Florabank Guidelines

Module 14

Direct Seeding

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Key points

- Direct seeding can be implemented by either placing seed below (e.g. drill seeding) or broadcasting it onto the soil surface.
- Seeding must be well planned in terms of methods, species selection, timing, preparation, resources and approaches.
- Site preparation is likley to be required to ensure good soil:seed contact and minimise weed competition.
- Various types of seeding machinery are available, which type may depend on project specifics, site characteristics, target species, user experience and available budgets.
- Calculating seeding rates is critical to ensure that seed is used efficiently, and that the targets, goals, and objectives of the project are met.
- Seeding rates should be based on parameters which include seed lot characteristics, estimated seedling survival and plant density goals.
- Post-seeding management is required for a number of reasons including to control threats such as weeds or herbivores.
- Monitoring is required to track and report the outcomes, enable adaptive management, and indicate when intervention (e.g. additional seeding) is required.
- As with all other activities, record keeping is critical to keep track of what was done, report on outcomes and learn for the future.

Introduction

This guideline is an introduction to the use of direct seeding for ecological restoration, rehabilitation, revegetation, reforestation, regeneration or other purposes, such as erosion or salinity control, fodder crops, riparian belts, shelter belts, seed production areas (SPAs), woodlots or amenity areas. These various restorative activities are hereafter termed restoration for simplicity. It focuses on the preparation and installation of native seed (wild or SPA sourced) into field sites across a range of vegetation types and landscape conditions. Guidance on practical approaches to planning, site preparation, seeding machinery, seeding approaches, and post-seeding site management is also included.

What is direct seeding?

Direct seeding is the practice of introducing a seed (and potentially other components such as fertilisers, inoculants or growth amendments) directly to the soil (at or below surface level) rather than installing a nursery grown plant at a later stage (for information on nursery propagation, Module 13 – Nursery Propagation of Tubestock). Direct seeding has been common practice in agriculture, and while the planting of nursery-grown tubestock has been general practice in Australia in restoration (and forestry), direct seeding is now being increasingly used, firstly for shrubs and trees (Buchanan 1989, Bird et al. 1991, Dalton 1993, Koch et al. 1994, Corr 2003) and more recently for grasses and forbs (Gibson-Roy et al. 2010, Gibson-Roy and Delpratt 2015).

Neither direct seeding nor tubestock planting are suitable for all situations and both approaches have positive and negative aspects (Table 1). In some situations, both direct seeding and tubestock planting are warranted. For instance, species diversity of seeded areas can be enhanced further by tubestock planting of species not suited to direct seeding (e.g. insufficient supply of seeds, rare species, clonal material, have low in situ germination or establishment from seed, or transplants). Likewise, planted areas can be enhanced through strategic direct seeding (e.g. native grasses between linear tree/shrub plantings). See also Module 13 – Nursery Propagation of Tubestock.

Table 1. Positive and negatives associated with direct seeding and planting approaches.

	Planting tubestock	Direct seeding
Positives	Plants of many species are relatively easily produced under nursery conditions. Desired numbers of target species can be sourced. Creates an immediate visual impact. Planting days are well suited to volunteer and community building events. Uses less seed compared with direct seeding. Easy to match micro-habitat with appropriate species. Cuttings can be used to generate tubestock when seed is unavailable.	Large numbers of species and plants can be established per unit area compared to tubestock plantings. Well suited to large scale restoration. Can also be undertaken at very small scales. Is comparatively cheaper to undertake than tubestock plantings. Sown seed responds to environmental cues and germinate when conditions are suitable. A broad range of genetic diversity can be introduced to restoration locations. Potential for natural selection to site conditions (i.e. where large range of genetic traits are present in sown seed). A range of seeding technologies are available. Broadcast seeding tends to result in a more naturalistic distribution of established plants. Direct seeding can be delayed when conditions are unsuitable. Direct seeding is less labour intensive than planting tubestock. Seeded plants tend to develop deeper and stronger roots than planted tubestock, which improves their establishment and survival. Seed (if banked) can be deployed rapidly to take advantage of what may be transient and rare opportune conditions, or respond to extreme events.
Negatives	Plant propagation costs for large scale restoration is prohibitive. Planting costs for large scale restoration is prohibitive. The growth and survival of some plant types (e.g. trees) can be negatively impacted by poor nursery practice. Post-planting survival is often low under harsh/ erratic or poorly managed conditions. Nursery grown plants are often targets for herbivory (and so may need greater levels of post-installation monitoring and management). Tubestock plantings are often susceptible to damage from vandalism, inadvertent events (e.g. road works, stock movements) and environmental factors (e.g. fire or flood). Transporting tubestock can be expensive and logistically difficult and plants must be kept alive between delivery and installation. Tubestock plantings are difficult to delay because stock cannot be held for extended periods. Tubestock takes time to produce and cannot usually be generated at short notice.	Native seed from a broad range of species is not easily sourced in large quantities. Seed of some native species is very expensive (although for some it is not). Uncleaned native seed of some species (i.e. grasses and forbs) are well not suited to use in conventional agricultural seeders (although see Module 12 – Seed Enhancement Technologies). Because of the wide range of variation in shape, size and structure, some native seed is difficult to handle or work with. Germination or establishment may not be consistent or reliable due to genetic diversity and seed dormancy. Cleaning native seed can be very expensive and time consuming. Depending on species and site, seeds can take a long time to emerge and establish (e.g. 12-18 months). Post-emergence weed control can be problematic (especially for seed mixes) due to difficulty of distinguishing weeds from natives. Requires specialised machinery and skilled operators. May have low reliability and can waste scarce seed resources.

