diversity. In many cases, it is not known whether subpopulations exist within species. It would therefore be prudent to maintain collections by provenance based on geographic criteria (e.g. clinal variation, separation by distance and/or altitude). This means that seed storage requirements are more complicated and that more seed, in total, may need to be collected. Collection of seed is often easier in terms of access and efficiency on some land tenures than others. National Parks, for example, often have strict rules governing seed collection techniques and volumes. There is therefore a tendency to collect from other, more accessible tenures, which may leave important subpopulations under-sampled. This is despite the finding that seed collection causes only minimal damage if carried out appropriately (Fairman et al. in preparation). Adjustments to policy for legitimate conservation collections may be necessary to ensure sufficient provenance-level samples are collected from parks and reserves as insurance against biodiversity loss in these high-value ecosystems.

5 How much seed would be required?

5.1 Seed for broadcast sowing of obligate seeder species

Aerial sowing of obligate seeder species is a viable intervention that has been successfully employed in Victoria following bushfires that have burnt immature stands that are not likely to have sufficient seed fall for effective regeneration (Bassett et al. 2015). Indicative sowing rates are given by Fagg et al. (2013). Average viability per kilogram and preferred sowing rates in viables per hectare for various Victorian forest species are given in Wallace and Fagg (1995): this latter publication also makes clear that actual rates should usually be based on the results of viability tests. On this basis, VicForests preferred aerial sowing rate was 0.8 to 1 kg/ha following timber harvesting. Lower, ‘ecological stocking’ rates, are now accepted in Victoria following bushfires (Bassett et al. 2014).

STT also aerially sow seed either to achieve adequate regeneration in harvested areas or in the aftermath of bushfires. In 2023-2024, STT sowed 149 million seed across 5,000 hectares (29,800 v/ha) to regenerate native forest, using locally sourced seeds from native species (Sustainable Timber Tasmania 2024). Table 6 shows STT statistics from the 2024 financial year. These data also indicate that, on average, STT disperses seed at around 1 kg/ha. Actual rates are determined on the basis of viability testing. In February 2024, bushfires impacted over 5600 hectares of forest near Bradys Lake in the Central Highlands, including 4000 hectares of public production forests. STT, partnering with Tasmanian Helicopters, aerially sowed 250 hectares with around 15 million seeds (60,000 v/ ha) including *E. delegatensis* and *E. dalrympleana*. This is expected to result in around 600,000 new trees (Sustainable Timber Tasmania 2024).

Table 6 STT harvest and sowing statistics (Sustainable Timber Tasmania 2024)

Site preparation type	Area assessed (hectares)	Proportion meeting quality standard (hectares)
Clearfell	1,658	1,599
Partial harvest	3,416	3,403
Total	*5,074*	*5,002*
Seed sown		
Area sown (hectares)		1,641
Quantity sown (kilograms)		1,553
Seed collected on-site		24%
Seed collected in-zone		76%
Proportion of seed collected out-of-zone		Nil
Number of seeds sown		149 M
Av. Viables/kg		96,000

1 Seed is only applied to areas where natural seed fall is likely to be insufficient for regrowing the forest

5.2 Ferguson study – obligate seeder species in Victoria

Professor Ian Feguson (2011) produced a comprehensive study on seed requirements for Victorian obligate seeder species based on modelling underpinned by detailed data on forest life-stage and assumptions about fire frequency (assumed to be generally increasing due to climate change) and post-harvest regeneration. This study applied to 'multiple use' tenure land (*sensu* Bureau of Rural Sciences (2002)) which, at that time, incorporated timber production (area given in Table 5). Although native forest harvesting has now ceased on multiple-use tenure lands, the risk of wildfire remains ever-present. Moreover, the fires of 2019-2020 and preceding fires have resulted in a very substantial area, around 80,000 ha of obligate seeder forest that will be vulnerable in the next one to two decades before they start producing enough seed to regenerate in the event of fires (T. Fairman Pers. Comm). Key messages from Ferguson include the need to build two new high quality seed centres to replace the then extant 12 facilities and to accumulate over 17 tonnes each of *E. delegatensis* and *E. regnans*. A facility at Laverton has since been built but has only been intermittently operational and is currently not used for extraction. Collection targets in good seed production years of around two tonnes for *E. regnans* and four tonnes for *E. delegatensis* were recommended. Although the demand for post-harvest regeneration is no longer a relevant factor, the need to re-establish extensive post-fire stands in National Parks, private tenures and State Forests suggests that the storage target of over 30 tonnes remains relevant. Had this volume been in store in the aftermath of the 2019-20 bushfires, it would have been possible to broadcast sow a larger area at more appropriate rates, sowing the additional 8,400 that were receptive to seed but not treated, acknowledging that personnel and suitable aircraft availability have historically been and were a limiting factor at the time (Bassett et al. in preparation; Bassett et al. 2021).

5.3 Seed volume requirements

Table 7 gives estimates of the quantities of seed that would be required to re-seed obligate seeders *E. delegatensis* and *E. regnans* following loss to bushfires. This considers potential demand from all land tenure types. Based on seeding rates in Victoria and Tasmania, a rate of around 1 kg/ha would be preferred. It is highly doubtful that any state currently has adequate reserves to meet the 5% area @ 1 kg/ha target (for example, at the time of writing in March 2026, Victoria had a combined total 12.3 t of *E. delegatensis* and *E. regnans* in store – O. Bassett pers. comm). It should be borne in mind that these seed reserves might be required to meet reseeding requirements for smaller burnt areas over a short run of years, where store restocking rates are outstripped by demand and/or to repeat-seed areas that are not successfully regenerated in the first attempt – due to ineffective stratification or ongoing drought, for example. Existing seed storage facilities in all states would struggle to house the seed required to meet the 5% target and would not be able to meet the 10% target, even though they may presently be able to meet the needs of restoration on the land tenures for which they were originally purposed. These estimates do not take into consideration the preferred option of deploying seed of appropriate local or regional provenance. Significantly greater seed stocks would be required to meet this need, as fires may burn >10% of a particular region of provenance and some seed of each provenance, especially those that are known to have significant immature forest areas, should be held.

Illustrative of this point, Bartlett (2024) suggested that 1000 kg (enough to sow 20% of the relatively small ACT *E. delegatensis* extent) should be held in the ACT. This suggestion seems rational, given that 67%, or 2680 ha of the ACT *E. delegatensis* extent burnt in the 2020 Black Summer fires, and 66% had burnt twice in the previous 18 years (Office of the Commissioner for Sustainability and the Environment (ACT) 2023).

Table 7 Seed requirements for *E. delegatensis* and *E. regnans* under various loss scenarios at two mean rates of sowing across all land tenures

		Seeding @ 1 kg/ha		Seeding @ 0.5 kg/ha	
	% of total species area to be seeded	5%	10%	5%	10%
	E. delegatensis (ha)	Seed (t)	Seed (t)	Seed (t)	Seed (t)
Tasmania	559,000	28.0	55.9	14.0	28.0
Victoria	380,150	19.0	38.0	9.5	19.0
NSW	147,047	7.4	14.7	3.7	7.4
ACT	4665	0.2	0.5	0.1	0.2
SEFH*	129,645	6.5	13.0	3.2	6.5
	E. regnans (ha)				
Tasmania	72,118	3.6	7.2	1.8	3.6
Victoria	249,550	12.5	25.0	6.2	12.5

*The SEFH total is inclusive of parts of the NSW and Victorian totals and all of the ACT

5.4 Who holds seedstock of obligate-seeder species?

The three main bodies storing bulk seed of obligate seeder species suitable for aerial or ground-based broadcast sowing are Sustainable Timber Tasmania, DEECA Victoria, and as of 2025, Forestry Corporation, NSW. Seed held by these bodies (or their predecessors) has traditionally been intended for use on 'multiple use' tenure land such as State Forests to ensure adequate regeneration after timber harvesting. National Park and reserve managers have typically not held seed stocks of obligate seeder species, although NSW did make some high-quality conservation collections (tens of kilograms for small scale rescue regeneration rather than broadcast sowing) following the 2019-2020 bushfires. These stocks are held by the ATSC. However, both DEECA and STT have made seed available for use in reserves in the aftermath of bushfires. Seed is usually collected from multiple use tenures rather than National Parks or other land in the reserve system. A lack of seed from provenances embedded in reserves may lead to issues of seed use across provenances or seed zones for which seed is not available. The ACT does not have a bulk store of *E. delegatensis* and has not previously conducted remedial broadcast sowing in the aftermath of bushfires.

The Australian Virtual Seed Bank (AVSB) is an online aggregator of data from several of the ASBP member seed banks. Table 8 shows the results of queries on the AVSB that examine the holdings of the 'minor' eastern state obligate seeders (i.e. excluding *E. delegatensis* and *E. regnans*) and a small selection of the obligate seeders from the GWW. The table also reports the ATSC's holdings of these species: the ATSC has not commenced uploading data to the AVSB and its data are not publicly accessible. This example shows (i) that the AVSB would be an excellent tool for examining the nation-wide holdings of FGR if thoroughly populated and (ii) there is much work to be done both in collecting seed of key forest species and making the information publicly available.

Table 8 Holdings of a selection of obligate seeding species in the AVSB and ATSC databases

Species	Accessions	Accession holders (accessions held)
Eastern states obligate seeders		
E. dendromorpha	4	PlantBank (3); National Seed Bank (1)
E. oreades	8	Brisbane Botanic Gardens (1); National Seed Bank (2); PlantBank (5)
E. paliformis	3	PlantBank (2); National Seed Bank (1)
E. stenostoma	3	PlantBank (1); National Seed Bank (2)
E. triflora	5	PlantBank (2); National Seed Bank (3)
Select GWW obligate seeders		
E. cernua	5	The Western Australian Seed Centre (3); PlantBank (1); ATSC (1)
E. clivicola	9	The Western Australian Seed Centre (5); PlantBank (3); ATSC (1)
E. extensa	2	The Western Australian Seed Centre (1); PlantBank (1)
E. megacornuta	13	The Western Australian Seed Centre (6); PlantBank (3); National Seed Bank (2); ATSC (2)
E. platypus	12	The Western Australian Seed Centre (4); PlantBank (5); National Seed Bank (1); ATSC (2)

