Florabank Guidelines

Module 7

Seed Production

Paul Gibson-Roy[1], Martin F. Breed[2], Martin Driver[3], Peter Harrison[4], Susan Logie[5], Tim Zwiersen[6] and Tim Berryman[7]

[1] Kalbar Operations, Bairnsdale VIC

[2] Flinders University, SA

[3] Australian Network for Plant Conservation

[4] School of Natural Sciences & Australian Research Council Training Centre for Forest Value, University of Tasmania, TAS

[5] Local Land Services, Murray Seed Services, NSW

[6] Ecotypic, SA

[7] Cumberland Plain Seeds, NSW

How to cite these Guidelines

Commander LE (Ed.) (2021) 'Florabank Guidelines – best practice guidelines for native seed collection and use (2nd edn).' (Florabank Consortium: Australia)

How to cite this module

Gibson-Roy P, Breed MF, Driver M, Harrison P, Logie S, Zwiersen T, Berryman T (2021) Florabank Guidelines Module 7 – Seed Production. In 'Florabank Guidelines (2nd edn).' (Ed. LE Commander) (Florabank Consortium: Australia)

Disclaimer

Please be advised that the recommendations presented in this document do not necessarily represent the views of the agencies / organisations in which the authors are employed. These guidelines are subject to change. No responsibility will be taken for any actions that occur as a result of information provided in these guidelines.

Copyright

The update of the Florabank Guidelines was funded by the New South Wales Government through its Environmental Trust, as part of the Healthy Seeds Project, and administered by the Australian Network for Plant Conservation (ANPC). It was overseen by the **Healthy Seeds Consortium** consisting of representatives from the ANPC, Australian Association of Bush Regenerators, Australian Seed Bank Partnership, Centre for Australian National Biodiversity Research, Greening Australia (GA), NSW Department of Planning Industry and Environment, Royal Botanic Gardens and Domain Trust, and the Society for Ecological Restoration Australasia. The **Florabank Consortium** which will oversee implementation of the Guidelines consists of the Australian National Botanic Gardens, ANPC, CSIRO and GA.

Key points

Seed Production Areas (SPAs) are used to increase volumes of seed available from native species for restoration.

SPAs allow varying levels of control over many of the factors that impact on seed availability in the wild.

SPAs can reduce the pressure of seed collection on wild populations.

Seed production approaches vary considerably; from managed remnant populations to cultivated crop systems.

Many (but not all) species are suitable for SPAs.

Seed growers must be aware of the potential of producing maladapted or genetically biased seed, and aim to mitigate those risks.

SPA seed should be appropriately labelled to indicate it comes from a production source, and to specify the origin/location of the parent material.

SPAs require investment in time, expertise, and infrastructure which requires careful consideration of economic returns relative to set up and running costs.

Introduction

This guideline is an introduction to the establishment and use of seed production areas (SPA) for native species. It focuses on the production of seed from native plants primarily for the purpose of restoring ecological communities that have been degraded or destroyed (noting that native seed is sought and used for a variety of other reasons). It also includes guidance on circumstances where SPAs are appropriate, approaches to planning, designing, establishing, and maintaining seed production areas, as well harvesting and processing the seed they produce. While acknowledging some similarities between the systems, the guide will not focus on forestry tree seed orchards, which are described as output systems to produce genetically improved material (Sweet 1995, Funda and El-Kassaby 2012).

What is seed production?

Seed production can describe a spectrum of management approaches, intensities and system models aimed at increasing the amount, quality, and diversity of native seed for restoration (Figure 1) (Delpratt and Gibson-Roy 2015, Nevill et al. 2016, Pedrini et al. 2020, Zinnen et al. 2021). This spectrum can range from the low input management of targeted remnant populations, through to the high input management of cultivated native crops propagated and grown under agronomic or horticultural settings. Seed production is undertaken in seed production areas (SPAs) which can vary in size, complexity, in the extent of management inputs, the technology and infrastructure utilised and, in their setup and running costs. SPAs typically generate seed for use in restoration but other uses include for conservation of threatened species/genetic diversity, infrastructure projects, urban landscaping, bushfoods or bush tucker (i.e. for commercial and cultural practice), medicinal compounds (*Eucalyptus* oil), and carbon capture. Where plants are grown for installation as SPA crops, the seeds (and in some cases plant cuttings and divisions) sourced for their establishment are most often taken from one or more wild populations. While less desirable (due to risks associated with the use of material of inappropriate origin or genetic variability) for a range of reasons that might include availability and price, some founding material may come from sources such as established restorations, seed merchants, seedbanks (e.g. botanic gardens), or even cultivated vegetation (e.g. landscaping or gardens).

Current Australian seed production approaches for restoration SPAs have been in development since the early 2000s (Delpratt and Gibson-Roy 2015). These have primarily been instigated by private landholders or enterprises, NGOs and land management agencies to support a range of government funded environmental programs such as Landcare, Caring for Our Country and 20 Million Trees. They are now a small but well recognised and growing segment of the seed sector (Hancock et al. 2020). Most knowledge created over this period has been through trial and error and has been poorly documented and/or disseminated and so there is still much to be learned. The ANPC National Seed Survey (Hancock et al. 2020) characterised SPAs nationally and found that while they are considered of high importance by the broader sector for their potential to mitigate seed supply shortages, currently they are overwhelmingly small in size, have low staffing, and grow seed from a limited range of species in relatively small quantities. A later state-focussed audit of SPAs in NSW was undertaken to investigate if SPAs were contributing to a reliable, genetically appropriate native seed supply for ecological restoration (Logie 2020). It also surveyed a wide range of sector groups to identify the barriers and opportunities in establishing and maintaining SPAs. Its findings revealed issues related to limited funding, difficulties associated with succession planning, and limited access to training (Logie 2020). Given the ongoing threat to native plant communities (making wild seed sources scarcer) and the ongoing need to restore them, it is logical to expect that seed production is required to assist with seed supply for future restoration programs, but it is also clear there remains a need to better coordinate and support their development and operation (Hancock et al. 2020).

Figure 1. SPAs can produce seeds of (clockwise from left) herbs, shrubs and trees. (Photos: J. Begley)

The need for SPAs

Seed is the raw material for direct seeding and the principal material for native plant propagation. In large parts of Australia (especially arable areas), remnant populations are becoming increasingly fragmented and degraded. Threats of continued clearing, bushfires and other extreme weather events mean many plant communities (especially endangered ones) have become unreliable as sources for seed – where seed quality, high species numbers and large quantities are required (Hancock et al. 2020). Increases in seed demand for restoration creates extra pressures on these wild seed resources. The scarcity of wild seed sources can lead to increased competition and friction among seed collectors, and cause further damage to plant communities (e.g., removal of seed in quantities that compromises remnant community structure, composition and viability).

Wild collection can be affected by various abiotic and biotic factors that make seed availability unreliable in the field. For example, harvest is often hampered by natural conditions, such as excessive or unseasonable rain or heat, both of which can affect seed set, maturation, viability and yields (while extreme weather events such as bush fires and flooding can also have dramatic impacts). Collections can also be negatively impacted by seed predation (e.g. insects and fauna) as well as by human actions such as roadside slashing, burning, stock movement, and roadworks (among many others). In addition, collectors face logistical difficulties in organising and obtaining collection permits and approvals, accessing and working in remote and at times difficult sites/locations, monitoring progress towards seed set and properly timing collections (so seed is collected near or at maturity), and organising harvests. For all these reasons, restoration practitioners and collectors are increasingly considering seed production approaches as a means to more effectively and reliably generate native seed and to increase seed supply, diversity and quality (Figure 2).

An increasingly recognised area of potential for SPAs is their capacity to contribute to the conservation of threatened species (Gibson-Roy 2010, Commander et al. 2018, Swarts et al. 2018, Pedrini 2020) where seed production can be a valuable tool in providing seed or plant resources (see also the ANPC Translocation Guidelines, Chapter 3). Traditionally, threatened species translocations are undertaken using seed/cutting material or whole plants from the wild, which are later grown or held in nurseries before planting in donor sites. However, SPAs have been shown as suitable long-term locations to house and multiply threatened species. Under these conditions, crops can produce seed or cutting material over many seasons for translocation into new or existing wild populations, thus helping to manage the risk that one-off translocations from limited material might fail. This method has been used to preserve and reintroduce new individuals from otherwise locally extinct populations to new sites (Cuneo et al. 2018).

SPAs are often developed in areas where particular species or plant groups are disproportionately impacted by clearing and fragmentation. For example, in many woodland and open woodland regions of Australia where native vegetation has not been completely cleared, the degradation, depletion and loss of shrub and ground layer plant groups has resulted in a major structural change to those ecosystems (Gibson-Roy and McDonald 2014). In many of these regions, sourcing enough seed from these depleted strata to enable cost-effective, broad-scale restoration has not been possible. In such situations, the scope/need to develop SPAs that provide the large quantities of seed required from these species groups (often containing primary colonisers) remains a significant barrier to overcome before effective restoration can take place at-scale (Gibson-Roy et al. 2010).

Restoration focussed SPAs are often established to produce understorey species (Hancock et al. 2020) however there are a significant number of rare tree species located across different regions/ecosystems that warrant inclusion in SPAs. These may include those that are currently becoming rare due to human disturbance or are naturally rare and/or widely dispersed across a landscape (leading to over harvest from low numbers of individual trees). This need may be accentuated where there are added concerns about species in decline or populations exhibiting low genetic diversity (Rossetto et al. 2019).

Do I need a Seed Production Area (SPA)?