Should I use direct seeding?

While direct seeding presents opportunities to effectively establish native vegetation, there are many factors that affect its success (Shaw et al. 2020). These include having access to appropriate machinery, limitations on seed (e.g. quality, quantity and diversity), prevailing site conditions (e.g. topography, soil type and obstacles), the effectiveness of site preparation (weed competition, seed bed quality) and prevailing weather conditions (Figure 1). Therefore, restoration practitioners must make decisions regarding what restoration approach to adopt early in the planning process.

Some questions that help to determine whether direct seeding is appropriate are:

- Is the scale of this project too large for planting tubestock?
- Is project location too inhospitable, or distant for planting tubestock?
- Is the project focused on ground layer species requiring a high target plant density per unit area (e.g. forbs and grasses)?
- Is seed available for the required species in the necessary quantity?
- Are there machinery and operators with necessary experience and knowledge available for this work?

If answers to these questions are mostly 'yes', then this indicates that direct seeding is the approach that best suits the situation, goals and budgets. Then the next logical step is to plan which seeding approaches are most suitable.

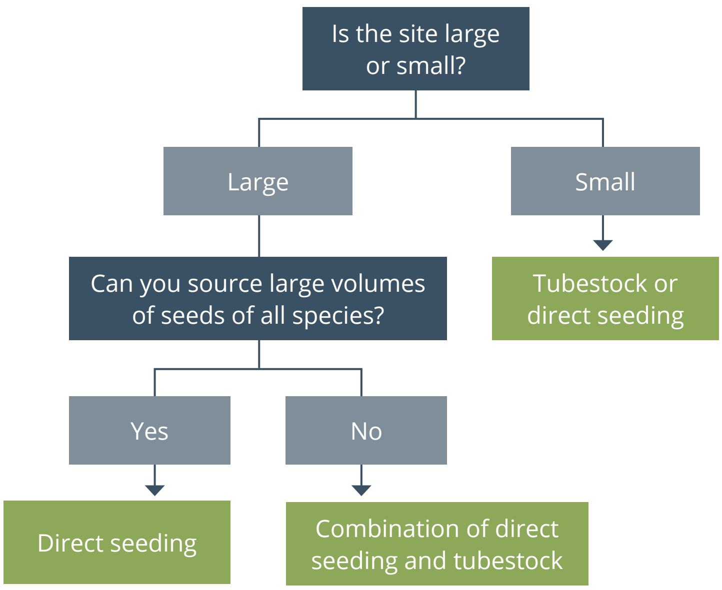

Figure 1. Simple decision tree for deciding between tubestock or direct seeding or both.

Direct seeding approaches

Direct seeding can be broadly allocated into two categories:

1. Seed burial.
2. Seed broadcast (i.e. surface sowing).

Niche Seeding

Niche seeding aims to place (and cover) seed in specific locations (often at precise soil depths) within a landscape. Niche seeding can entail sowing single or multiple species over small to large scales, using hand or various forms of mechanised seeders (from very low to high technology). The choice of approach (non-mechanised or mechanised) is often dependent on the scale of the seeding project, the availability of equipment and expertise, the type/s of seed being used and project budgets.

Many mechanised niche seeders used for native restoration are variations of the influential Rodden tree seeder developed in the 1980s by Rod Burford and Dennis Daniell from Primary Industries South Australia. Mainstream agricultural and horticultural niche seeders are also used for seeding native vegetation (from small hobby-farm implements to large scale agricultural air-seeders).

Broadcast seeding

Broadcast seeding describes the application of seed (single or multiple species) onto the ground surface. Broadcast seeding can be undertaken by hand or using low to high levels of mechanisation (e.g. hand-held devices, mechanised curtain or zone spreaders, aerial technologies (plane, helicopter, drone) or hydro-mulch applicators). Seed can be broadcast in a pure cleaned state (as might be the case for niche seeding) or in various uncleaned states (from seed mixed with chaff through to seed hay). Depending on the approach, seed might be broadcast over a non-prepared surface, onto cultivated soils, onto soils with incisions, indents, or onto soils where vegetation has been restricted, opened-up or removed (e.g. slashing and raking, burning or scalping). Some approaches use rollers to lightly press seed into the ground surface to achieve better seed to soil contact.