5.5 Seed of other threatened species

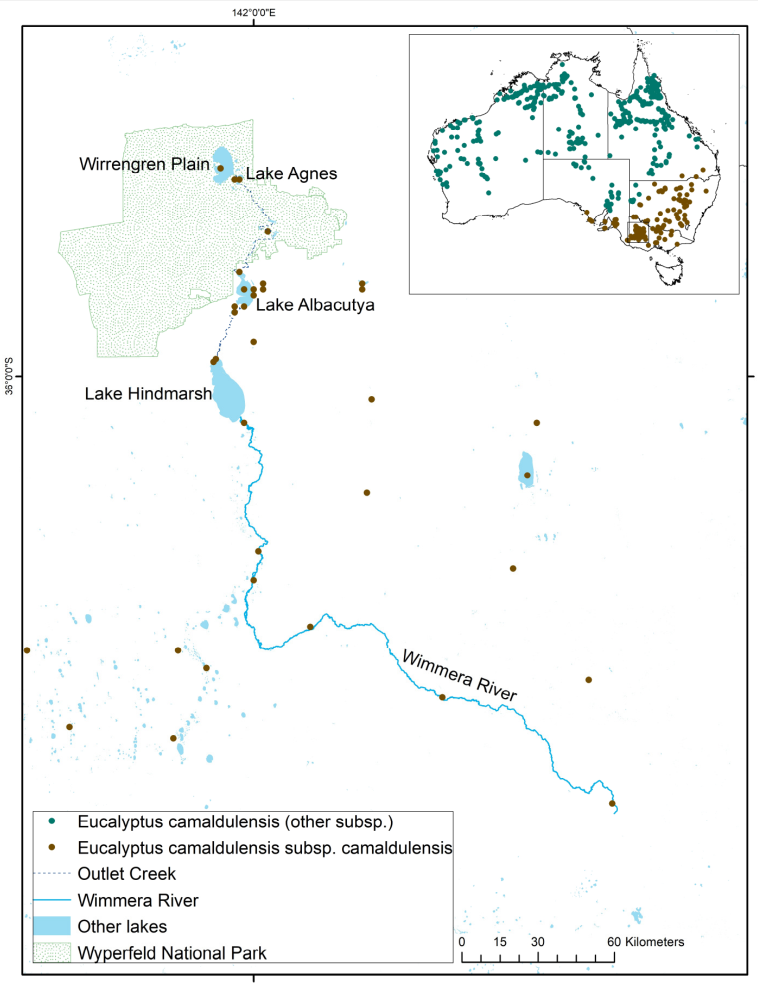
Volumes of seed of other species do not need to be as large as for the obligate seeders. However, the list of species that is potentially vulnerable to climate change is very long, so the combined total could be significant for a collection that provides statewide or national coverage. The list should not be limited to formally listed threated species, as this would not include species for which key subpopulations or provenances are threatened. For these species, small amounts of seed (a few grams per tree for an adequate sample of trees, a few hundred grams or kg per provenance) would suffice to provide a genetically diverse sample that could be used to rescue a population or species if used carefully. Guidelines for establishment of conservation populations of forest trees are well established (e.g. Kemp et al. 1993). There are several seed centres and seed collections throughout Australia that would have the correct storage conditions for such collections (see Section 6; Table 9). However significant challenges include: (i) conserving many rainforest species, as the seed are recalcitrant and do not store well (ii) identifying and prioritising species that should be conserved and (iii) obtaining the required permits and funding required to make the field-based collections.

Box 3 examines the collections of *E. camaldulensis*, Australia's most widely distributed eucalypt species, as an example of a working collection.

Box 3 How much seed is needed to conserve a species? – *Eucalyptus camaldulensis* example

Meaningful conservation interventions for tree species can be made using modest volumes of seed. Storage volume and conditions will be dependent on several factors including the range of the species, the amount of time that seed needs to be in storage and the viability characteristics of the seed. Research into subpopulation differentiation will help guide the appropriate level of sampling: if this information is not yet available, samples from different provenances should be made, assuming that these may be genetically distinct. This example focuses on *E. camaldulensis* which has the widest natural range of any eucalypt.

Although the species is not listed as Threatened, some populations are under threat, for example the Hunter (NSW) population is listed as an endangered (NSW Scientific Committee 2005) and is the subject of conservation interventions (Fahey et al. 2024). Figure A shows the distribution of collections the ATSC has made across its range. This substantial collection range has been influenced by the fact that *E. camaldulensis* is one of the world's most widely planted and commercially important species. Some of the best-performing provenances in Mediterranean environments are those of the Wimmera River. This river flows inland into a series of terminal lakes. Climate change and significant water extraction have resulted in declining flows into the saline lake system: Lake Hindmarsh is the first to fill, L. Albacutya fills when L. Hindmarsh spills, and so on. The Wirrengren Plain last filled in 1874 and L. Agnes in 1918. Lake Albacutya partially filled in 1995. The remnant populations of *E. camaldulensis* surrounding these lakes are therefore threatened by protracted drought and the seed reserves are a valuable *ex situ* conservation resource. ATSC collection sheets going back to the 1980s note that trees were already in decline then, and this has been noted by others (Bren and Sandell 2004).



Box 3 Figure A The terminal lake system of the north-flowing Wimmera River and locations of ATSC seedlots of *E. camaldulensis* subsp. *camaldulensis*. The inset map shows the distribution of the ATSC's collections of *E. camaldulensis* subsp. *camaldulensis* and other *E. camaldulensis* subspecies across Australia.

How much seed has been collected?

Historically, the ATSC has collected 229 provenance seedlots of *E. camaldulensis* subsp. *camaldulensis* and seed remains in 59 of these collections totalling 46 kg (around 25 million viable seeds). A total of 24 seedlots comprising 337 individual mother trees have been collected from the Wimmera River terminal lakes- seed weighing 8.4 kg remains in store (initially, around 4 million viable seeds). These seed collections are probably adequate to serve as an *ex-situ* conservation population. However, as the seeds were originally collected more than 20 years ago for the purposes of active deployment, they have mostly been stored in a 20°C constant temperature store. For conservation purposes, they should ideally be stored at a temperature below freezing. Some seedlots have been transferred to a -18°C store.

What would be the ideal outcome for the Wimmera seed collection?

The ideal conservation intervention, apart from restoring water to the natural environment, would be to establish a genebank, comprising cultivated trees of the correct provenance, at a suitable, secure riverine site(s) using some of the seed in store. In 1994, the ATSC established two mixed provenance *E. camaldulensis* trials at Deniliquin, NSW involving 100 individual-tree open-pollinated families, with around 50 progeny planted per family (Bush et al. 2013). The weight of seed required for the two trials was only 0.5-2 g per family, totalling 121 g. A similar sized planting, based on the Wimmera River families only, would be suitable as a genebank.

As *E. camaldulensis* can potentially live for hundreds of years, this would be complementary to seed banking, and the stand would provide the opportunity for further seed production. Another action would be for the ATSC to either relocate some of their holdings to a lower temperature store, or to lodge seed with a store that already has this facility.

Box 3 Figure B Over-mature (foreground) and younger (background) *E. camaldulensis* growing along the Wimmera River at Horsham, Victoria. Trees in this section of the river are generally healthy, receiving adequate water.

6 Storage infrastructure and seed collection

Australia has significant FGR storage. This is widely dispersed among states and institutions. The various facilities have different purposes, but typically there is a regional, often state-based, focus. It is also possible to distinguish between facilities based on the type of storage that they provide. Some are purposed to house bulk quantities (hundreds or thousands of kg) of seed for broadcast sowing, for example after bushfires, for direct-seeded rehabilitation of mine sites, or landscape-scale revegetation. Others store seed that is destined to be used more efficiently to produce tubestock for purposes including conservation, forest plantations, targeted native forest enrichment plantings and urban greening. Many of the conservation seedbanks are managed as long-term *ex situ* stores, with seed only released for research or highly targeted restoration projects. The differences in seed volume required for these two styles of planting are significant: one kilogram of broadcast-sown *E. delegatensis* seed will re-establish 1-2 hectares of burnt forest, while the same kilogram of seed, which might include around 107,000 viables (Boland et al. 1980) could produce enough tubestock to establish 50 - 100 ha of plantation, although this would give a less-natural result than broadcast sowing which will replicate early competition effects and natural selection of the fittest genotypes.

6.1 General requirements

Many of Australia's tree species produce *orthodox* seed which is relatively easy to store and typically has a relatively long storage life under appropriate cool, dry conditions. Conversely, rainforest species often have fleshy *recalcitrant* seeds that cannot usually be dried down and/or frozen and are typically short-lived in storage. Other rainforest species have intermediate seeds which have storage characteristics intermediate between recalcitrant and orthodox seeds. The main eastern states obligate seeder species and related species (see Table 4) are best stored under refrigerated, constant temperature conditions (at around 3°C or below). Seed should be stored in sealed containers as soon as it is extracted to prevent uptake of atmospheric moisture. Most other eucalypts and acacia species can be stored at a higher constant temperature of around 20°C for ten or more years. For long-term, conservation collections, storage at -20°C, -80°C or cryogenic storage will lengthen the viable storage period significantly.

Seed storage infrastructure throughout Australia is of variable size and quality and designed for various specialised purposes. The design of seed stores varies according to the scale and purpose of the activity. However, a self-contained seed centre will have extraction, storage and viability testing facilities.

Another key aspect of seed germplasm banks is that the accessions are carefully documented. This involves recording the details of the provenance of the accession which might include aspects of the landform, soils, species associations etc. This data should be databased. The database is used to locate the accessions, monitor stock levels, track viability and record deployments of the seed.

High quality publications covering the design equipment and, by implication, staffing requirements are reviewed below. Details of seed extraction and storage facilities covering a wide range of species can be found in the ATSC Operations Manual (Gunn 2001).

Seed/germplasm banks for long-term *ex situ* conservation

Typical conservation seed banks collect and hold small amounts of seed (fractions of a gram to hundreds of grams) for a wide range of species. The usual objective is to store the seed for as long as possible as *an ex situ* conservation measure. There is a strong emphasis on extracting and storing the seed in such a way as to maximise its storage life. This can be achieved for small batches of seed using extraction techniques that minimise heating (active desiccation may alternatively be used) and storage at low (-18°C) very low (-80°C) or cryogenic temperatures between about -130 and -192°C (Funnekotter et al. 2021) (see also section 9.2). For orthodox seed, management of drying and moisture uptake is a significant part of the process. These seedbanks will often be equipped with specialised equipment for accurately measuring seed dryness and carrying out viability tests for a variety of species including those that require specialised dormancy-breaking treatments. Some of the equipment and specialised strategies for this type of seedbank are given by Gunn (2001) and Martyn Yenson et al. (2021). As the strategies used in these seedbanks are often highly variable and specific to particular seedlots, they must be staffed by people with specialised technical knowledge of seed biology. A comprehensive guide to collection, storage and testing of seed for conservation seedbanks, with contributions from may Australian seedbanks, '*Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising* Ex Situ *Collections*' is given by Martyn Yenson et al. (2021).

Seed stores for bulk storage of seed used in broadscale deployment

Bulk seed stores will typically stock a restricted range of species with orthodox seed storage behaviours. Mining companies, landscape-scale revegetation programs, large-scale producers of forestry plantation seed and managers of obligate seeder forests typically have this type of infrastructure. Individual seedlots may be measured in tens of kilograms and seedbank capacity in tonnes. The scientific and engineering challenges associated with construction and running bulk seed stores is well developed in Australia. Wallace and Fagg (1994) present information on extraction and storage of larger volumes of seed, focusing on Victorian species including *E. delegatensis* and *E. regnans*. The DEECA Laverton seed facility has its own operating procedures outlined in a series of six documents developed by Forest Solutions Pty Ltd covering aspects including transport, handling, processing, storage and testing of capsule crops and seed; allocation and dispatch of seed for sowing; and, tender procedures for seed collection. Similarly, STT (Forestry Tasmania 2010a) have comprehensive technical advice for collection, storage and deployment of eucalypt seed for broadcast sowing. If eucalypt or other species seed collection targets are in the thousands of kilograms, seed processing infrastructure is necessarily large scale. One green ton of eucalypt capsules may produce in the order of 15 – 70 kg of seed, so handling and drying equipment needs to be capable of handling capsule charges of up to 250 kg. Workflows may have significant seasonal peaks – e.g. around winter sowing – and require staff experienced with the logistics of managing contractors involved in collection and sowing, handling significant inflow volumes of capsules and organising rapid export of seed in response to bushfire events or large seasonal sowing campaigns. Bulk stores should also have a database that can be used to store accession information as well as allow queries that aid in the deployment of appropriate provenances, management of seed volumes and provide a historical record of deployment.