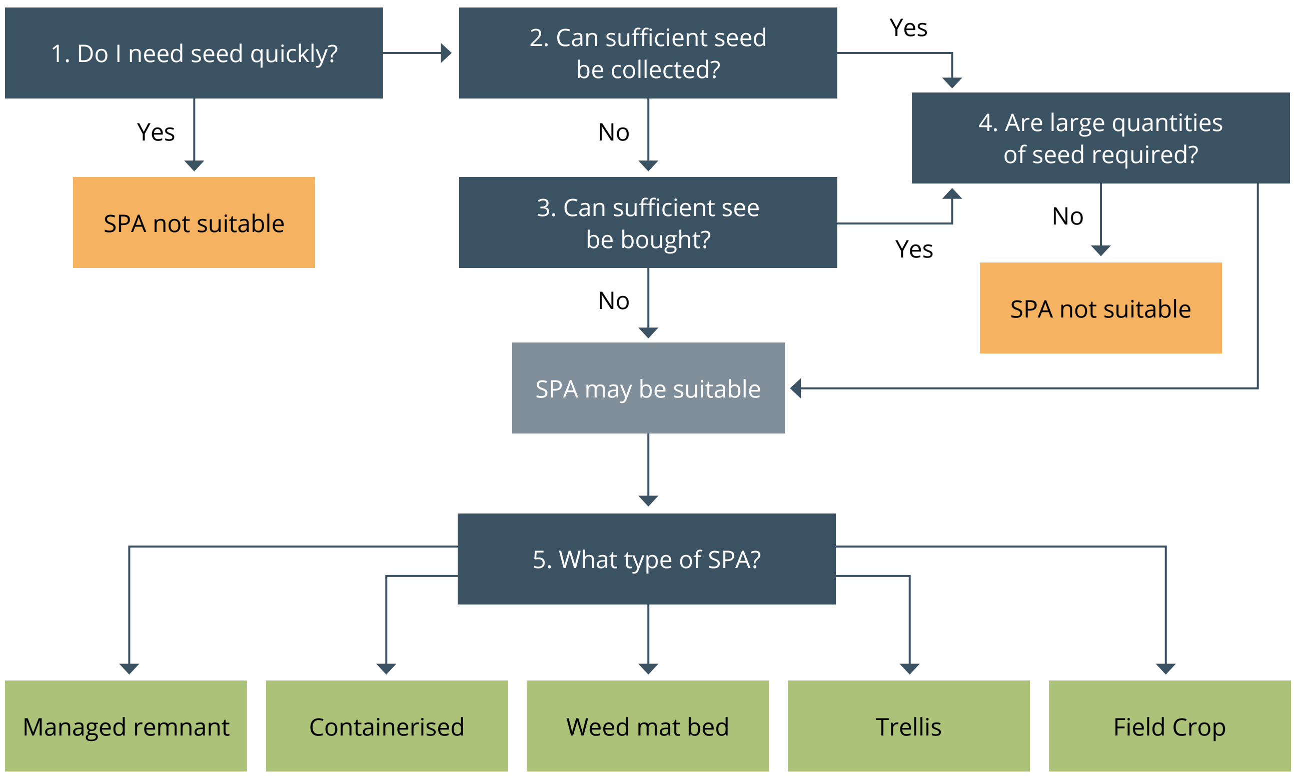

Figure 2. Decision tree for assessing the need for a SPA.

Benefits of SPAs

Over the past decade, the uptake of SPAs has increased, as has the recognition of their importance to conservation and restoration (both in Australia and globally). Many of the potential benefits include:

- SPAs utilise a range of well-established ecological/agronomic/horticultural/silviculture principles, techniques and technologies to successfully manage and/or cultivate a broad range of native species and plant types (e.g. trees, shrubs, grasses and forbs).
- SPA produced seed can be used to supplement or in some cases replace wild seed collection needs.
- SPAs have the potential to produce seed quantities required to undertake at-scale restorations in a way that small and fragmented remnant populations may not.
- The increased use of seed from SPAs has the potential to reduce the impact of repeated field collections on wild populations.
- SPAs increase the ease of seed collection by locating crop populations in known, and easy to access, manageable locations.
- Many (but not all) species are relatively easy to manage or cultivate as seed crops.
- Many (but not all) species (particularly ground layer species), can produce seed in the first to second season after planting.
- Well planned and managed SPAs can produce seed yields and quality with less yearly variation compared to wild populations.
- Improved SPA seed quality (and potentially genetic health) can give SPA progeny in restorations greater chance of success.
- SPA approaches allow varying levels of management control over many of the factors that limit plant growth and seed availability in the wild (e.g. irrigation, fertilisation, pruning, pest management).
- In some situations, SPAs can provide important ongoing floristic resources and refuge / habitat for pollinator species.
- Because they can contain large assemblages and diversity of species under managed conditions, SPAs can represent important resources and/or opportunities for research, education, training and community engagement.
- SPAs can be a valuable tool in conserving and restoring threatened species and threatened ecological communities.
- SPAs impact on the cost of collection by reducing travel time, kilometres and trip number as species are in one location. This is an important benefit as reducing harvest costs means the funds saved can contribute to the management of the SPAs.

Downsides of SPAs

While seed production offers an effective and sustainable way to generate native seed there are some downsides associated with their development, operation and use. These include:

- SPAs necessitate suitable land access and tenure (e.g. ownership, leases, agreements).
- It can take lengthy periods of time taken to establish productive crops (especially for tree species) and/or to develop SPA infrastructure, which requires a long term commitment by the grower.
- Sourcing appropriate material in a timely fashion to initiate crops (seed, cutting, divisions) may be problematic in some instances (e.g. genetic issues (ploidy, inbreeding), poor seed-set, difficult topography). This is especially so for threatened species and ecological communities (e.g. regulatory approval).
- Growing, establishing, and maintaining native seed crops requires considerable levels of knowledge and expertise.
- The cost of developing and operating a large or complex SPA can be high, requiring a sound funding base.
- In good climatic years, SPAs can be exposed financially when wild collected seed is widely available to buyers at a much lower cost than can be met under SPA systems.
- Certain seed production practices (from sourcing founding material through to crop harvest) can influence the genetic composition or characteristics of the produced seed (Nevill et al. 2016, Broadhurst et al. 2017, Perini 2020, Zinnen et al. 2021).
- Over time SPA offspring have the potential to dominate restoration populations numerically and genetically (Zinnen et al. 2021).
- SPAs require long term and highly targeted control of weed and adjacent species to maintain productivity and seed purity.

Will a SPA be viable?

Potential seed growers must reflect on a number of factors when deciding if a SPA will be a successful/viable undertaking. Typical of the sorts of factors that might influence this outcome are:

- Is there a demand for native seed (quantities and/or species diversity), over and above what can be sustainably sourced from wild collections?
- Is there a demand for seed that is of higher quality than wild collected seed?
- Is there access to suitable locations, land, facilities and technologies (or the financial resources to develop these) to establish and operate a SPA?
- Are there likely to be sufficient financial returns from seed sales above those for the development and operation of a SPA?

If the answer to all these questions is yes, then a SPA is likely to be a viable undertaking.
If the answer to one or more is no, think carefully as to whether a SPA will be practical or financially viable.

Considerations when planning a SPA

SPAs require time, energy and planning to develop and operate. Cost-wise, small simple SPAs (such as single or few species in managed paddocks or container plantings) can be relatively inexpensive to set up and maintain (i.e. $1,000+), medium sized SPAs with more complex setups, infrastructure and maintenance needs will be more so (i.e. tens of thousands) and large-scale (i.e. 20 ha – 100 ha+), multi-species, multi-system (i.e. container, weed mat and field beds) SPAs with large infrastructure (processing sheds, nurseries, storage sheds etc) and staffing requirements (e.g. 5-10 full time staff) can require in the order of millions of dollars to develop and operate. Therefore, it is critical to fully explore the likely SPA set-up and operating costs and carefully balance these against project goals (i.e. single project-based requirements) or seed sale returns (multiple project sales).

The time it will take from project inception to the production of SPA seed must be realistically considered. Even for simple SPA systems (e.g. foam boxes on weed mat and/or pallets) sourcing and constructing SPAs can take weeks or months, while complex SPAs systems can take 12-24 months to set up. As with most developments, there are typically moderate to lengthy time periods required to satisfy relevant planning and regulatory requirements (State or Local Government) and then to construct infrastructure and SPA systems and install crops. Beyond construction, sourcing both seed and plants to initiate SPA crops is always time consuming and should not be underestimated. Many actions must take place before SPAs produce seed and these include; scoping/sourcing wild founding populations, seed collection licence preparation and approvals, working within the windows of opportunity that wild seed is available in any given season, time taken for wild harvest and drying, plant propagation, stock maintenance until plants are large enough to be installed as crops, crop planting and establishment. From start to finish this long list of actions can take 12 to 24 months (or more).

Because SPAs operate on a spectrum of input and management intensities, in addition to economics and timing, seed growers must also reflect on various other impacting factors when planning or deciding what SPA-type is most suitable for their situation. The following questions might provide a further check-list to guide these considerations.

SPA type

- What SPA system is most appropriate for the species, scale and budget (wild managed, container, weed mat beds, field beds – sown or planted, trellis beds, other) (Figure 3, Figure 4)?
- Is there expertise (tradespeople/suppliers/practitioners/consultants/researchers), local or otherwise available to help design and implement the SPA?
- What is the most appropriate location/tenure for the SPA (on farm, in urban areas, near to/ adjoining or within native vegetation)?
- Are there regulatory or planning requirements for developing the SPA (licensing, building, water, power)?
- How reliable or long term is the land tenure (e.g. MOU, leased), what are the costs associated with acquiring or leasing this land and are agreements in place to safeguard access to the site in the case that ownership changes?

- What species or functional groups (and numbers) are to be grown (herbs, grasses, climbers, shrubs, trees)?
- How long might it take to get species to a productive age and how long will they remain productive?
- Are the breeding and mating systems of the target species known (i.e. selfing, outcrossing, clonal)?
- Are there pollinators/pollinator-resources within or near to the SPA?

SPA infrastructure and operation

- What types of infrastructure are required for the type and scale of SPA selected (cool rooms, cleaning sheds, machinery sheds, staff sheds/amenities, propagation houses, growing houses, standout areas, irrigation)? (Figure 5)
- What staffing levels would be required to operate the SPA (plant propagation, crop installation, crop maintenance, seed harvest, cleaning processing, packaging)?
- Are there the proper staff amenities and other work health and safety (WHS) requirements in place?
- Are adequate training and induction processes in place for staff, volunteers and visitors?
- Is there a SPA Management Plan in place that gives basic overview of SPA goals, crop types, crop systems and general design?
- What types of equipment and machinery will be needed to maintain the system (harvesters, seed cleaners, tractors, other)?
- What are the water and power requirements for this type of SPA (is a water license required, how much water is needed, what is the cost of installation and power usage)?
- Is the site adequately secure/protected (theft, herbivores, fire, flooding, wind)?
- Is there appropriate access for SPA function and operation (e.g. to/within crops, deliveries, shipping seed, maintenance)?

Figure 3. A Seed Production Area with weed mat bed and field beds. (Photo: P. Gibson-Roy)

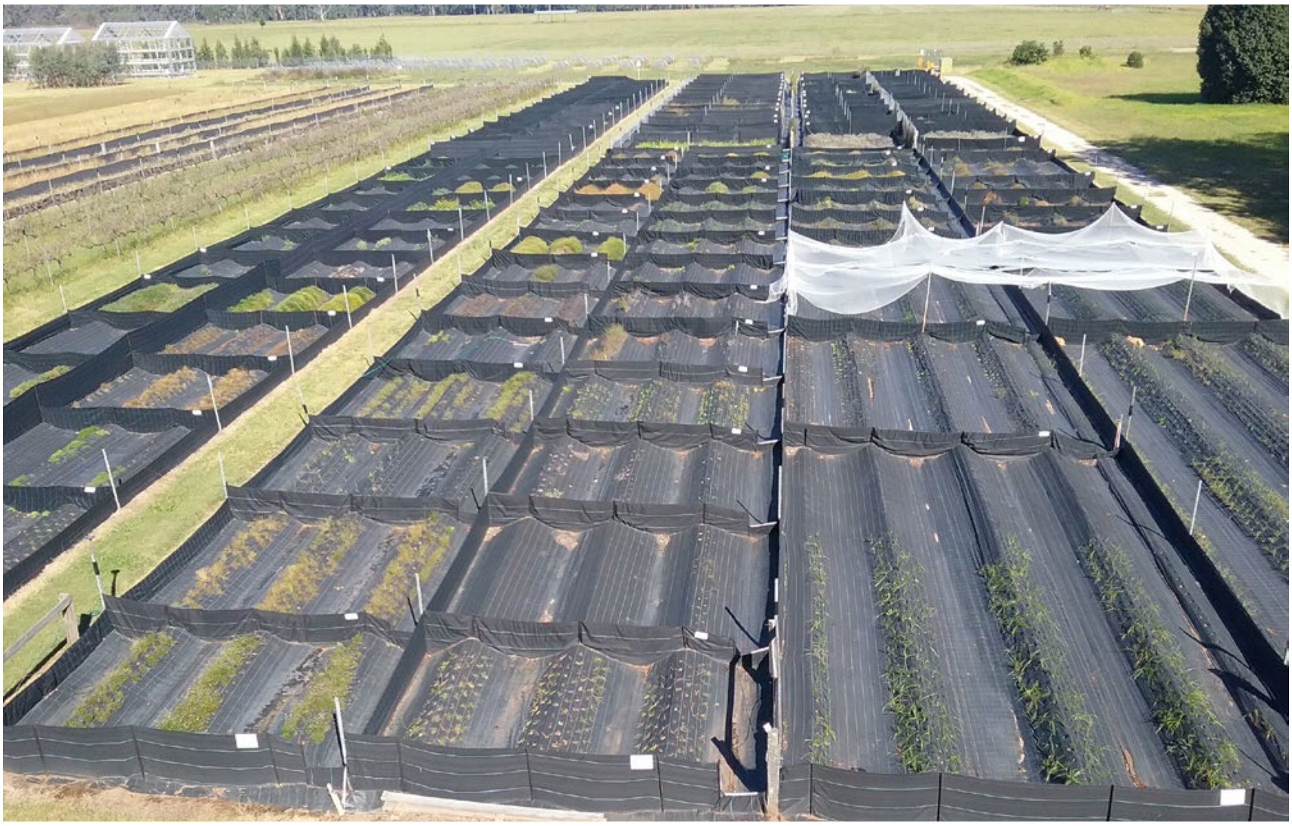

Figure 4. Overview of a weed mat bed with barriers and bird netting.

Figure 5. Infrastructure at SPAs may include a machinery storage igloo and equipment storage containers, and a seed processing shed. (Photos: P. Gibson-Roy)

Sourcing founding material

Ideally, to avoid inbreeding depression, SPA crops or managed populations should be comprised of genetically healthy individuals (i.e. not maladapted) and represented by appropriate numbers of individuals (i.e. well over 50 to thousands of individuals). To achieve such outcomes there are various collection strategies used when sourcing germplasm (seed, cuttings, divisions, or transplants) to create SPA crops or enhance remnant populations for production purposes. Broadly speaking, SPA sourcing strategies are likely to be similar to those for seed sourcing for use in restoration (see Breed 2013 and Module 5 – Seed Sourcing). Factors underpinning specific sourcing decisions are likely to reflect a mixture of idealism and pragmatism. Some questions to be considered in this regard might be:

- Is the SPA focused on producing seed for a single project (e.g. a particular Landcare group, restoration of a specific mine site) or is it producing seed for a wide range of projects (e.g. across a catchment management region or beyond)?
- Is the SPA focused on production of seed for ecological restoration (and maintaining a wide range of genetic variability from wild sources) or for functionally-focussed revegetation where specific traits may be desired (e.g. land stabilisation, hardiness to drought, water-sensitive urban design)?
- Over what geographical ranges is the seed likely to be used?
- What landscape types and under what levels of disturbance are the eventual restoration locations to be?
- Over what timeframe is it likely that SPA populations will be in production (where the more generations in production increases the likelihood of unintended selection effects on seed – Figure 7)?
- Are climate change considerations a priority for the intended use of the seed (i.e. traits suited to predicted conditions)?

Understanding the answers to these types of questions may help refine decisions around why, how, and where to source genetic material for SPAs.

If a SPA is focussed on growing native seed for ecological restoration a goal would be that once planted, this material would have sufficient genetic variability so that it is resilient and able to adapt to changing environmental conditions, increasing the likelihood it will be persistent, self-sustaining, and an overall contributor to ecological/community function at a site. For this to occur, the wild (or other) seed used to establish those crops should have captured a wide range of genetic variability (e.g. collect seed from many non-closely related individuals). Conversely, where a SPA is focussed on growing seed for low diversity functionally focussed restoration (windbreaks, roadside cover, buffer plantings, and amenity plantings) founding seed might be taken from wild plants that exhibit specific desired traits - such as drought tolerance, flower size/colour, plant height/stature. This approach is characteristic of agricultural or horticultural domestication. Likewise, if a SPA produces seed for projects with climate adjusted strategies in place (Breed et al. 2013, Williams et al. 2014, Prober et al. 2015) founding material will be taken from specific locations that match climate change projections for a restoration site or region.

Under all these scenarios, key details for founding collections should be properly recorded and communicated to the market and buyers, thereby ensuring that whoever uses/buys seed from a seed grower will be fully aware of its origin details (Figure 6).

To help maintain the desired range of genetic variability in a SPA, growers should periodically reintroduce wild-sourced material back into SPAs. Material can be reintroduced by creating new adjoining beds, by over-sowing crops, by removing older plants and replanting. This ongoing introduction of genetic material will help to guard against the aforementioned biases depleting the original range of wild traits and also ensure that new adaptive changes in source genomes enter the SPAs system. It should also be recognised that for outcrossing species, where SPA populations are genetically healthy (and where they are representative of multiple source populations) there will be opportunities for new crosses leading to modified traits. Under some circumstances it is likely that gene flow for some species will also occur between SPA populations and those located outside SPAs (i.e. within range of pollen vectors).

Figure 6. Wild seed sorting day for seed production at Euroa Arboretum Seedbank, Victoria. (Photo: J. Begley)

Selection biases – sourcing founding material and through the production cycle

Selection bias (conscious or unconscious) (Figure 7) can lead to the disproportionate capture of specific heritable plant traits (Nevill et al. 2016). It can first occur when collecting founding material (seed, cuttings, divisions, transplants) from the wild to establish SPA crops or to enhance managed populations. Thus, while growers must remain aware of the need to source genetically healthy founding material (i.e. from an appropriate number of non-closely related individuals), they must also take care to avoid biases for preferred traits such as plant stature (tufting, spreading, low-hanging) seed characters (size, number, colour), floral attributes (shape, size, colour) or due to ease of collection (e.g. more collection from easy to access locations). Biased collections representing only narrow samples of the range of heritable traits exhibited at the plant, population or species levels, can also eventuate where when collections are limited to single or few occasions over a whole seed ripening period. Unfortunately, such practice is common for many seed collections (SPA or restoration) for practical and cost reasons (i.e. it is simpler and cheaper to collect seed as a one-off occurrence rather than over several occasions spanning months and considerable travel), and where possible these practices should be modified (or detailed as such in records).