6.2 Existing infrastructure

Table 9 shows facilities that might be used for processing, storing and testing tree seed for conservation purposes. Additional facilities in conservation-focused seed banks and seed centres may be available via the network of partners in the Australian Seed Bank Partnership (ASBP) where capacity allows (Figure 8) (www.seedpartnership.org.au/our-partners/).

NSW, Tasmania and Victoria all have facilities designed for bulk storage of obligate seeder species. A fully equipped obligate seeder storage facility needs to have significant capacity, and seed is best stored refrigerated at a constant temperature of around 3°C. An electric or gas kiln, often with a rotating drum sieve, is typically used to extract seed from the capsules (Figures 9,10). Other equipment includes heavy plant such as a forklift, stock picker, pallet jack for moving barrels and wool bales filled with capsules; large blowers, sieves etc for cleaning seed and a small laboratory equipped for cold-moist stratification and germination testing. The facilities in southeastern Australia are of varying ages and sizes: NSW Forestry Corporation has recently constructed a small facility at Eden to store seed collected in its newly commenced obligate seeder recovery project (Figure 11). There is also capacity to store seed at an existing Forestry Corporation seed store at Grafton. As the Eden facility is new and the Forestry Corporation program is currently designed to collect up to about one tonne of seed, this facility is adequate in terms of storage, with the task of seed extraction outsourced to the seed harvest contractor. However, if it were to service a larger area such as the SEFH zone, which includes large areas of obligate seeder forest across multiple tenures, it would need to be significantly expanded (see section 12 for a case study on the SEFH zone).

STT has a major facility at Perth, including good quality and recently upgraded seed extraction facilities and a basic but functional seed viability laboratory. There is additional storage capacity at Geeveston. STT has recently established a section of its storage specifically allocated to re-establishment of forests following bushfires. This is additional to storage of seed by coupe and zone that can be used for supplementary post-harvest seeding of coupes if the retained seed trees do not give a satisfactory natural germination. Although the STT facilities are ageing, they are fully operational and supported by STT as a core component of their silvicultural operations. If the requirement to supply seed to respond to revegetation requirements on all tenures of forest land emerged, then some expansion of the facilities would likely be required.

There are currently six operational DEECA seed stores situated in Victoria. The largest and most modern is at Laverton, constructed in 2010. Orbost is near capacity. Alexandra and Mansfield are functional stores that provide core capacity. Both O. Bassett (quoted by Australian Broadcasting Corporation 2022) and Ferguson (2011) have called for an expansion and upgrade of the facilities in Victoria, as they do not have the capacity to process and store the amount of seed required to deal with future bushfire threats. The estimated current capacity is around 30 t. DEECA is currently undertaking a review of its seed processing and storage assets and associated program. This is due to be completed in 2026 (Paul 2025).

Table 9 Seed storage facilities in Australia

State	Organisation	Facility location	Capacity	Type	Purpose
ACT*	CSIRO	Canberra	20,000 seedlots; bulk store with max. capacity of circa 12 t. (3°C) and 120 m^2 of store @20°C/30% RH.	Small seedlots stored as individuals within provenances	Genebank, research, small scale revegetation, genetic improvement – sale and supply of seed
ACT	National Botanic Gardens	Canberra	800 accessions; Large capacity for small, conservation-focused seedlots	Specialises in alpine species including trees, shrubs, herbs, grasses	Conservation and research
NSW*	Forestry Corporation	Grafton Eden	2 t – smaller seedlots 1 t+ (3°C) obligate seeder store	Bulk collections, improved seedlots, conservation lots	Forest re-establishment, tree improvement, strategic uses, limited sale and supply of seed
NSW	Botanic Gardens of Sydney	Mt Annan	State of the art storage for conservation/ research seedlots and tissue culture	Conservation and research	Genebank, conservation, research
TAS*	Sustainable Timber Tasmania	Geeveston Perth	3 t? 12 t?	Bulk collections identified by coupes and zones	Post-harvest forest re-establishment, sale and supply of seed
TAS	Tasmanian Seed Conservation Centre (TSCC)	Hobart	Suitable for storage of small seedlots for conservation	Small seedlots	Genebank, conservation, research
VIC*	DEECA	Laverton Mansfield Alexandra Noojee Orbost Swifts Creek	12 t 6 t 4-5 t Around 30 t in total. Facilities in variable service-life stages	Bulk collections identified by coupes and zones	Forest re-establishment, previously harvesting and wildfire, now wildfire and/or other environmental restoration
WA	Threatened Flora Seed Centre Dept Biodiversity Conservation and Attractions	Perth	5000 accessions of various species	Small seedlots by provenances	Genebank/threatened species conservation
WA*	FPC Nursery and Seed Centre	Manjimup	Seedlots for tree improvement, conservation, public use	Small- medium seedlots by provenances	Genebank/small scale revegetation, public sales of some accessions Sale and supply of seed

* Tree FGR specialist stores – others have a broader remit

Figure 8 Locations of the ASBP members (Source: www.seedpartnership.org.au/our-partners/)

Table 9 also lists seed centres designed for the processing and storage of smaller quantities of seed that might be used for population conservation, tree improvement and population recovery. These seed centres are generally well-suited to the function that they carry out and are equipped with a variety of appropriate equipment and storage solutions. This includes controlled temperature- and humidity-controlled stores at various temperatures above and below freezing: longer-term conservation is best carried out lower temperatures, typically -20°C, -80°C or using cryogenics for the most valuable accessions. The Tasmanian Seed Conservation Centre (TSCC) in Hobart is actively acquiring seedlots of Tasmanian tree species for conservation and research purposes. While some of these conservation seed banks have been recently upgraded, others have limited or no additional storage capacity and/or are housed in buildings that are only marginally fit for purpose.

The Australian Tree Seed Centre in Canberra has a wide-ranging collection of Australian forest species and aims to make range-wide collections of populations including individual trees. The FPC Seed Centre in Perth, WA and Forestry Corporation seed store at Grafton formerly held similar functions focused on species endemic to or of economic importance to those States. These stores, while still operational, have scaled back and/or refocused operations during the last 20 years. The Queensland Forest Research Institute seed store closed in the early 2000s.

Figure 9 Seed extraction container at STT designed for extraction of smaller capsule collections. This modular unit can be used together with the main kiln. A much larger rotating drum unit is used for larger capsule crops.

Figure 10 Removal of a rotating-drum kiln charge at the DEECA seed extraction facility at Orbost [Photo: Caitlin Cruikshank, DEECA]

In addition to the facilities listed in Table 9 and shown in Figure 8, there are numerous restoration-focused seed stores. These includes stores belonging to regional organisations such as catchment management authorities. There are also privately owned seed stores including those belonging to Greening Australia (Nindethana Seeds), tree improvement initiatives including Tree Breeding Australia and seedEnergy, and commercial seed suppliers. The level of documentation that the commercial seed stores retain on their accessions is quite variable, ranging from no provenance information to highly detailed pedigree data.

Figure 11 Demountable 14 m^3 cool room (3°C) facility commissioned by Forestry Corporation, NSW. The self-contained cold store is currently situated within an existing field depot. The facility stores up to 1 t of *E. delegatensis* and *E. fraxinoides*. Note that seed is stored in airtight containers [Photo: D. Mannes, Forestry Corporation)

6.3 Seed collection

Seed collection for conservation of FGR is a function that relies on both scientific method and technical skills. It is important that seed is collected in a way that ensures it is genetically representative of the source population, properly documented and harvested in a way that is appropriate to the required seed storage objectives and the type of forest that it is harvested from. Technical guidelines for seed harvesting for different purpose are given by various authors (Wallace and Fagg 1994, 1995; Bassett et al. 2024; Gunn 2001; Martyn Yenson et al. 2021).

Seed collection of FGR draws on considerable expertise including botanical expertise needed to verify that the correct taxa are being collected, knowledge of plant breeding systems and seed biology required to ensure collected seed is ripe, properly extracted, stored and tested. Pre-identification of stands that have good seed crops is an important and increasingly difficult task in the face of climate change. Many trees are physically large, and the technical skills required to harvest large volumes are considerable. Specialised arboricultural and silvicultural techniques are required. In both Victoria (DEECA) and Tasmania (STT), the harvest of ash-type seed is largely handled by specialised private sector firms working under the direction of dedicated scientific management teams in these organisations. Both organisations have developed considerable 'corporate knowledge' over decades of research and collection activity, and this is critical to providing the functions they provide. In Victoria, seed collection of ash species is underpinned by annual flower and seed crop availability forecasting – up to three years ahead of time, including annual aerial flowering assessments (Bassett 2011; Bassett et al. 2024).

Collection of FGR in Australia has become increasingly regulated. All states require permits or licences to collect seed on at least some tenures. These licences may restrict the purpose for which collected seed can be used, require agreements for access and benefit sharing in some cases, and often take considerable lead time to acquire. Collection of seed from threatened species is robustly regulated. This may have led to collection biases with less seed being collected from tenures such as National Parks and wilderness areas which typically have strict rules on seed collection. While the reason for these rules is understandably to protect vulnerable stands and forests from exploitation and damage, it may have led to under-representation of germplasm that can be used for conservation interventions in some seed collections. The issue of seed collection from reserve tenures also impacts on the maintenance of an appropriate seed bank for obligate seeder species. Collection is typically restricted in National Parks, for example, even though there are significant, and potentially, genetically distinct, obligate seeder populations within these. New research in Victoria indicates that the impacts of seed collection by climbing are minimal and transient (Wagner and Nitschke 2025) and outweighed by the significant landscape-scale benefits. Legislation pertaining to seed collection across states is not harmonised, and this also adds to the complexity of acquiring representative collections across borders and tenures. Adjustments to policy that (i) make seed collection for FGR conservation easier and (ii) clarify the strategy and need for locally collected seed to guard against local and landscape-scale loss of biodiversity in the national reserve system are required.

6.4 A centralised national seedbank or a network of seedbanks?

The establishment of a centralised national seedbank that could comprehensively service the varying conservation and reafforestation needs in the states and territories is probably not practical. Shifting the large quantities of seed that are required to respond to widespread loss of the eucalypt obligate seeders to and from a centralised collection would be a major logistical and administrative challenge. It is best that these collections continue to be housed close to the forests that they are protecting in NSW, Victoria and Tasmania. Whether sufficient representation and volume of WA's obligate seeder eucalypts are being held should also be closely examined: this seed would logically be stored in the west. A secondary issue is that state quarantine laws make the rapid movement of seed in some directions a slow process involving phytosanitary treatments and certifications. Tasmania and Western Australia both have quite strict restrictions on the import of eucalypt seed, for example. It would also be expensive to mount collections of threatened species from a centralised point. To a certain extent, the ATSC, Australian National Seed Bank and Australian PlantBank do provide national coverage, but none has the comprehensive collection of species and provenances that would be required to adequately conserve Australia's vulnerable FGR.

While a fully centralised seedbank may not be practical, it would be worth examining the option of shared facilities that could cope with seed demand across tenures and the Victoria/NSW State borders for storage of *E. delegatensis*, *E. regnans* and potentially the 'minor' obligate seeders (Table 4).

It is therefore recommended that a well-integrated network of seed centres, based on the stores that already exist throughout the states and territories, be established. The establishment of a centralised database capable of being viewed across centres and national coordination would be key supporting elements. As shown in the example given in Table 8, the Australian Virtual Seedbank portal https://seedbank.ala.org.au/ aggregates, and makes publicly available, information on ASBP partner seedbank accessions. The data uploaded to this, while incomplete and variable in detail, is very useful for querying accessions across multiple institutions. Further development of this, or a similar resource, would allow a better assessment of whether adequate seedstocks of particular species, and provenances within species, are collectively being held.

6.5 What new infrastructure and collection resources are required?

Australia has a variable standard of facilities with some very high-quality seed storage infrastructure and many requiring significant upgrades.

6.5.1 Bulk stores for obligate seeders

'Bulk' seed stores for obligate seeder species are of variable quality and are, overall, not carrying sufficient volumes of seed to deal with larger fires. In Victoria, the 2019-20 bushfires demonstrated that greater volumes of seed need to be stored if ecological type change is to be avoided. In fact, the Victorian DEECA (including VicForests prior to closure) seed stores probably did have the capacity to store sufficient seed (around 18 t) to almost resow the full extent of 8,400 ha that was not likely to recover due to having already been burnt within the last 20 years but did not have sufficient seed volume in store. This illustrates that storage infrastructure is not the only limiting factor: collection and deployment infrastructure and resources are required to complement the storage. However, it has also been noted by Ferguson and Bassett that several of Victoria's seed stores are at end of life and need replacing.

In Tasmania, the STT seed store is well maintained and can handle the seed volumes required to resow harvested coupes where necessary and reestablish after bushfires. However, the store may not be large enough to cope with extensive loss of obligate seeders on Parks and Private land tenures.

In NSW, the newly commissioned seed store (Figure 10) designed to store seed of *E. delegatensis* and *E. fraxinoides* has sufficient storage for the regeneration requirements on Forestry

Corporation tenure. This would not be adequate to deal with simultaneous losses in NSW Parks: an expanded collection and storage program is required in NSW, ideally coordinated between stakeholders. The ACT does not have a seed storage facility for *E. delegatensis* or other species: one should be commissioned (with an accompanying collection and deployment strategy) as a high priority. Coordination of seed stock management to respond to losses in the Namadgi and Kosciusko National Parks, which share a border and many ecosystem elements, would make sense. The following points apply:

- Obligate seeder infrastructure in Victoria needs to be increased and upgraded to reach the recommended 30+ t processing and storage capacity, including replacement of some aging facilities.
- Obligate seeder infrastructure in Tasmania is suitable to carry out its function within the context of STT's operational requirements. It has some extra processing and storage capacity that it has recently commenced using to increase bushfire response stocks. An analysis of whether this store could adequately deal with extensive fire losses in the private and reserve tenures (totalling around 330, 000 ha) should be conducted (acknowledging that storage for these tenures is currently beyond the organisation's remit). The store and associated collection operations may need to be expanded.
- NSW would require a significant upgrade its storage and collection capacity to cope with loss of obligate seeder species outside of the multiple-use forests in National Parks and on private tenure. The recently commissioned obligate seeder store and seed collection program are currently focused on multiple-use tenure.
- ACT does not have suitable infrastructure for storage of *E. delegatensis*: this could be of a similar scale and type to that recently installed by Forestry Corporation assuming they adopt the recommendation of Bartlett (2024) to store around a tonne of seed (see also section 12- SEFH case study).
- Additional deployment infrastructure may also be required. This includes access to suitable aircraft fitted with seed deployment equipment and skilled operators. Rapid post-fire deployment logistics management is a key skillset.

6.5.2 Conservation seedbanks

While some of the state conservation seedbanks have high quality facilities, others would benefit from extra capacity or upgrade. The Australian PlantBank (NSW) is a state-of-the-art facility; the Australian National Seedbank and ATSC have been recently refitted. Lack of staff to carry out collection maintenance is an issue for several of the conservation seed banks listed in Table 9. Identification of target species and collection of seed may also be limited by staff in several cases. Employing specialised staff is a significant, ongoing costs to a collection that may pose a greater financial challenge than upgrading the infrastructure itself.

- An analysis of the infrastructure, staff and stocks of the conservation seedbanks would help to identify vulnerabilities in the conservation capacity for threatened tree species and communities

- State and National seed stores could be used to provide some redundancy for smaller seed collections.

6.5.3 Databasing

Databasing is an important aspect of seedbank management. A centralised database would be useful for ascertaining whether seed of certain species has been collected and stored, and if so, the quantity and diversity of seedlots. This would be especially valuable for species that occur across states and tenures. The AVSB database, which is already in use by several of the conservation seedbanks listed in Table 9, might be modified for this purpose or a dedicated database commissioned. Sharing collection and stock data among obligate seeder bulk stores would be a critical step required to for cooperation across states and tenures.

7 Training, expertise and engagement

Collecting, storing and deploying tree seed depends on people. Access to a workforce with the necessary technical skills is essential. Our trees and forests are an important asset that belong to all Australians. Engagement with and support from the owners, custodians and stakeholders of the forests is critical to their conservation.

7.1 Building and maintaining expertise

Collection, storage and deployment of tree seed is a field of applied science that requires significant specialised knowledge supported by theoretical research. This knowledge is typically developed through formal tertiary (e.g. arboriculture, ecology, forestry) and in some cases postgraduate training which is then built upon by on-the-job training. Corporate knowledge held by institutions is an element critical to the successful management of seed centres and downstream operations including seed deployment. A decline in undergraduate forestry training has been a problem in Australia for over two decades (Kanowski 2006), although a range of TAFE, university undergraduate specialised courses and postgraduate options are available (https://www.forestry.org.au/forestry-education/).

Figure 12 A specialist contract seed collection crew harvesting *E. delegatensis* by climbing and delimbing in the Tea Tree Range, Ovens, Victoria [Image: Caitlin Cruikshank, DEECA]

Corporate knowledge resides in the both the public and private sectors. Examples of key private sector knowledge include seed collection carried out by climbing and aerial dispersal of seed, both of which are essential operations associated with obligate seeder collection and deployment (Figure 12). It is vital that this knowledge is retained and strengthened within and across institutions.

Generally, collection of Australian native plant seed is a fragmented industry (Broadhurst et al. 2015; Andres et al. 2024; Hancock et al. 2020), and this partially applies to collection of tree seed. Seed collectors are based in both private and government sectors. In Tasmania, there is a well-organised program of tree seed collection of certain species run by STT. This involves collection of specific species that are likely to be required in future for post-harvest and fire recovery. The silvicultural expertise and systems required to do this have been developed over may years in the government sector, involving coordination between the STT Seed Centre, planning foresters and contractors working in the forest. This system also extends to deployment, with coordination between the STT Seed Centre, forest management staff and specialised, contract aircraft services. The expertise is maintained year-round as there is always some demand for post-harvest seeding where natural regeneration has not met the prescribed standards. This had also been the case in Victoria up until 2024 when commercial logging ceased. While the specialised silvicultural expertise transferred from VicForests to DEECA, the role of the private sector seed collectors and associated silvicultural and logistic expertise is now focused on post-fire recovery, and is therefore likely to be less constant, with spikes of demand for seed and seeding immediately after fires, followed by quieter periods.

A pattern of sporadic demand for seed and reseeding is likely to make maintenance of a skilled workforce more difficult. While it may be possible to retain the silvicultural specialisations within government organisations, the highly skilled arboriculture expertise, which is typically sourced from the private sector, will be harder to maintain. If there is not a constant demand for seed, it may not be worthwhile for private operators to invest in the specialised equipment, skills and development of corporate knowledge required to operate efficiently. Generally, it has become harder in recent years to retain skilled seed harvesting contractors, as unstable demand has caused some experienced operators to leave the industry (O. Bassett pers. comm).

Knowing what species of seed are required in store, their quantities, and the seed resource available across the landscape for collection ahead of time is critical for planning future skills resource needs. Forecasting seed crops by ongoing and long-term monitoring of floral and seed development supports this planning (Bassett et al. 2024; Bassett 2011). This knowledge can also predict seasonal gaps in seed availability, to help manage human resources in quieter times by prioritising the species targeted, based on their availability.

The expertise required to collect smaller amounts of seed that might be used for *ex situ* population rescue as described in **Box 3** is maintained in various seed centres throughout Australia. Expertise in these centres is developed by activities such as support and co-research with universities including development of postgraduate students, in-house training of staff and participating in collaborations such as the ASBP. The need to train private sector and community initiatives in seed collection for revegetation and conservation was recognised in the 1990s and saw the establishment of the Florabank partnership by CSIRO, Greening Australia and the Australian National Botanic Gardens.

7.2 Stakeholder engagement

The ownership and custodianship of Australian forests and woodland is complicated and there are numerous stakeholders including various levels of government that carry out management and regulatory functions, private owners, industry, community groups and Traditional Owners. Approximately 40% or 36 million hectares of Australia’s national reserve system is covered by 53 Indigenous Protected Areas (Hill et al. 2013) and broad engagement with the communities and leadership of this land will be key to successful conservation outcomes. In Victoria, an ‘Eminent Panel for Community Engagement’ has been formed to provide guidance on forest management following the conclusion of commercial timber harvesting on public land (State of Victoria 2025).

Engagement with stakeholders is a critical step in socialising the issues connected with seed-based conservation, shaping policies that will improve conservation outcomes, such as collecting seed from reserve tenured land and practical implementation of recommended actions including revegetation and seed production.

7.3 Recommendations – training, expertise and engagement

Ensuring that there is a core of expertise that will enable Australia to collect, store and deploy seed is a priority on which the future of the obligate seeder forests depends. Historically, the skills base has come from a combination of formally trained staff dispersed across the government and private sectors in support of the native forest industry. As commercial native forestry is scaled back, it is important that the skills and knowledge needed to regenerate the forests is maintained. This will require a concerted effort and coordination across states and land tenures. Private sector engagement can only be relied upon if there is a sufficient commercial incentive that would involve a reliable source of activity each year rather than unpredictable spikes of activity.

Some actions that could retain and build essential skills include:

- Development of national training and accreditation courses and their coordination across states and land tenures to ensure skills are maintained and developed
- Development of specialist tertiary units in arboriculture with an emphasis on essential skills such as tree climbing and seed science in association with existing seed banks, linking industry with training providers
- Professional development programs for seed collectors such as Florabank training for native seed collectors (see www.anpc.asn.au/florabank/) and development of relevant programs by industry bodies such as Forestry Australia (www.forestry.org.au/)
- Industry placements and incentives for students to learn skills relevant to seed collection, banking and deployment in real time. Such programs can lead to permanent placements.