Employing protocols that help to minimise selection biases through stages in the seed production cycle are equally important (Gibson-Roy 2010, Delpratt and Gibson-Roy 2015, Pedrini 2020). To avoid some common selection practices, ask the following questions:

- Has there been appropriate mixing and sub-sampling of wild seed batches (or other material) when propagating individuals for planting or direct seeding as crops?
- Has there been any bias when choosing propagated seedlings/plants for crops (e.g. size, vigour, lack of dormancy, morphology)?
- Have certain wild traits disappeared from production populations over time due to prevailing conditions and/or practices (e.g. irrigation factors, soil types, fertilisation regimes, cultural practices)?
- Is there a bias created during seed harvest through timing, frequency, harvest method (e.g. hand, mechanical)?
- Is there a bias created during seed processing (e.g. grading large from small seed, selection based on seed colour)?
- Is there a bias created due to the type, conditions or duration of seed storage (i.e. do some genotypes perform differently under particular storage conditions?).

It is recommended that growers monitor key sets of functional traits in SPAs to track potential biases (e.g. plant morphology, seed characteristics). If there is evidence of directional changes, then selection may be occurring, and management protocols may need to be reviewed.

Some question if SPAs are able maintain the range of characteristics displayed in wild sourced founding populations (wide or narrow) through the production cycle. Whether or not sourcing and SPA managing strategies assist in achieving this outcome might be tested by genetic analysis of SPA outputs against source populations to ensure there is similar representation and relatedness (but only where detailed records on founding collections exist and production actions are well documented; e.g. Jordan et al. 2018).

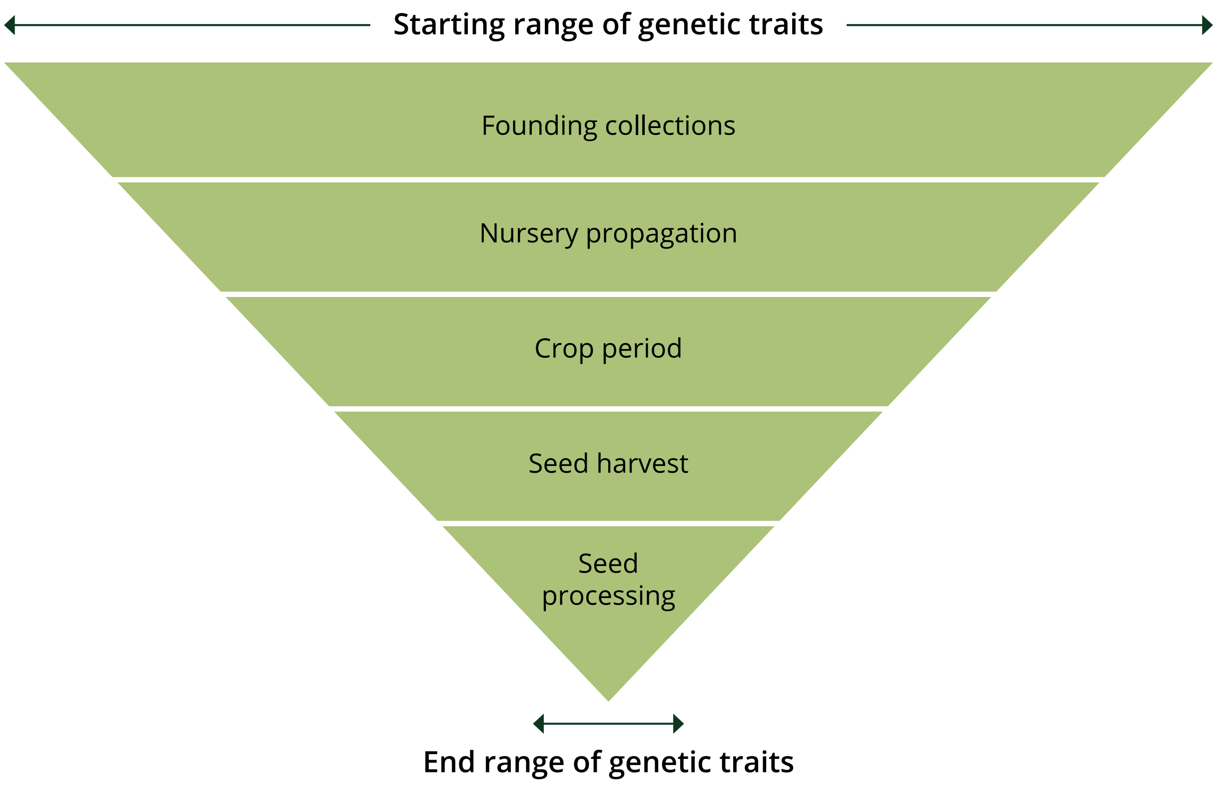

Figure 7. Cumulative selection pressure across SPA operation can reduce or skew the genetic diversity represented at the end of the SPA cycle.

Designing a SPA

There are many important points to consider when designing a SPA, some of which are related to the way plants grow and produce seed and others which are not. Many design factors relate to the way SPA species and management practices interact with the abiotic and biotic environments (Figure 8).

Layout

Decisions on how a SPA system or crop is set out should consider a range of factors which the following questions may help illustrate:

- What is the most appropriate SPA system/s for the goals and budget (e.g. managed wild population, container crops, weed mat crops, trellis crops, field crops)?
- Is the available production footprint appropriate for the number of species and plants required?
- What is the most appropriate crop/bed layout to maximise plant health (e.g. large enough so chosen plant densities do not create disease or pest issues)?

- Are the topographical and geographic features of the site appropriate for the growth of species chosen and for their management (e.g. is there appropriate light, soils)?
- Does the crop/bed layout facilitate crop management (e.g. is there access for maintaining crops and harvesting seed)?
- Is the crop/bed layout likely to facilitate genetic health (has there been appropriate sampling of founding materials so that crops are composed of non-closely related individuals, will there be opportunity for cross pollination, are there bed layout features that might lead to inadvertent selection (e.g. difficult to access areas), is there a risk of gene-pollution from nearby non-SPA populations)?
- Is there knowledge about the potential for inter-specific hybridisation between SPA species (e.g. potential for crossing) and has their position relative to one another taken this information into account and/or are there measures beyond physical separation that could restrict pollination vectors (insects/birds) through features such as buffer plantings, constructed screens and infrastructure?
- Are the beds located within efficient distances from seed handling and processing facilities?
- Does the overall design accommodate all related infrastructure requirements (walkways, tracks, roads, irrigation, seed processing areas, chemical storage, seed storage, machinery storage, staff facilities, loading areas)?

It is very useful to have up to date SPA layout maps that show the position of beds and species. These allow workers and visitors to understand where species are located. They can be also used to note and track crop management tasks and outcomes. For many reasons (including ensuring good communication of tasks within a SPA, and for education and training) it is also useful to erect signage/labels for crops noting (as a minimum) their common and scientific names (Figure 9). This signage can be done cheaply using nursery tags and permanent makers, but these tend to fade quite quickly. A better (but more expensive) long-term option are printed aluminium plates.

Figure 8. Before (left) and after (right) planting at Regent Honeyeater Seed Production Area, Benalla, Victoria. Note that the planting lines are curved or straight, according to the topography. (Photos: A. Guerin)

Figure 9. Signs at a seed production area in Utah, USA, displaying scientific and common names, and planting year. (Photo: L. Commander)

Abiotic environment

One of the first steps in SPA design is to consider the environmental and climatic conditions under which the species grows naturally. For instance, does the species grow in full sun, under a canopy, in waterlogged soil, or what soil type does it prefer? As a broad rule, it is useful to try and approximate (where possible) those conditions in the SPA. Even though many species do grow well under quite different non-natural conditions (e.g. potting mixes, under weed mat, under irrigation), matching or mimicking natural environmental conditions is a good starting point.

Biotic interactions

Many biotic interactions can take place within a SPA, some are beneficial (e.g. pollination, resource exchange), some are neutral (provision of habitat, movement corridors) some are negative (e.g. herbivory, disease). However, given that seed production is the primary aim of a SPA, it is essential to consider these biotic interactions in that light to consider if/how they assist or hinder.

Some knowledge of plant breeding systems and pollination syndromes of species in SPAs will be essential to planning and design of SPA layouts that facilitate pollination (and in some cases restrict it – see notes on hybridisation). Many plant species are full or partial out crossers (i.e. they need to breed with an unrelated individual) and where pollination is aided by a biological vector (typically insect or bird) it is in the interests of the seed grower that a suitable range of vectors and the resources for those vectors (e.g. vegetation, protection from predators, nectar rewards over extended periods) are available in the vicinity of the SPA (Smidt et al. 2020). Beyond this, crop bed layouts might block species into flowering types, colours and morphologies to provide more attractive targets for pollinators. Other species are self-fertilising (i.e. they can breed with themselves) with a non-biological vector (e.g. wind, water). Wind pollinated species might be planted facing into prevailing winds to enhance pollination outcomes (i.e. unobstructed by perimeter barriers or wind breaks).

Some plants are parasitic or semi-parasitic and need to be grown in association with a host. Most plant species also develop associations with beneficial mycorrhizal fungi and so management practices that impact negatively on these relationships (e.g. high use of synthetic fertilisers, excessive cultivation) must be balanced against those impacts.

Minimising weeds

As with many similar agricultural and horticultural enterprises, weeds are one of the most significant hurdles to overcome in operating SPAs and to producing high quality native seed. Weeds, which include exotic species and even other natives growing in SPAs (where they cross contaminate other crops or colonise from outside SPAs) can impact on crop yield through plant competition, and reduce seed quality when they contaminate a harvest. Therefore, a major consideration underpinning SPA design must be how to best minimise weed impacts, which can be done using a variety of means.