8 Is seed collection and storage the only answer?

8.1 Seed orchards, genebanks and seed stands

Collection and storage of wild tree seed is undisputably a key intervention required to guard against loss of species and populations of Australian tree species. However, seed storage is not the only way to preserve FGR. Unlike many agricultural crops which have short lifespans once germinated, most Australian forest species live from decades (e.g. 'short-lived' *Acacia* spp.) to centuries (many eucalypts) or longer (e.g. *Arthrotaxis* spp., *Lagarostrobus franklinii*). Planting trees in protected, *ex situ* conservation stands that serve as genebanks, and that are available for seed harvesting, would be effective for many forest species. These plantings can also be used to test the environmental adaptability of species and provenances – information that is required in the face of climate change (Broadhurst et al. 2017). Although the practice has not been widely adopted, establishing genebanks that double as seed production areas (SPA) could be readily integrated into revegetation projects. For threatened, and therefore protected species, such stands have a major advantage over remaining wild stands because they can be silviculturally manipulated for seed production and harvested more efficiently. **Box 4** gives an example of an *ex situ* program to conserve *E. benthamii* (Camden white gum) a Vulnerable eucalypt native to NSW. Establishment of *seed stands* – groups of wild trees that are managed *in situ* for seed production (Matthews 1964) – is an allied concept often practised in Europe and North America that could also be further explored. Seed stand creation in appropriate locations might be an efficient management technique for obligate seeder species for which large amounts of seed are required.

Engagement with public and private stakeholders on establishment of cultivated seed production areas and seed orchards is a significant opportunity. Embedding SPAs within wider revegetation or carbon sequestration plantings would be a cost-effective method of establishment. SPAs on farms, lands managed by communities and Traditional Owners could both produce seed and provide additional benefits that stands of trees provide (Figure 13). Australia's network of botanic gardens, which are coordinated through Botanic Gardens Australia and New Zealand (BGANZ), may also be an important source of germplasm and, in some cases, have capacity to support cultivated seed production through establishment of stands and/or through the considerable plant propagation skills that the gardens possess.

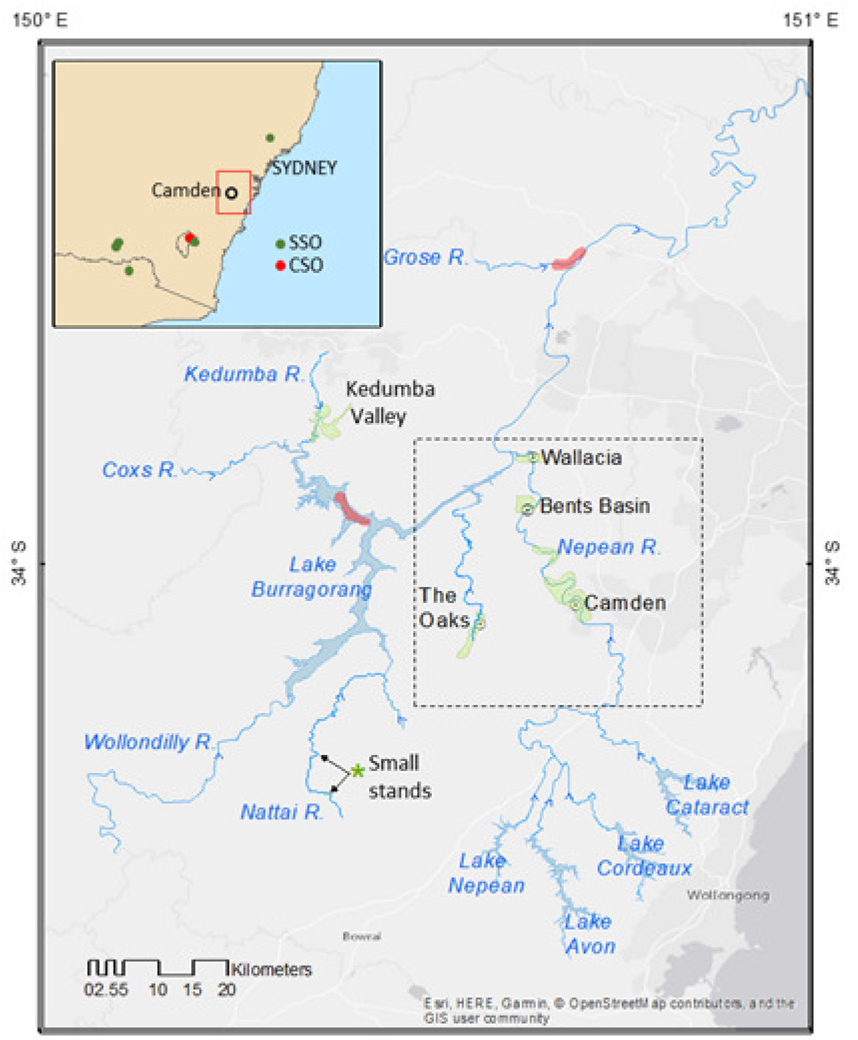
Figure 13 An *E. tricarpa* seed orchard established in partnership with the Lake Tyers Aboriginal Trust on their land in East Gippsland, Victoria. The stand serves as a genetic repository and seed source for the species

8.2 Cryopreservation and tissue culture

Cryopreservation and tissue culture are alternative techniques that can be used in place of traditional seed storage. These techniques can be effective for plants that either don't produce much or any seed and/or have high water contents (i.e. they exhibit recalcitrant seed storage behaviour) (Funnekotter et al. 2021; Sommerville et al. 2021a). Both techniques are under investigation at the Australian PlantBank (Botanic Gardens of Sydney) for conservation of rainforest species that are notoriously difficult to store as seed (Sommerville et al. 2018). The PlantBank is well equipped and staffed for these techniques. Cryopreservation has shown considerable promise in the preservation of the rare Bunya pine (*Araucaria bidwillii*) (L.K. Hardstaff in Funnekotter et al. 2021) among other rainforest species. Tissue culture (TC) is another technique that can be used to vegetatively conserve and reproduce FGR. Both the Queensland Alliance for Agriculture and Food Innovation and PlantBank NSW have facilities and conduct research on FGR that involve TC. It is particularly useful for conservation of species that produce no or very little viable seed. Only a few of Australia's seed banks/conservation centres (Australian PlantBank, Kings Park, WA; Royal Botanic Gardens, Victoria; the National Seed Bank, Canberra) have the capacity to undertake cryopreservation and/or tissue culture: there is no cryopreservation facility in Tasmania which is home to extensive temperate rainforest. Upscaling of these facilities and associated specialised staff would be required to adequately preserve a significant proportion of rainforest FGR.

Box 4 Seed orchards for *ex situ* and *in situ* species rescue – *Eucalyptus benthamii* example

Eucalyptus benthamii (Camden white gum) is a threatened (Vulnerable) species endemic to a naturally restricted range in the floodplains of the Nepean-Hawksbury River system west of Sydney. It has been impacted heavily by clearing for agriculture, construction of the Warragamba Dam for the Lake Burragorang reservoir and in recent years, urban sprawl. A natural stand comprising a few thousand trees at Kedumba is now protected and relatively intact. Only scattered trees remain in a second subpopulation along the Nepean River near Camden.



Box 4 Figure A Natural distribution of *E. benthamii* and location of CSIRO's clonal and seedling seed orchards. The Nepean population is within the dashed box. The Kedumba Valley subpopulation is at the top of Lake Burragorang. Red shaded areas denote known extinct populations. Green shaded areas denote extant populations

What has been done to conserve the species?

In collaboration with WaterNSW, the ATSC collected seed from around 50 individual Kedumba subpopulation mother trees in the 1990s. In 1994, an *ex situ* conservation stand covering over 2 ha was planted in the ACT, followed by others in the NSW Riverina. These have been managed as a seedling seed orchards (SSO) since the early 2000s. Management techniques used to maximise seed crops include thinning, pollarding and application of paclobutrazol, a plant growth regulator that promotes flowering. Several million viable seeds have been produced in the SSOs and used to establish plantations in Australia and overseas: some thousands of hectares of plantation are now estimated to exist.

The small population of only a few hundred trees along the Nepean River was shown, using molecular markers, to be distinct from the Kedumba population. Due to fragmentation and weed ingress, it produces little outcrossed seed and few seedling recruits. The ATSC commenced a program of grafting individual trees from the Nepean into a small clonal seed orchard (CSO) in the 2010s. While the grafting program is ongoing, the CSO has produced enough seed to reintroduce seedlings back into the natural habitat along the Nepean (Figure B).

Box 4 Figure B Local Landcare Coordinator Adrian O'Hara shows school students how to plant a Camden white gum seedling back into its natural range. The seedling was raised from seed produced at CSIRO's grafted CSO [Image: NSW Department of Climate Change, Energy, the Environment and Water]. Around 500 seedlings have been planted back, supplementing the fragmented natural population that has been reduced to around 300 trees due to causes including clearing, weed ingress and altered flooding regimes.

What are the advantages of seed production stands?

Seed orchards or seed production areas have several advantages for FGR conservation. Unlike many food crops, which have only a short life once planted, forest trees typically have lifespans in decades or hundreds of years. Conservation plantings can therefore be expected to last a long time if properly sited and maintained. These stands can be used to produce more seed. This removes the need to harvest seed from fragile natural populations. Seed orchards can also be treated to boost seed crops using irrigation, fertilizer and plant growth regulators. If harvesting seed from protected areas such as National Parks, reserves or threatened populations is impractical or best avoided, it makes sense to establish a seed production stand. For some tree species that have recalcitrant seed, accumulating genetic resources in a seed production stand is a more-practical option that trying to store seed. Although the opportunity has not been widely taken advantage of, integrating seed production stands with appropriate design and genetic diversity into broadscale revegetation projects would be a valuable conservation intervention.

9 Research needs

Research on Australian forest species ecology is variable. Some ecosystems are well researched and understood – for example the recently published Silviculture manual, 'Alpine ash in Victoria's Native Forests' (Bassett et al. 2024) is a comprehensive summary of decades of research on this species. A research partnership involving Greening Australia and Edith Cowan University is currently underway to improve knowledge of NSW and Victorian *E. delegatensis* provenance variation. This will better inform the need for management of seed collection and deployment based on STZ or finer-level units and potentially inform on whether and how much seed should be collected from high-value conservation areas in the reserve system. Similar research to define subpopulation structure is an outstanding need for many of Australia's widely or clinally distributed FGR as this underpins the level of sampling required to adequately represent species in conservation seed stores.