If plants are cultivated and grown in containers, then using clean (sterilised) potting media is critical. Weed matting can be used for surface covering in container and field beds. Woven polymer weed mat can significantly reduce weed emergence to that occurring only from the area associated with planting holes or gaps/joins. Good quality matting is readily available from horticultural suppliers and should last for five years or more before replacement is required. Physical barriers can also be erected around the perimeter of crops (e.g. shade cloth, polymer belt, buffer plantings) to reduce weed ingress.

Field crops are more difficult situations in which to control weeds. They can be planted at densities that help to restrict weed colonisation (but this must at times be balanced against increased risk of plant disease at very high densities) and chemical controls can also be very effective in restricting weed loads - especially where selective action of chemicals (e.g. broadleaf selective, grass selective, seedling selective), formulations (granular, sprays) or delivery methods (wick wiper, spray, cut and paint) allow the targeting of weeds. Chemical controls should always be undertaken in compliance with label directions and stipulations and using the necessary personal protective equipment.

Mechanical or physical removal of weeds can also be important in SPA settings, especially where crops are of high value (e.g. managed natural population, threatened species, difficult to grow species). Mechanical removal of the soil weed seedbank can be undertaken by removing weed seed laden topsoil prior to crop bed set up (i.e. scalping, inversion, capping). Mechanical removal of standing weeds can be undertaken by hand using a range of landscaping tools (e.g. whipper-snippers, mulchers, trimmers, lifters).

Ideally SPAs should have a detailed weed management plan in place which identify prevailing or likely weeds and outlines appropriate control measures. Weed maintenance actions/outcomes should also be tracked through SPA management monitoring systems.

Irrigation

For improved and reliable plant growth and seed production, most SPA crops can benefit from irrigation (Figure 10). When grown under benign climatic conditions, many crops produce adequate seed, but under adverse climatic conditions (i.e. very hot and/or windy) this is not the case and crops become less productive. In particular, adverse conditions affect crops growing in potting mediums in containers (which may have less capacity to hold water). Irrigation can be used to supplement rainfall and systems can be designed to suit any of the growing systems described in this guide. They can range from simple low-cost systems of the types used in home gardens to ultra-sophisticated types used in high value horticulture. Matching the watering system to the needs of the SPA species and to available budgets is therefore critical. Growers need to consider the infrastructure required to source, pump, store, treat (i.e. hard or saline water) and distribute water (effectively and judiciously). For these reasons, growers should consider the water needs of target species, water sources and access requirements (permits, licences), water storage and water distribution methods at the earliest stages of planning. This planning is often assisted by consultation with irrigation specialists.

Projected irrigation costs need to be gauged against outcomes (i.e. ease/reliability of use, plant growth, seed output, staff time). For example, in both hand watered plants growing in containers and larger crop areas irrigated using travelling irrigators, there are labour, time and water efficiency considerations (i.e. standing and holding a hose or moving irrigators all day can be costly). Nowadays, there are highly effective and automated low water use systems (i.e. drippers or low flow heads) that cut staff time requirements and which direct water to plants in the most effective and efficient manner. While these may be more expensive up front – in the long term they may represent sound investments.

The following questions might guide growers when considering irrigation needs:

- Will irrigation boost seed output?
- Is flowering or seed production impacted or promoted by irrigation?
- Does the watering requirement change between species?
- Does the watering requirement change within a species (i.e. stage of growth)?
- Is it better to keep above-ground vegetation dry to lower fungal impacts (i.e. sub surface or base watering vs overhead)?
- Does irrigation type or timing affect pollinator behaviour (i.e. sub-surface or base watering vs overhead, day vs night or morning delivery)?
- Does the watering requirement differ between seasons (i.e. summer vs winter)?
- What is the most effective and efficient irrigation system for this SPA design (e.g. sub-surface, overhead, trickle, travellers, mixture)? (Figure 11)

Figure 10. A travelling irrigator at an SPA.
(Photo: P. Gibson-Roy)

Figure 11. Raised beds with irrigation.
(Photo: P. Gibson-Roy)

Wind protection

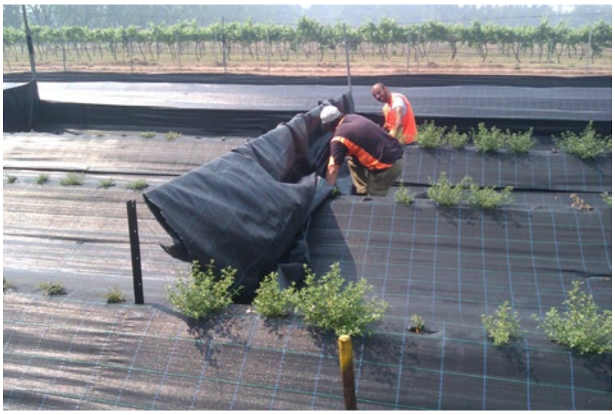

Figure 12. Barrier set up. (Photo: P. Gibson-Roy)

While some air movement in SPAs is important to reduce the risk of fungal disease or to assist with seed maturation, in many locations and at certain times of the year (e.g. spring in some locations), high winds are a factor that can negatively affect SPAs. Winds can impact on plant growth, pollinator activity, SPA infrastructure (e.g. blowing over barriers or lifting weed matting) and seed movement (i.e. blowing seed out of catchment bays or blowing in weed seed). To lessen wind impacts, it is common for growers to install windbreaks or wind barriers. These windbreaks can take the form of vegetative plantings, fences, shade-cloth, polymer barriers (Figure 12). Windbreaks are typically set up at various heights as combinations of crop bed perimeters, perimeters to block plantings and around SPAs perimeters. The cost of installing and maintaining these barriers can be significant and should be properly considered in preliminary budgets.

Herbivore protection

Species growing in SPAs can be very attractive to a range of fauna for food, harbour and for habitat. Fauna can have significant negative impacts on crop beds, plant health and seed output. In settings where SPAs are established at smaller scales using container, weed mat or small bed systems, small herbivores such as possums, birds, mice and rats can be problematic. These can be controlled by physical barriers such as tall perimeter fences. Some growers even keep small dogs (i.e. Jack Russel) as residents in SPAs to frighten off these pests. In these smaller scale settings where birds (especially parrots) become problems for SPAs (i.e. eating seed or lifting/damaging plants), overhead netting can be erected for protection of crops (at some cost).

In areas where SPA crops are growing at larger scale as managed wild populations or field crops, perimeter fencing (permanent or temporary – electric) can be used to control impacts created by large animals such as stock (cattle, sheep), feral animals (rabbits, hares, goats, pigs) or native fauna (kangaroos) (Figure 13).

Figure 13. Options from protecting plants from herbivores (clockwise from left): fencing; tree guards; netting (above); netting (below); cages. (Photos: J. Begley and P. Gibson-Roy)

Fire protection

Fire can be used as an effective tool to manage biomass in SPA crops (in some systems) or to reduce fuel loads around SPAs (Figure 14). However, because uncontrolled fire poses a considerable risk to SPAs (crops and infrastructure), it is recommended a Fire Management Plan is developed for the SPA with input and/or guidance from local fire authorities, especially if SPAs are situated in fire prone areas. A fire management strategy should seek to identify and understand risks, prioritise actions, plan responses and ensure protocols are sufficient to meet all scenarios. Fire management strategies will also guide the need for fire breaks, buffering zones, asset protection zones, firefighting equipment and supplementary resources required to protect crops, infrastructure and staff.

Figure 14. Fire used as a management tool in an SPA. (Photo: P. Gibson-Roy)

Growing systems

There are several ways in which SPA crops can be grown. Many take their cue from horticulture, agriculture, forestry, and landscaping, with adaptations being made to suit the specific growing needs of individual species. In general, outside of wild managed SPAs, there are four common systems used for growing cultivated crops in SPAs, which are; container, weed mat, trellis and field systems. These are often used in combination within a single SPA and the suitability and extent to which any or all are used is site specific and determined primarily during the planning process.

Managed populations (wild or restoration-sites)

In some instances, seed growers actively manage specific wild populations (or even restored vegetation) as seed crops (Pedrini et al. 2020). Here, management seeks to improve the production of seed above that which would have been achieved without management. It is important that characteristics of species and location are well understood (e.g. is it a natural or revegetated population, what are its ploidy characteristics, what is its genetic health, what species co-occur) before any actions occur. State regulatory and licensing requirements may apply for the management of wild populations and so all approvals for access, management actions and seed collection should be in place prior to initiation (this would also include from landowners or land managers) (see also Module 3 - Approvals, Principles and Standards for Seed Collection). The location, physical extent and features of the population should be properly recorded and any changes or alterations over time tracked (e.g. maps, images, plan drawings, monitoring). Low input actions such as the management of biomass (slashing, burning), removal of weeds (herbicides, burning, removal), restriction of herbivores (fences, barriers) can all assist in increase seed supply and quality. While more problematic under field conditions, actions such as over-sowing or infill planting to increase population size/density/vigour, fertilisation or irrigation are also possible when the value of the seed return is warranted (i.e. rare or difficult to cultivate species). It should be noted that in natural settings it is rare to find areas of mono-cultures, rather various species cohabiting. For this reason, the impacts of management (negative and positive) on co-occurring species must be well understood as should the implications that seed collections are likely to include seed from non-target species (i.e. cleaning and separation may be required).