Research is needed on:

- Climate change impacts on species distributions and adaptability. The impacts of climate change on survival and growth are not completely understood. Dieback events in the last two decades indicate that some species are struggling to cope with warmer and drier conditions. Other species are apparently less susceptible. Better understanding how species adaptability influences seed collection and revegetation strategies – use of the climate adjusted provenance revegetation approach (see Section 4.2) for example. The effects of climate change on reproductive processes are also a high priority. A better understanding of how altered temperature rainfall and climate seasonality will affect reproductive process including flowering, seed set, ripening stratification and germination is required.
- Rainforest regeneration and seed biology is a challenging area that requires more research. The rainforests are particularly vulnerable to drought and fire, and rainforest species seed often stores poorly. Seed biology of many species is still being actively explored. More research into alternative conservation methods is required (see also section 9.2).
- Extend forecasting of flowering and seed availability currently undertaken in ash species in Victoria to other states and into non-ash species to assist with their future seed collection.
- Recent research in Victoria by University of Melbourne has investigated the impacts of seed collection by climbing on local ash forests in both State Forest and National Parks, showing that the impacts are minimal and are easily outweighed by the benefits (Wagner & Nitschke 2025). This research should be extended more broadly and the findings used to facilitate conservation seed collections across all tenure classes.
- Investigate the development of seed stands (seed production zones) in native forests using techniques usually applied to cultivated seed production areas including thinning, pruning and the use of plant growth regulators

10 Recommendations

The biodiversity of Australia's forests is under an undeniable threat from climate change, fragmentation, pest and disease incursion and several other interacting stressors. Seed collection and storage provide insurance against loss of our valuable FGR. The major reseeding of the ash forests in Victoria in the aftermath of the 2019-20 bushfires is an impressive, recent demonstration of the effectiveness of and need for stored seed. However, Australia's seed storage capacity is not sufficient to meet the current demand and should be grown in the face of a climate that is predicted to become hotter and more prone to drought, fire and disease incursion. The following section outlines recommendations.

10.1 Coordination

Australia has some high-quality seed collection and storage infrastructure dispersed across states and agencies, but this could be made more effective if it was better coordinated. The need for improved coordination in the revegetation sector has been previously recognised (Hancock et al. 2020). The following recommendations apply:

1. Coordination of seed collection and deployment across states and tenures for the extensive obligate seeder ash forests in Victoria, NSW and the ACT would be highly beneficial. The long-running collection and storage program active on multiple-use land in Victoria should be extended to all land tenures in these States. This would require a well-organised working group to set priorities and initialise ways of working collaboratively. Tasmania would logically participate in this group as it has a similar program of seed collection and storage on multiple-use tenure that should be expanded to other tenures.
2. The coordination described for the obligate seeder seed banks above would also be beneficial for management of other seed-based conservation. Better coordination of collection and storage across states and tenures would result in better representation of widespread taxa in the various conservation seedbanks and the opportunity for collaboration on seed collection and collection redundancy (i.e. back-ups of important seed collections).
3. National coordination would require a dedicated coordinator. Coordination as described above would require significant effort to initiate. This role would probably be best placed within an organisation with a national remit. ASBP is an existing possibility. This organisation currently has a membership and focus on *ex situ* seed collections rather than bulk seed stores. Investigation of the suitability of this, the ATSC, the National Seed Bank or, alternatively, standing up a new coordinating body, in consultation with the abovementioned working group(s) is recommended.
4. It is not currently possible to determine how well Australian FGR are represented by the various seed banks and stores. While some stores undoubtedly have good collections of a wide range of species, it would be highly beneficial to (i) undertake a stocktake across seed banks, especially of threatened species, and (ii) commission a database (or upgrade the

data and capabilities of the AVSB) that can aggregate data across collections. This is both a coordination and infrastructure priority.

10.2 Infrastructure

Australia has some very good quality seed storage infrastructure, although there are some significant gaps in seed storage capacity and the need to upgrade or replace some facilities. The abovementioned recommendation to better coordinate across states and tenures would also potentially affect the distribution and capacity of seed collection infrastructure. The following aspects are relevant:

5. Recommendations to upgrade the Victorian ash seed store network have been made previously and DEECA is currently reviewing its program and infrastructure. Increased storage capacity is required – current capacity is around 30 t and this should be increased to at least 40 t. Some facilities do not meet modern health and safety standards and require some modification to meet changed workflows following the transition from forest harvest restoration to fire recovery functionality.
6. A review of the STT seed store should be conducted to determine whether it would require expansion to cope with losses to the substantial reserve and private property tenured forests, recognising that this responsibility is not within STT's current remit.
7. Similarly, the NSW Forestry Corporation store has been designed to cope with losses on State Forest tenure but would require some expansion to cope with additional losses on the reserve system. The ACT does not have seed storage capacity: this should be created or the needs met via partnership with another seedbank in the ACT, NSW or Victoria.
8. Cryopreservation infrastructure for storage of rainforest species that cannot be conserved by seed is absent in the Northern Territory and Tasmania where monsoonal and temperate rainforests are distributed, respectively. Tissue culture and cryopreservation facilities are required in these states and/or a national facility equipped to research and cryopreserve rainforest FGR is required.

10.3 Training and expertise

9. It is likely that conservation collections will continue to involve the private sector. There needs to be a consistent work program of seed collection so that skills are retained, particularly as these relate to the high-volume, technically demanding collections required for the obligate seeder species in southeastern Australia. The Victorian native forest industry ensured that there was a baseline of coordinated regeneration work. A consistent program of work with five-to-ten-year plans would provide some certainty and incentive for seed collectors to engage in this type of work and maintain skills. This priority is complementary to priority 14 – annual variability of seed crops may exacerbate skills shortages.
10. Much of the work required for seed collection, storage and deployment is specialised and depends on a combination of formal education and training and acquisition of corporate knowledge through on-the-job experience. An expansion of seed collection and storage

activity will be contingent on growing and maintaining the workforce. To support this training opportunities are required. These may be provided by traditional paths such as postgraduate university study and/or short courses in specialised aspects offered by the seed banks themselves or peak bodies such as Forestry Australia or the ASBP. Identification and organisation of training opportunities could be organised by the National Coordinator and working group recommended in section 10.1.

10.4 Stakeholder engagement

11. Engagement with stakeholders will be a critical pathway to success. In addition to various government stakeholders who are responsible for management and regulation of forest land, engagement with industry, private landholders, communities and Traditional Owners will be essential. In addition to raising awareness of the need for seed collection, storage and deployment, there is a considerable opportunity to enlist the help of community groups to influence management policies that will improve conservation outcomes.

10.5 Research

The following research is required to underpin seed collection, banking and deployment priorities:

12. A systematic effort to identify species and populations that are under the greatest threat is required. A first step would be to assess what is already stored (see priority 4).
13. More work to define STZs and investigate whether climate-adjusted provenance selection is necessary and effective would allow prioritisation of collection and storage needs
14. Further research into species plasticity (ability to tolerate changes to the climate and environment) especially the climate impacts on flowering, seed set and other reproductive processes is required.
15. Rainforests are difficult to regenerate following drought and fire due to the high proportion of non-orthodox seeding taxa, requirements for shade and high biological diversity. Existing research into strategies for regenerating rainforest should be continued as a priority
16. Research into vulnerability to loss, and if necessary, assessment of seed requirements to recover the extensive obligate seeder eucalypt woodlands of Western Australia should be carried out.

10.6 Policy

17. Coordination of seed collection and storage activities across states and tenures will require development of policies that enable collaboration. Policy that guides re-establishment of obligate seeder ash forests in some state and land tenure combinations requires further development as a matter of urgency. A policy on seed-based recovery in the ACT and NSW reserve systems would underpin and highlight the need for seed collection, storage and deployment activities. Generally, seed collection of higher volumes of seed from National Park tenures is restricted, and this policy may need to be reconsidered so that stores of

seed for bushfire and/or other disaster recovery in these high value ecosystems can be accumulated in storage.

18. Harmonisation of threatened species classification and regulation across states would facilitate management of species with geographic ranges that span state borders. Some scientific licence requirements may be restricting activity that would help to conserve threatened species.

11 Implementation

11.1 Coordination

The recommendations made in Section 10 rely heavily on coordinated activity among stakeholders who are spread among various State and Commonwealth organisations as well as the private sector. Many of the forests are public assets and engagement with community stakeholders will be critical to successful outcomes. A key recommendation is that a dedicated coordinating body and coordinator are required. These functions will require some dedicated funding, as well as in-kind support from the stakeholders.

11.2 Governance, monitoring and evaluation

The proposed collaborative approach will require governance, monitoring and evaluation to set objectives, ensure these are being met, and that co-invested funds are being used efficiently. Assuming a working group is established, a steering committee should be formed from among its members that will set monitoring and evaluation targets. These should be laid out as a component of a collaboration strategy. This should have clearly defined long-term goals with milestones that provide a gauge of quantifiable interim achievement. The milestones set by the operational partners would be in addition to those that may be required by a funding body.

11.3 Feedback on draft and roundtable discussion

A draft of this document was circulated among stakeholders in November 2025. An online roundtable discussion was held on 10 December 2025. A list of stakeholders and roundtable participants is given in Appendix B. Stakeholders provided both written and verbal feedback on the document and discussed its content. There was broad agreement on the Recommendations given in Section 10 and support for the abovementioned implementation actions. The document has been updated to incorporate feedback received.

12 Case study: Seed Banking for the South East Forestry Hub

The SEFH region spans areas of southeastern NSW, the ACT and a small area within Victoria (Figure 14). The region includes over six million hectares of diverse forest types including alpine forests, rainforest, obligate seeder ash forest, wet and dry sclerophyll forests, open woodland and plantations. Much of the region is private property, with significant areas of National Park, including the Namadgi National Park in the ACT, sections of Kosciusko NP and several other coastal and inland parks within NSW. State Forest (multiple use forest) is another major land tenure type, with some native forest harvesting being carried out. Forest stakeholders include a diverse mix of private, government and community groups. Traditional Owners of Country include the Bidwell, Ngarigo, Yuin, Ngunawal, Ngambri, Gundungurra and Tharawal. The requirements and challenges associated with seed banking in the SEFH region, in many respects, reflect those faced more broadly in Australia.