Containers

Growing crops in containers (of various types and dimensions) can be an extremely effective way to cultivate and manage plants (Figure 15). For most herbaceous and many sub-shrub species it is possible to grow genetically appropriate numbers of plants (e.g. 50+) in relatively small spaces using containers. Plants in containers are best grown in commercial potting mixes which are designed to

Figure 15. Seed production in containers at the Euroa Arboretum grassland Seed Production Areas. (Photo: J. Begley)

provide plants with stability, adequate aeration, water retention, water movement and nutrients (supplied as fertiliser). Most potting mixes (i.e. those that meet Australian standards) are well suited to a broad range of native species. Some mixes are specifically designed for natives (often with low P) which should be trialled if species are struggling with general blends.

Options for containers are numerous (Figure 16). Foam boxes (vegetable boxes) are often used because they are easy to source, relatively cheap, light, easy to handle, insulative and hold a suitable volume of potting mix to sustain plant growth. Among their downsides are that they are relatively short lived and begin to break down in direct sunlight after a few years. There are also issues with their disposal (i.e. may not be recyclable). More permanent containers are now readily available from most nurseries where they are sold as raised growing beds (typically for vegetables or ornamentals). These are often made of corrugated iron and come in various sizes (height, length, width) and shapes (square, rectangle, circle). These containers are more expensive than foam boxes, but are much sturdier, long-lasting and visually amenable. Larger containers can also be constructed out of timber (such as treated pine or hardwood). These larger and more permanent container systems are more expensive to buy or build but offer longer term and more manageable crop beds. Deep containers are usually part filled with base material (such as coarse gravel) and the top growing layer (i.e. 300 mm) filled with potting mix - otherwise the cost of installing potting mix and replacing every few years to depths beyond 300 mm may be cost prohibitive, especially with multiple containers.

Figure 16. Examples of various raised beds and foam containers. (Photos: P. Gibson-Roy)

Weed Mat Beds

Weed mat (typically woven polymer) is used as a surface cover for growing beds into which plants (or seed) are then simply inserted at desired patterns and densities (Figure 17). Before laying the matting, soils are cleared of standing vegetation and prepared for plant installation (e.g. irrigated, tilled). This means that existing soil weed seedbanks remain in place (unless the weed seedbank has been treated beforehand by scalping, inversion, capping), allowing the weed mat to suppress or halt the growth of weeds in covered areas, however they can and will still emerge from areas where soil is exposed – such as planting holes or along joints in matting (and in some instances, through it). Therefore, the effectiveness of weed mat is often dictated by the quality of the product, the effectiveness of its installation and the competitiveness of the native crop (or weed). A further benefit of weed mat is that fallen seed can still be harvested off that surface if it is not left too long (to be predated or degraded by the prevailing conditions).

Weed mat beds can be configured in various ways from flat to raised beds, and from small to very large areas. Vertical barriers made from matting or polymer belt can be erected between different crops to minimise seed cross-contamination (and reduce wind loads). In some cases, weed mat is permeable, and in cases where it is not, water generally enters the soil via the planting hole. Black or dark coloured weed mat are the most used types, and these can reach very high temperatures. For some species, high temperatures may impact on growth or performance of plants (particularly at vulnerable life stages) or may impact on viability of the seed laying on or near the surface. These high temperatures can make working in such areas during high summer temperatures difficult and uncomfortable for people.

Because weed mat degrades over time (i.e. to the point that it will tear easily from foot traffic or wind) those surfaces will need to be renewed periodically. SPA growers should plan and budget for the cost of removal (matting & vegetation), purchasing new material, re-installing and then replanting beds on a 4 to 5-year cycle.

Figure 17. Examples of weed mat beds. (Photos: J. Begley, P. Gibson-Roy)

Trellis

Many crop species (native or other) produce greater numbers of flowers and higher seed yields when exposed to greater amounts of sunlight. Many native twiners or climbers actively grow up or over other species to seek this solar resource. Therefore, for such species, vertical trellis structures can be very effective in allowing them to climb and access sunlight. In production settings, trellises typically result in easier management and greater seed production than if they were left to ramble along ground surfaces. Trellis structures can be set up in containers, matting or field bed systems (Figure 18). Galvanised wire netting is an effective and reasonably cheap material for supporting plant growth on the trellis structure. At the ground level plants are installed directly underneath the wire. If plants are installed into weed mat surface covers and surrounded by perimeter barrier (approximately 500 mm to either side of trellis) then fallen seed can be trapped in these 'bays' on clean dry surfaces for easy harvest.

Figure 18. *Hardenbergia* sp. growing on a trellis. (Photo: J. Begley)

Field Beds

Field beds like those used in agronomic and horticultural production are also used to grow trees, shrubs, grasses and wildflowers for seed – although typically at much smaller scales than the former (note: in the USA some native SPA field crops are grown at scales of >1000 ha; Gibson-Roy 2018) (Figure 19). As with other cropping systems, field beds should have soils and growing conditions that suit the desired SPA species (see abiotic environments). For installation, beds should be well prepared before planting or seeding (i.e. weed free, weeds removed, suitable planting/seeding surface, adequate soil moisture). Where feasible/available, field beds produce seed more reliably where natural rainfall can be supplemented by irrigation. Bed layout should ensure good access for machinery, maintenance, and harvest. Where necessary, perimeter fencing or buffer vegetation or dividing barriers for protecting crops should be in place.

Weeds are a big issue in field systems and knowledge of the historic use of a site will help to inform the likely severity and nature of weed issues. For shrubs and trees growing in field beds, weeds need mainly to be managed during the early period of tree/shrub growth after which the plant becomes large enough to outcompete herbaceous weeds (or these are managed under that growth). For native grasses and wildflowers which do not 'overgrow' their weed competition, control is more problematic. Control measures include seeding/planting natives at high densities to outcompete weeds (although many herbaceous species are slower to develop than fast growing introduced weeds), herbicide controls, treating soil seedbanks (soil manipulation prior to installation, pre-emergent herbicides) or by mechanical means (e.g. slashing, burning).

Figure 19. Field beds of (left) *Melaleuca* sp. and (right) *Kennedia* sp. at Tahbilk. (Photos: J. Begley)

Crop establishment

Depending on the SPA design and system, SPA crops are established most often by planting or direct seeding (Figure 20). Some SPA managers propagate and grow their own crop material while others contract out the growing to nurseries. Whichever approach is used, when planted, seedlings should be of appropriate size and health. Ideally plants are installed at times of the year most suitable for establishment (typically autumn and spring), and where this is not possible, extra care should be taken to 'nurse' crops along (i.e. watering, shelter). For annual species in particular, planting times (or pre-planting management of stock) must be cognisant of any vernalisation requirements (e.g. period of cool temperatures) that are needed for inducing flowering. Plants and seed should always be installed/sown into friable, watered, weed free beds (of whatever type). Crops should also be installed at densities and patterns that match growth, health, maintenance and harvest requirements. Installing large plant beds can be time consuming and laborious work and this should not be underestimated in planning or budgets. Seeding can be done at field scale by mechanised seeders or as niche seeding (by hand) into containers or weed mat holes. Once installed/sown, where possible, irrigation and ongoing weed control will improve crop establishment.

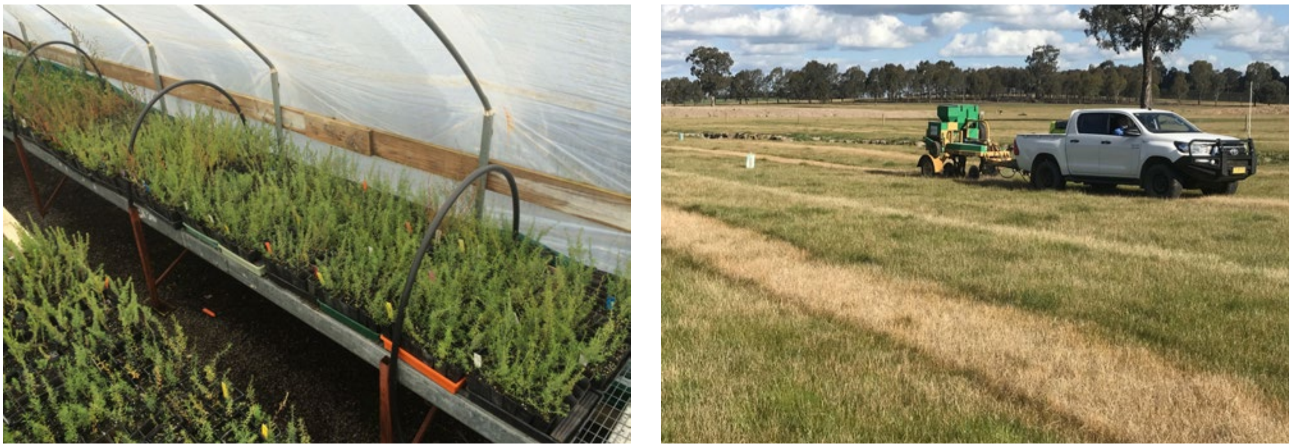

Figure 20. Seedlings to be planted in an SPA (left) and direct seeding of an SPA (right). (Photos: J. Begley)

Maintenance

SPAs require ongoing maintenance and effective and efficient crop care is essential for reliable seed production. SPA maintenance requires people, which has budgetary, Work Health and Safety, training and other implications that must be considered in SPA planning stages. SPA maintenance actions are in some ways similar to those for nursery production or horticulture except that their end goal is related to seed output (not plant or food). Actions that are standard maintenance practices which result in healthier crops, increased seed production and quality, and extended crop life include:

- Pruning to restrict height, promote flowering, promote lateral growth, or to encourage seed production at lower heights (e.g. for trees or shrubs).
- Biomass reduction (especially for herbaceous species) to increase plant vigour and promote new growth).
- Bed maintenance (e.g. for removing litter or debris, repairing damage).
- Enhancement (e.g. installing new plants or beds).