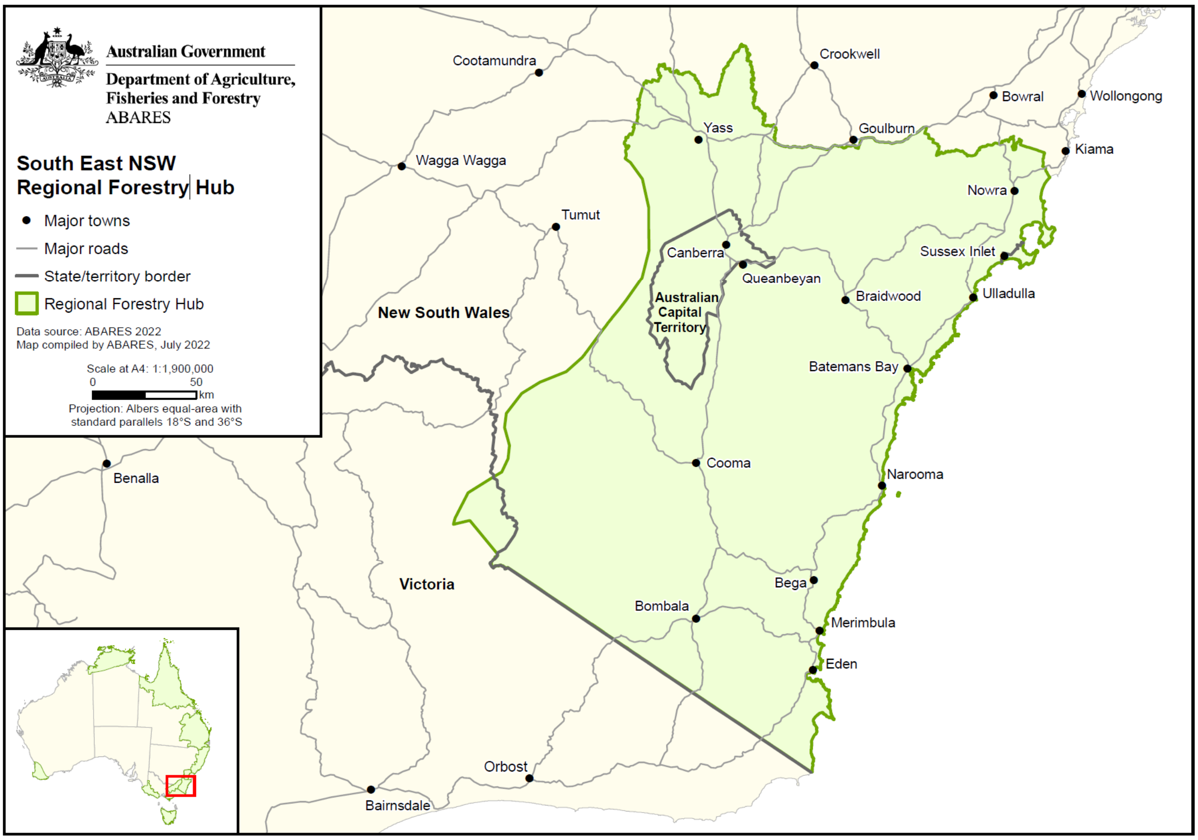


Figure 14 The SEFH region

12.1 Obligate seeder ash forests of the SEFH

The SEFH region contains extensive (around 125,000 ha), *E. delegatensis* forest (Figure 15) comprising around 70% of the NSW *E. delegatensis* extent. There is an additional 4645 ha of *E. delegatensis* within the ACT. Most of the *E. delegatensis* lies within reserve tenure. There is also a small amount in multiple use forest tenure, within the Ingebirah and Mowamba State Forests. Larger Forestry Corporation *E. delegatensis* seed zones, i.e. ash extent within multiple use forest, (see also Figure 7) occur to the west of the SEFH boundary within the Murray Forestry Hub (Bago, Bondo and Maragle State Forests).

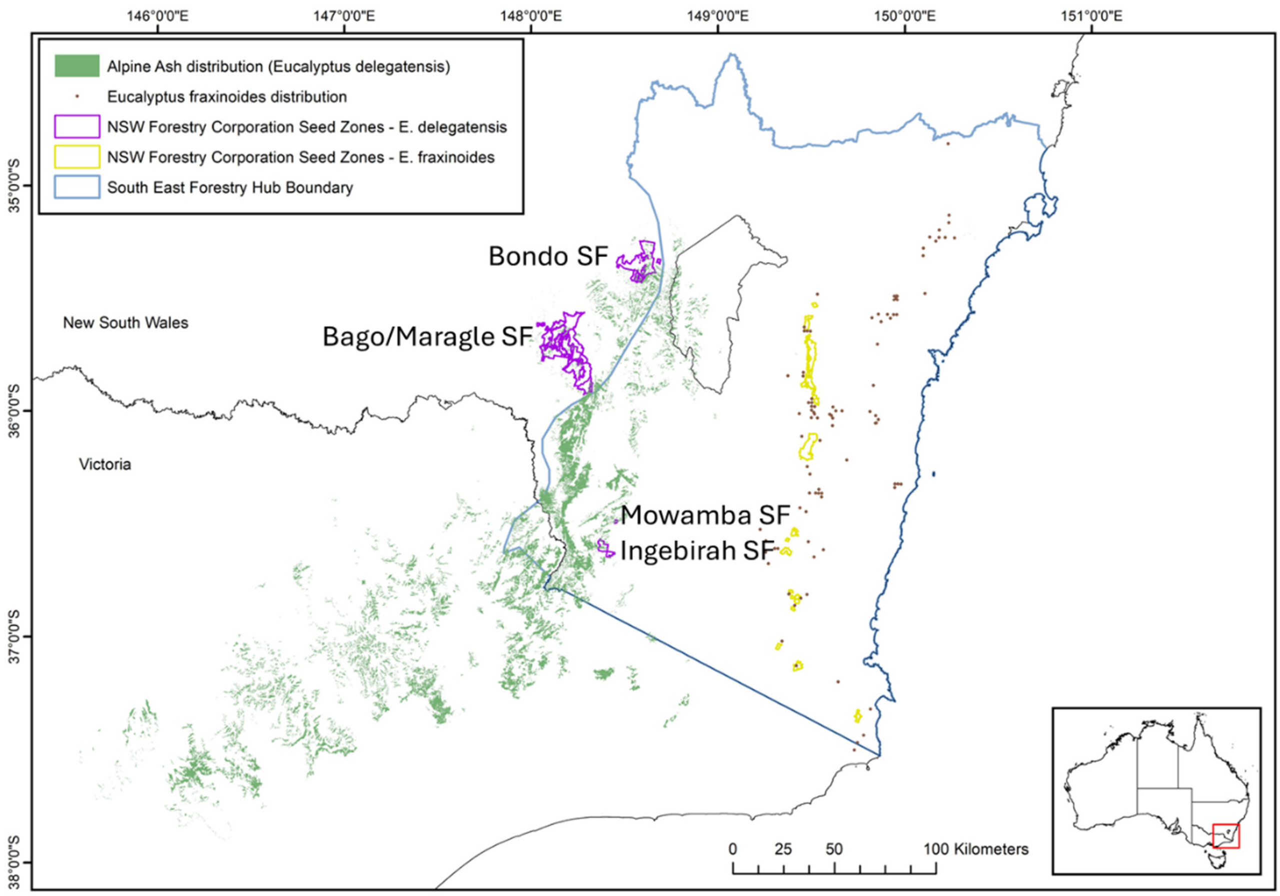


Figure 15 The extent of *E. delegatensis* and *E. fraxinoides* in NSW and Victoria and within the SEFH boundary. The *E. delegatensis* extent is based on NVIS data https://www.dcceew.gov.au/environment/environment-information-australia/national-vegetation-information-system. Forestry Corporation seed zones for both *E. delegatensis* and *E. fraxinoides* are overlain. The *E. fraxinoides* extent is indicated by points taken from the Atlas of Living Australia (www.ala.org.au).

A second, extensive obligate seeding ash species within the SEFH zone, is *E. fraxinoides*. The SEFH encompasses nearly all of the species' natural range.

Three other ash species occur in the SEFH zone. The entire range of *E. paliformis* (Wadbilliga ash), a species with a highly restricted distribution and listed as Critically Endangered (EPBC), is on the Wadbilliga Plateau, east of Cooma. The entire range of *E. stenostoma* (Jillaga ash), (Endangered, EPBC), which occurs within the catchments of the Deua and Tuross Rivers, is also within the SEFH boundary. A significant part of the uncommon, but locally abundant, *E. dendromorpha* (Budawang ash) range extends north from Braidwood. This species is not considered to be threatened.

Threatened forest types and species

The SEFH contains several forest types that are vulnerable to the threats of climate change and other stressors detailed in Section 2. Table 10 gives a summary of threatened species listed in the South East Coast Corner IBRA (Interim Biogeographic Regionalisation for Australia) Region and the Ettrema, Jervis and Monaro IBRA subregions. These IBRA regions have significant overlap with the SEFH borders and cover diverse forest types from rainforest to woodland and alpine ecosystems. In addition to the listed threatened species, there are several tree species experiencing dieback, including *E. viminalis* and *E. blakelyi* in the Monaro tablelands and the ACT and *E. pauciflora* in the alpine regions of Kosciusko and Namadgi (Section 2.3, Table 3). Local populations of these species are certainly at risk of extinction (Ross and Brack 2015) and possibly extinct.

Table 10 Summary of 88 threatened tree, shrub and mallee species found in the South East Corner, Ettrema, Jervis and Monaro IBRA region/subregions that have significant overlap with the SEFH zone

IBRA vegetation type	No of species	Examples
Mallees	6	*Acacia georgensis*; *E. imlayensis*; *E. recurva*; *Syzygium paniculatum*
Trees	9	*E. kartzoffiana*; *E. paliformis*; *E. stenostoma*
Shrubs	73	*Banksia vincentia*; *Grevillea renwickiana*; *Rhodamnia rubescens*

12.2 What seed collections are available and how much seed would be required?

Due to the diversity of threatened forest types and large area of obligate seeder ash forest in the SEFH area, substantial volumes of seed would be required to safeguard against loss. The recently established Forestry Corporation seed store at Eden holds around 800 kg of *E. delegatensis* seed and 200 kg of *E. fraxinoides* seed. This is an extremely important asset for the obligate seeder species. However, it is far from sufficient to deal with widespread losses across all tenure types in the SEFH. Referring to Table 7, totals of 6.5 and 13 tonnes of seed would be required to sow 5% and 10% of the SEFH area, respectively, at 1 kg per hectare (or half these amounts for "ecological stocking rates" *sensu* Fairman et al. (in preparation)). A proportion of this would ideally be collected from reserve tenures in the southern extent of the SEFH, as the current Forestry Corporation holdings were collected from the northern part of the *E. delegatensis* range, just outside the SEFH.

It is more difficult to fully assess the adequacy of the Forestry Corporation *E. fraxinoides* seed storage, as less is known about preferred rates of sowing, and it is challenging to ascertain the area extent outside of Forestry Corporation's management area, although Figure 2 indicates that the State Forests within the SEFH boundary overlap with much of the southern extent of the range. Provenance variation in this species has not been researched. In any case, the physical volume storage requirements will be much lower than for *E. delegatensis* and the stocks in hand may be adequate. This should be assessed in greater detail.

As outlined in Section 5.4, it is difficult to determine which forest tree species accessions reside in the conservation seed banks, and whether there is sufficient seed and genetic diversity among the collections to effectively deal with climate-related and other threats. Table 10 shows that the SEFH is home to 88 threatened species in addition to other species that are locally threatened due to dieback. While multi-provenance collections of *E. pauciflora* and *E. blakelyi* have recently been undertaken by the ATSC, some of the threatened species (e.g. *E. recurva* and *E. imlayensis*) have proven difficult to conserve because they do not produce much or any viable seed (James and McDougall 2007; Department of Environment and Climate Change (NSW) 2010). Other interventions such as vegetative propagation might be needed for these species.

The AVSB database shows that seed of all three minor ash species, *E. dendromorpha*, *E. paliformis* and *E. stenostoma,* are held in the ACT and NSW conservation seed banks, but only in small quantities suitable for tube stock production (Table 8). Ideally, some larger quantities of these species should be collected or cultivated, enabling the option of broadcast sowing following fire. As is the case for *E. fraxinoides*, while it is known with surety that these species are obligate seeders, research on reproductive maturity and effective broadcast sowing rates is required.