This is especially relevant in SPAs that house high numbers of species for which maintenance needs can be many and varied.

Seed Harvest

The production of seed is the prime goal of seed production and so effective, timely and efficient seed harvest is arguably one of the most critical tasks in a SPA. Growers use a range of methods and types of equipment to harvest seed (Figure 21). These may include:

- Hand harvest.
- Vacuum harvesters (Figure 22).
- Sweeping and lifting.
- Slashing/cutting and lifting.
- Slashing and baling.
- Brush harvesting.
- Combine harvesting.

Harvest approaches and equipment used will be influenced by a range of factors that include:

- Seed type and morphology (e.g. large or small, hairy, burry, fruit, capsule, other, heavy or light).
- SPA bed design and surface (e.g. container at ground level or raised, open surface (e.g. potting mix or soil) or covered surface (weed mat), trellis grown.
- SPA scale (e.g. small containers to field beds >1 ha).
- Plant densities (are crops density grown (e.g. forbs and grasses) or widely more spaced (e.g. shrubs and trees).
- Staffing levels (e.g. are there enough people to hand harvest crops).
- Budgets (i.e. is there access to harvest equipment needs).

Figure 21. Harvesting grass crops in an SPA. (Photos: P. Gibson-Roy & T. Zwiersen)

Figure 22. Vacuum harvesting. (Photo: P. Gibson-Roy)

One of the great advantages of SPAs over wild seed sources is that in SPAs there is more capacity to harvest seed over the whole ripening period (rather than as one-off collections as time and opportunity present). Also, in SPAs (as opposed to wild sources) all seed can (potentially) be harvested. Therefore, effective SPA growers develop clear planning, timelines, and protocols for collections (and track these actions over time). In most high diversity SPAs, this inevitably means balancing/juggling seed collection with maintenance and other tasks. See also Module 6 – Seed Collection.

For most species, seed is harvested at the time of full ripening or dehiscence, however, for some species (e.g. whose seeds are explosively dispersed, or where seeds ripen differentially along a stem), seeds can be harvested prior to full ripening - where fruits or pods are taken along with a suitable amount of stem. This material is then dried and stored leaving the stem to provide enough carbohydrate for the seed to continue to mature, after which pods and fruits open and release the seed (Delpratt 2007, Hall 2007). When growing on weed matting, seed can be harvested after dropping to the ground by sweeping, vacuuming or brushes (Figure 23).

Figure 23. If crops are grown on weed mat beds, seed can be allowed to drop then can be harvested by sweeping or vacuuming. (Photo: P. Gibson-Roy)

It is critical that harvested seed is held under appropriate conditions immediately following harvest to avoid compromising its quality. For most orthodox species (where seed can be dried and stored) this entails placing the harvested seed in settings of low relative humidity and good air movement (to facilitate seed drying and to restrict the growth of fungi or other rots) (Figure 24). For non-orthodox seed which do not tolerate desiccation (often tropical species) seed longevity post-harvest is very short, and so maintaining seed in stable moist conditions where seeds are not mechanically damaged by impacts or abrasions is desirable. Following harvest, SPAs need to have access to appropriate storage facilities to ensure that stored seed maintains its viability. For further information see Module 9 – Seed Drying and Storage.

Figure 24. Seed drying in purpose-built facilities. (Photos: P. Gibson-Roy)

Processing

Following harvest and drying seed needs to be processed so it is ready for storage and sale/use. Seed processing typically includes seed drying, cleaning/extraction, testing, documenting and finally storage. Processing can be followed by packaging and labelling or may happen prior to storage.

The level of cleaning required for any seed-lot will depend on a range of factors which include:

- Seed morphology (e.g. has the seed released from fruits and appendages).
- Harvest method (e.g. vacuum or sweeping off bed floor may include other material, seed hay used as seed mulch).
- Storage capacity (e.g. there is not enough room for storage of uncleaned or partly cleaned material)
- End use (e.g. to be broadcast as seed/chaff mix, required for plant propagation, required for certain types of seeding equipment).
- Buyer requirements (e.g. require seed in defined state - pure seed, seed with appendages, seed and chaff, seed mixes).

Cleaning aims to remove contaminating materials captured in the harvest process (attachments, stems, seed or other species, dirt or other inert materials). Cleaning typically separates these materials from the target species through differences in seed size, weight, shape (but seed colour, affinity for liquid and electrical properties are others - Delpratt and Gibson-Roy 2015). At its simplest, cleaning entails sieving approaches. These can be handheld sieves (which are available in a large range of sizes and dimensions) through to mechanical equipment that utilise multiples sieves. In addition to sieving, mechanised cleaners can incorporate indented screens, brushes, air flow, vibration, and capture screens. Like sieves, air flow is sometimes used on its own to separate lighter chaff from heavier seed (especially for *Acacia* species). Small-scale mechanical cleaners are effective but can relatively expensive (new). Because of their limited capacity they are not suited to processing large quantities of seed and are best suited to smaller SPA operations (and are often used in seedbanks). Larger sized agricultural-type cleaners are capable of processing larger seed volumes. These are commonplace in the US where large-scale SPAs are features of the restoration sector (Gibson-Roy 2018). These equipment types are likely to be effective for many Australian natives, but as-yet, the size of the seed market and size of Australian SPAs does not seem to justify their widespread adoption. However, many of these agricultural cleaners can be sourced second-hand for very reasonable prices and their use warrants further investigation and trialling. Alternatively, some SPA growers opt to send high value seed to agricultural contract seed cleaners. For further information, see Modules 8 – Seed Processing, 9 – Seed Drying and Storage, and 10 – Seed Quality Testing.

Testing

Testing SPA produced seed is essential to assure purchasers of seed quality characteristics. Testing with relatively simple equipment and infrastructure can be done within SPAs (e.g. nursery facilities, germination cabinet tests, microscopes, a hand lens and scalpels), although staff will need to be trained to perform and interpret such test results (although it should be noted that results may be variable due to factors such as equipment or user inaccuracy).

Otherwise, seed can be sent to external/independent seed labs for testing. Where testing is done by accredited labs (e.g. International Seed Testing Association - ISTA) this provides the most transparency for buyers. Whether testing is done internally or externally it comes with an associated cost which must be integrated in the price of the sale product. The most common types of seed testing focus on seed purity (composition by weight of; pure clean seed of the species, inert matter and seed of other species), seed viability (proportion of seeds that are alive), seed germination (proportion of seeds that germinate under test conditions) and pure live seed (% of viable seed that will germinate to a viable seedling). For further information see Modules 10 – Seed Quality Testing and 11 – Seed Germination and Dormancy.

Storage

The production of viable saleable seed is the prime goal of seed production. Therefore, effective post-harvest seed storage (and packaging) is a critical component in the operation of a SPA to maintain seed viability. In general, storing seed under dry, cool conditions with low relative humidity will prolong the life of the seed. See Module 9 – Seed Drying and Storage for information on storage conditions and duration. If SPAs store seed onsite, then they will require appropriate storage facilities. Depending on the volumes of seed to be stored these may include domestic refrigerators, refrigerated insulated shipping containers, air-conditioned cool rooms with dehumidifier, or freezers.

Labelling

As with testing, labelling SPA produced seed is also essential to clearly communicate to purchaser's various characteristics of the seed-lot (Figure 25). At a minimum, labels should include the scientific name, founding material origin/s, batch number, batch age (or harvest date), batch quality characteristics (e.g. purity, seed fill, viability), batch weight, seed cost. See Module 10 – Seed Quality Testing for a sample spreadsheet in which to record seed quality and examples of seed labels. Also, see RIAWA seed standards for native-seed focussed labelling standard and Australian Seed Federation National code of practice for labelling and marketing of seed for sowing for example of code for agronomic and horticultural seed.

Figure 25. Labels of seed from a seed production area in Utah, USA. (Photos: L. Commander)

Tracking progress

Good SPA management involves effective and ongoing audits of SPAs to identify emerging issues, guide management and provide a record of actions and outcomes. For example, having a tracking system from seed to seedling to crop plantings (Figure 26) and keeping accurate and timely records of crop progress (growth, maintenance, yields) will help seed growers to better understand the various nuances of each crop species, and help to refine and improve their management practices (which in the end will improve seed production outcomes).
Form templates are useful for tracking actions (see example Appendix 1). Hard copies are often used but hand-held electronic devices that can record all details (and images) directly to data bases are the ideal model.

Areas that might be focussed on in SPA monitoring would include:

- SPA bed layouts (e.g. set up, and over time).
- Crop installation (e.g. site prep, timing, planting details).
- Flowering and seeding (e.g. features, periods, issues) (Figure 27).
- Harvest (e.g. dates, methods, volumes).
- Maintenance actions (e.g. pruning, biomass reduction, bed renovations).
- Crop enhancement (e.g. over-sowing, plant installations, bed renovations).
- Pest or disease (e.g. identity, impact type, intensity, control actions).
- Irrigation (e.g. application, timing, period, outcomes).
- Time spent on tasks (e.g. for various actions above).

Figure 26. Tagged seedlings in the nursery for the Regent Honeyeater SPA Project. (Photo: J. Begley)

Figure 27. Flowering at the SPA in Tahbilk. (Photo: J. Begley)

Acknowledgements

Thanks to Local Land Services – Murray Seed Services for providing SPA Site Audit Form. Thanks to Alexandra Wyatt, Amelia Martyn Yenson, Ross Rapmund, Andrew Fairney and others for reviewing this module. The first edition of this module was written by Warren Mortlock and the Australian Tree Seed Centre and published by Florabank with the assistance of Bushcare – a program of the Commonwealth Government's Natural Heritage Trust.

Online resources

RIAWA seed standards
https://www.riawa.com.au/accreditation

Australian Seed Federation National Code of Practice
https://www.asf.asn.au/wp-content/uploads/2016/06/ASF_Code-of-Practice_WEB.pdf

References and further reading

Askew GR (1988) Estimation of gamete pool comparisons in clonal seed orchards. *Silvae Genetica* **37**, 5-6.

Broadhurst LM, Hopley T, Li L, Begley J (2017) A genetic assessment for seed production areas (SPAs) for restoration. *Conservation Genetics* **18**, 1257-1266. https://doi.org/10.1007/s10592-017-0977-z

Breed MF, Stead MG, Ottewell KM, Gardner MG, Lowe AJ (2013) Which provenance and where? Seed sourcing strategies for revegetation in a changing environment. *Conservation Genetics* **14**, 1-10. https://doi.org/10.1007/s10592-012-0425-z

Chaix G, Gerber S, Razafimaharo V, Vigneron P, Verhaegen D, Hamon S (2003) Gene flow estimation with microsatellites in a Malagasy seed orchard of *Eucalyptus grandis. Theoretical and Applied Genetics* **107**, 705-712.

Commander L, Auld T, Rossetto M, Ooi M, Reiter N, Swarts N, Monks L, Byrne M (2018) Pre-translocation assessment of biology and ecology. In 'Guidelines for the Translocation of Threatened Plants in Australia (3rd edn).' (Eds LE Commander, DJ Coates, L Broadhurst, CA Offord, R Makinson and M Matthes) (Australian Network for Plant Conservation: Australia).

Cuneo P, Gibson-Roy P, Fifield G, Broadhurst L, Berryman T, Crawford A, Freudenberger D (2018) Restoring grassy woodland diversity through direct seeding: Insights from six 'best-practice' case studies in southern Australia, *Ecological Management & Restoration* 19(2), 124-135.

Delpratt CJ (2007) The influence of harvest method on seed yield, seed size and germination capacity of *Bulbine bulbosa*. In 'Seeds: biology development and ecology'. (Eds SW Adkins, S Ashmore, SC Navie) (CAB International: Oxfordshire).

Delpratt J, Gibson-Roy P (2015) Sourcing seed for grassland restoration. In 'Land of the Sweeping Plains, Managing and Restoring the Grasslands of South-eastern Australia'. (Eds N Williams, A Marshall, J Morgan) pp. 285-330. (CSIRO Publishing: Clayton, Victoria).

Funda T, El-Kassaby A (2012) Seed orchard genetics. *Plant Science Reviews* 2012, 21-43.

Gibson-Roy P, Moore G, Delpratt J, Gardner J (2010). Expanding horizons for herbaceous ecosystem restoration: The Grassy Groundcover Restoration Project. *Ecological Management and Restoration* 11, 176-186. https://doi.org/10.1111/j.1442-8903.2010.00547.x

Gibson-Roy P (2010). Reconstructing new populations of the endangered *Rutidosis leptorrhynchoides* (Button Wrinklewort) at two sites in south-western Victoria. *Australasian Plant Conservation* 19, 13-14.

Gibson-Roy P, McDonald T (2014). Reconstructing grassy understories in south-eastern Australia: Interview with Paul Gibson-Roy. *Ecological Management and Restoration* 15, 111–122. https://doi.org/10.1111/emr.12116

Hall M (2007) Effect of early harvest on Chocolate Lily seed yield. Grassy Groundcover Gazette, August 2007. https://www.greeningaustralia.org.au/wp-content/uploads/2017/11/3_Grassy_Groundcover_Gazette_Aug_2007.pdf.

Hancock N, Gibson-Roy P, Driver M, Broadhurst L (2020) The Australian Native Seed Sector Survey Report. (Australian Network for Plant Conservation: Canberra).

Jordan R, Breed M, Prober S, Miller A, Hoffmann A (2019) How well do revegetation plantings capture genetic diversity? *Biology Letters* 15(10), 20190460.

Logie S (2020) Audit of Seed Production Areas in NSW Report. (Australian Network for Plant Conservation: Canberra).

Nevill PG, Tomlinson S, Elliott CP, Espeland EK, Dixon KW, Merritt DJ (2016) Seed production areas for the global restoration challenge. *Ecology and Evolution* 6(20), 7490-7497.

Pedrini S, Gibson-Roy P, Trivedi C, Gálvez-Ramírez C, Hardwick K, Shaw N, Frischie S, Laverack G, Dixon KW (2020) Collection and production of native seeds for ecological restoration. *Restoration Ecology*. 28(S3), S228-S238. https://doi.org/10.1111/rec.13190

Prober S, Byrne M, McLean E, Steane D, Potts B, Vaillancourt R, Stock W (2015) Climate-adjusted provenancing: a strategy for climate-resilient ecological restoration. *Frontiers in Ecology and Evolution* 3(65).

Rossetto M, Bragg J, Kilian A, McPherson H. van der Merwe M, Wilson PD (2020) Restore and Renew: a genomics-era framework for species provenance delimitation. *Restoration Ecology* 27(3), 538-548.

Swarts N, Hancock N, Beaumont L, Moore JL, Van Leeuwen S, Byrne M, 2018, Selecting source and recipient sites, In 'Guidelines for the Translocation of Threatened Plants in Australia (3rd edn).' (Eds LE Commander, DJ Coates, L Broadhurst, CA Offord, R Makinson and M Matthes) (Australian Network for Plant Conservation: Australia).

Schmidt LA, Gilpin AM, Cook JM, Rymer P, Gibson-Roy P, Craigie S, Power SA (2020). Restoration of native wildflower patches in agronomic settings for diverse and healthy pollinator populations. *Australasian Plant Conservation* 28, 17-19.

Sweet GB (1995) Seed orchards in development. *Tree Physiology*. 15, 527-530.

Williams AV, Nevill PG, Krauss SL (2014) Next generation restoration genetics: applications and opportunities. *Trends in Plant Science* 19(8), 529-537.

Zinnen J, Broadhurst LM, Gibson-Roy P, Jones T, Matthews JW (2021) Seed production areas are crucial to conservation outcomes: Benefits and risks of an emerging restoration tool. *Biodiversity and Conservation* 30, 1233-1256.

Appendix 1. Sample Audit Sheet used by Murray Local Land Services.

SPA Site Audit Sheet

Land Owner: (if different from SPA owner) ______________________________

SPA Owner: ______________________________

Email: ______________________________

Address: ______________________________

Staff member: ______________________________

Date: ______________________________

On site

- Accurately GPS site boundary using handheld GPS
- Draw mud map with layout of each species block planted within SPA area
- Take photos of the site showing the condition of the plants and any management issues that need attention.
- Identify species present. If unsure take samples and photos of the plants showing form, leaf and flower if possible. Bring back to the office for identification.

Overall quality of SPA:

Does the SPA have easy access? (circle) **YES** **NO**

Comments: ______________________________

____

Fencing: Is the site fenced? **YES** **NO**

What is the condition of the fence? (circle) **Repair** **Replacement** **Good** **Condition**

Comments: ______________________________

____

Weeds: What is the weed burden like on the site (% of groundcover that is weeds this includes exotic grass species eg rye grass): (circle)

Few Weeds 0-10% **Some Weeds 10-25%** **Weedy 15-50%** **Very Weedy >50%**

Main Weeds Species: (if you are not sure take photos) ______________________________

____

Are the weeds impacting on the health of the SPA plants? **YES** **NO**

Are the weeds creating an issue for access and collection? **YES** **NO**

Pest Animals: Are there evidence of pest animals impacting on the site? **YES** **NO**

If **YES** what pests are present? (circle) **Rabbits** **Hares** **Kangaroos** **Other**

How much impact are the animals having? (circle) **Minimal** **Moderate** **Significant**

Any other comments on the health and condition of the site: ______________________________

____

____

What management actions would you recommend be undertaken to improve the health and productivity of the SPA?

- ☐ Weed Spraying
- ☐ Manual removal of weeds
- ☐ Slashing
- ☐ Repair fence
- ☐ Replace fencing
- ☐ Control rabbits or hares
- ☐ Replanting/ Replace plants
- ☐ Pruning existing plants
- ☐ Remove existing plants
- ☐ Other: ....
- ☐ Other:..
- ☐ Other:..

Is the landholder interested in continuing the SPA? (circle) **YES** **NO**

Is the landholder willing to sign a new Memorandum of Understanding for the SPA which outlines the roles and responsibilities in maintaining the SPA and providing seed to Murray LLS? **YES** **NO**

Is the SPA producing seed? **YES** **NO**

Does the SPA have the potential to produce seed in the future? **YES** **NO**

What level of investment do you feel would be needed to make the SPA productive?

Minimal **Moderate** **High**

SPA Audit

Species:

- Please fill in a column for each plant species present on the site.
- If unknown list them as Species 1, Species 2 etc and label photos with numbers for plant ID.

Species:	**E.g. *A. montana***						
Planted area							
Approx. area (m x m)	20x50						
Number of rows	4						
Spacing btw. rows (m)	4						
Plant spacing in row (m)	3						
Species							
Number plants surviving	25						
Are they healthy?	No						
Are there gaps in rows?	Yes						
Any sign of disease e.g. galls	Yes						
Number needing pruning	All						
Other notes:							
Other notes:							

Species suitable for pruning:
Acacia acinacea, A. montana, A. brachybotrya, Dodonea viscosa cuneata, Dodonea viscosa angustissima, Senna spp, Bursaria spinosa

MAP:

Please hand draw SPA and mark where you have taken your GPS points on the map.

Mark the planting lines and where each species is located on the site and mark gates.