12.3 What resources would the SEFH require?

For the SEFH to store the obligate seeder species seed (mainly *E. delegatensis*) to cope with 5% and 10% stocking targets (see Section 5.3, Table 7), expansion of storage capacity by a factor of 6 to 13 times would be required. This would imply a similar scale of infrastructure to that found in Victoria. Assuming an approximate contract seed collection and extraction cost[2] of between $550/kg and $750/kg gives a cost between $3.5M and $4.9M for 6.5 tonnes (enough seed for 5% resowing of 5% of the estate at around 1/kg per hectare). This cost would be accrued over several years of collection. A larger storage facility would also be required – the demountable cold room (approximate cost $50,000) currently used to store the Forestry Corporation ash seed is near capacity. A larger cold store in a central location or smaller stores in various locations, potentially including the ACT, would be required to meet the bulk seed storage requirements. For this scale of operation, it would make sense to consider dedicated extraction equipment, weighing up the cost against the alternative of making use of facilities that already exist in Victoria. The approximate cost of building a suitable seed depot, based on broadly similar, recently-built private sector field facilities in South Australia and Tasmania, would be between half and one million dollars, depending on the level of built-in equipment. A larger seed store would also require more staff dedicated to organising seed collection and extraction, storage and ongoing viability testing and post-fire deployment and logistics. Forestry Corporation is actively developing staff expertise in these areas but would need to increase capacity if it were to assume wider responsibility for collecting and deploying seed to reserve tenure.

As the extents of *E. stenostoma* and *E. paliformis* are highly restricted, smaller collections of these species would be required. The *E. paliformis* range is less than 5 km^2 (Prober and Austin 1991) , and it may be practical to establish an *ex situ* SPA that captures an acceptable fraction of this Critically Endangered species' genetic diversity rather than disturb the small stands with ongoing bulk seed collections. This concept may also be valid for *E. stenostoma*. Research on reproductive dynamics of both species is required to determine how susceptible they might be to interval squeeze caused by higher fire frequency.

The SEFH is already home to two conservation-oriented seed repositories (ATSC and NSB) that have storage capacity to house smaller amounts of seed required to guard against loss of non-obligate-seeder tree species. These collections have existing accessions of the threatened species, but they do not have a mandate or collection programs that are systematically targeting collection of threatened species in the SEFH. Such collections would require some extra resources in terms of seed collection and processing to secure the required seedlots. This could be achieved as a targeted project running over several years, guided by an initial study undertaken to determine which species and populations should be prioritised for collection. These seed banks also have experience in cultivated seed production (e.g. SPAs) as well as expertise in vegetative reproductive and other advanced techniques that would be required for conservation of some of the species.

12.4 Policy and management considerations

Policies concerning the collection and deployment of seed across tenures, state and territory borders, and responsibility for collecting, maintenance and deployment of seed are major considerations affecting seed-based conservation in the SEFH. Neither the ACT nor NSW currently collect or deploy ash seed from reserve tenures in the aftermath of fires, and they do not have policies that provide guidance on these potential interventions. Multiple agencies are responsible for forests across various land tenures, and these would need to cooperate to prove a comprehensive conservation outcome. As outlined in Section 7.2, stakeholder

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[2] This section includes some approximate cost estimates and ranges of costs that were provided to CSIRO during consultation with private and government sector stakeholders.

engagement across agencies, with industry, communities and Traditional Owners would also be required as a starting point for a comprehensive seed-based conservation program.

12.5 Should the SEFH increase its seed storage capacity?

Australia requires a holistic solution to its seed-based conservation challenge, and the SEFH zone contains extensive forests and woodlands that require protection. Lands of the SEFH zone are managed by major stakeholders, who by working together, could enable policies and management interventions that would significantly improve conservation outcomes. The zone contains most of the NSW/ACT obligate seeder ash forests and a large number of threatened tree and shrub species.

Seed storage of obligate seeder and other threatened tree species in the SEFH is currently inadequate, especially for the extensive *E. delegatensis* stands on reserve tenure. There would logically be a bulk ash storage facility situated within the SEFH, with seed representative of the entire NSW/ACT section of the *E. delegatensis* range, along with *E. fraxinoides* additional and complementary to the Forest Corporation store. This might be centralised, possibly as an extension of the newly created Eden storage facility or established as two or more coordinated seed repositories. An alternative strategy would be to rely on Victoria for *E. delegatensis* seed. This is not recommended, as Victoria does not currently have sufficient capacity, and the Victorian provenances on which their collections are based may not be well adapted to the more northerly NSW part of the *E. delegatensis* range. Notwithstanding this, there should be close coordination between Victorian and NSW/ACT to provide a comprehensive conservation effort across borders.

While there is probably adequate storage capacity for other threatened tree species between the two larger conservation seed banks within the SEFH, and PlantBank at Mt Annan, a systematic program of collection and storage, complemented by other conservation interventions such as creation of SPAs, is required. The storage for *E. fraxinoides* may be adequate, although this should be confirmed, but increased seed stocks of the two threatened ash species endemic to the SEFH zone should be secured, possibly by creation of cultivated SPAs.

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Appendix A Terms of reference

Proposal for a National Review of Forest Tree Seed Collection and Storage for Post-Climate Events

Background: Recent climate events, including the catastrophic bushfires of the 2019/20 Black Summer, have highlighted the vulnerability of southeast Australia's forest ecosystems and their genetic resources. Other slower acting, but potentially devastating, phenomena such as extensive eucalypt dieback are also of grave concern. The importance of maintaining a robust seed storage system is crucial for the recovery and conservation of forest species affected by such events. Effective seed storage ensures the availability of high-quality genetic material for future restoration efforts and can mitigate the loss of biodiversity.

Advice to Government – In a drying climate, southern Australia can expect more drastic bushfires and storms which will have a major impact on our natural forests. Many eucalypts are episodic seeders, and if a major event occurs in a non-flowering year or in a non-mature forest, there is a risk of significant loss of tree populations and genetic diversity, a phenomenon placing Australia's iconic ash eucalypt forests at risk. Periods of drought interact with other stressors including changed patterns of burning, forest fragmentation, altered soil and water regimes and increased insect and pathogen attack, leading to the slow decline of numerous forest types ranging from river redgum to snow gum. The question then arises: what seed should be stored for such events to ensure successful regeneration?

Proposal: This proposal aims to lay the foundation for a comprehensive national strategy for forest tree seed storage, focusing on ensuring the availability and viability of seeds following catastrophic climate-related events like bushfires and the impacts of long-term environmental change, such as dieback. The strategy will include the assessment of current seed storage practices, identification of gaps, and recommendations for improvements to enhance the resilience of forest ecosystems.

Objectives:

- Outline the threats to forest ecosystems driven by recent environmental change Characterise the threats that Australian forests are facing from more-recent environmental changes caused by human actions including climate-change-induced severe bushfires as well as forest fragmentation, pest and disease incursion and altered flooding regimes.

- Delineate the main forest types that are in particular need of conservation interventions involving tree seed reserves and storage

- Assess Current Seed Collection and Storage Practices: Review existing seed storage facilities and methodologies across Australia.

- Assess which species are being collected in the context of which species are particularly vulnerable

- Evaluate the effectiveness and adequacy of current storage conditions and protocols in preserving seed viability and genetic diversity including provenances.

- Identify and document challenges and limitations faced by existing seed storage facilities.

Assess whether the diversity and volumes of stored seed would be sufficient to 'rescue' species and/or populations following catastrophic losses.

Establish standards for seed collection *(who can do it? and how*), handling, and storage to maximize seed longevity and viability.

Develop protocols for the assessment of seed quality and germination potential before and after storage.

Provide guidelines for the safe and effective storage of seeds from different forest species, with a focus on those most affected by recent climate events.

Assess whether cultivating seed in seed orchards or production would be an appropriate and efficient management intervention

Recommend improvements to existing storage facilities or the development of new facilities as needed.

Explore innovative technologies and practices in seed storage, including cryopreservation and other advanced methods.

Develop a national network for seed storage that facilitates collaboration and resource sharing among states and territories.

Propose the establishment of a centralized national seed bank or an enhanced national network of regional seed banks.

Ensure that the national seed bank has the capacity to store a comprehensive collection of seeds from various forest species across Australia.

Develop a coordinated approach to seed collection and storage to support recovery efforts following major climate events.

Recommend training programs for stakeholders involved in seed collection, storage, and management.

Develop resources and workshops to improve knowledge and skills related to seed storage and conservation.

1. Develop Guidelines for Best Practices:
2. Identify potential impediments to seed collecting
3. Identify whether there are impediments to access of important tree species and/or populations due to land tenure or other issues that might prevent their adequate protection. Identify what steps are needed to overcome barriers.
4. Enhance Storage Capacity and Infrastructure:
5. Implement a National Seed Bank:
6. Training and Capacity Building

Monitoring and Evaluation: Establish a framework for ongoing monitoring and evaluation of seed storage practices and the effectiveness of the national strategy.

Develop metrics and benchmarks to assess the success of seed storage initiatives and make necessary adjustments.

Outputs:

- Strategy Document: A comprehensive strategy document detailing the current state of seed storage, best practice guidelines, and recommendations for improvements.
- Documentation of proposed infrastructure enhancements required for a centralised or decentralised national seed bank capable of addressing the strategic seed requirements
- An implementation section detailing recommended practices and infrastructure improvements.
- A timeline and resource plan for executing the regional strategy.
- Stakeholder Engagement An oral presentation of findings and recommendations to key stakeholders, including government agencies, interest groups, and forestry organizations.
- Facilitation of stakeholder workshops and discussions to gather input and foster collaboration.

- **Conclusion:** A national review and enhancement of forest tree seed storage practices are essential for ensuring the resilience of Australia's forest ecosystems in the face of increasing climate events. By developing and implementing a comprehensive strategy, we can safeguard the genetic diversity of forest species and support effective recovery and conservation efforts.
- **Purpose and use of the strategy**: The strategy can be used by Regional Forestry Hubs and other stakeholders
- **Implementation plan:** Propose timing and identify steps that need to be put in place to implement the strategy
- **Delivery**: CSIRO will lead the delivery of the strategy to a consortium of Regional Forestry Hub members including the SE NSW Forestry Hub, the Tasmania Forestry Hub and others.
- **Cost**: The strategy will be jointly funded by Regional Forestry Hub (+ other stakeholder) consortium and CSIRO.
- **Timing**: Delivery of draft report by end of June 2025; report finalised end of August 2025.

Appendix B Organisations represented in the December 2025 roundtable discussion

List of roundtable participants

ACT Government

Australian Seed Bank Partnership

Botanic Gardens Australia and New Zealand

CSIRO

Department of Energy, Environment and Climate Action (Victoria)

Eurobodalla Regional Botanic Garden

Forest Solutions Pty Ltd

Forestry Corporation, NSW

Natural Resources Commission, NSW

Renewables, Climate and Future Industries Tasmania

South Coast Flora Pty Ltd.

South East Forestry Hub

Sustainable Timber Tasmania

University of Tasmania

South East Forestry Hub
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