Depending on the broadcast method, whether or not the pre-broadcast ground surface has been prepared and what state the seed is in at the time of broadcast (e.g. cleaned, with attachments intact, treated, with coatings or other types of amendments), the sown seed will settle into niches with varying levels of success. Generally speaking, seed that is broadcast onto friable soils (e.g. recently ploughed, harrowed (Figure 2), raked (Figure 3), ripped (Figure 4), indented or slotted) will have improved opportunity for germination and establishment (particularly when this is followed by rollers, rakes or light mulches), whereas seed that is broadcast onto non-friable surfaces will have an increased likelihood of poor soil-to-seed contact, and/or loss to predation, wind and surface water flows.

Figure 2. A harrow that is used for soil preparation in the USA. (Photo: L. Commander)

Figure 3. Raking can be used to break the surface crust, especially at a small scale, to improve soil to seed contact and prevent seed removal by wind or water. (Photos: L. Commander)

Considerations that might guide decisions on what are the most appropriate seeding approaches would include:

- What plant types and species are to be used (tree, shrub, grass, forb, other)?
- What quantities and seed state will be used?
- Are the plant or seed types better suited to burial or broadcast seeding approaches (e.g. trees for niche seeders)?
- What is the scale of the restoration (small can be hand seeding, large must be mechanised seeding)?
- What is the topography of the restoration site (e.g. flat, steep, rocky)?
- What seeding patterns are required (e.g. none – prefer naturalistic, linear for woodlots, SPA beds or shelter belts)?
- Is there native vegetation already present or resilience at the site (seed or bud banks)?
- Are the types of equipment available to match these goals?
- Do practitioners have sufficient skill or experience?

Planning direct seeding

Appropriate planning is critical to ensure seeding projects stand a good likelihood of success (Standards Reference Group SERA 2016). Planning helps practitioners to better understand the many factors that underpin seeding programs. Critical decisions on a range of factors that impact on seeding outcomes are made during the planning period. These would include:

- What is the expected outcome for this work (e.g. small wind break, large scale ecological restoration, bush enhancement, establishing SPA crops, roadside amenity plantings, development offsets)?
- What resources are required to achieve these goals (e.g. budgets, staffing levels, collection licences, training levels, appropriate timelines, seed supplies, equipment types and availability, development approvals, infrastructure)?
- What are the target species, and can their seed be sourced in sufficient quantity, quality and appropriate price in the desired timeframe (e.g. wild collection, seedbanks, seed suppliers, seed production)?
- What is the weed load of the site, both as living plants and in the soil seedbank?
- What are the characteristics of the land to be restored (e.g. farmland, roadside, reserves, flat, steep, hilly, vegetated, unvegetated, etc)?
- Are there limiting factors such as black cracking clays, high nitrogen and phosphorus levels, high weed loads or hydrophobic soils?
- What actions are required to prepare the site for seeding (e.g. weed control, ripping, scalping, fallowing)?
- What is the most suitable seeding approach and equipment type (e.g. hand seeding, drill seeders, broadcast seeders, hydro seeders).
- What will the seed mix composition and seeding rates be?
- What is the most appropriate timing for key actions (e.g. seed collection, site preparation, seeding)?
- Who will be responsible for any ongoing maintenance (e.g. weed control, herbivore control, maintaining fencing, watering/irrigation)?
- What is the maintenance plan for the site following seeding (e.g. actions required, labour and equipment needs, timing, duration, budgets).
- What is the monitoring plan (e.g. monitoring emergence and/or survival; monthly, seasonally or annually; presence/absence or density; individual plants, plots or transects)?
- What systems can be put in place to accurately keep records of costs, actions, and outcomes (e.g. what was done, what happened)? See also Module 4 – Record Keeping.
- Who will be responsible for reporting outcomes?

Identifying and assessing seeding sites

To better inform planning, site-specific and regional factors should be considered before a direct seeding project is undertaken.

Site-specific factors might include:

- Land use history (e.g. cropping, grazing, resource extraction, stock route, urban).
- Fire history (and access to fight fires).
- Site accessibility (e.g. permissions, biosecurity risks (i.e. inadvertent spread of pathogens or weeds), health and safety considerations).
- Site topography/terrain (e.g. gradients, evenness, obstructions, wetness).
- Soil characteristics (e.g. structure, pH, nutrient status, organic content, permeability, compaction, soil crust).
- Soil degradation (e.g. salinity, acidification, erosion, contamination, hydrocarbons).
- Degree of vegetation degradation (e.g. degraded, mostly cleared, completely cleared, cleared and landform reconstructed).
- Weed characteristics (e.g. dominant or sub-dominant, noxious, agronomic, environmental).
- The condition and composition of adjacent vegetation (e.g. fire risk, harbour for pests, seed rain resource or risk).
- Herbivore risks (e.g. invertebrates, livestock, introduced feral animals, native marsupials, native birds).
- Site security (e.g. adequate fencing, functional gates, proper locks, risk of vandalism).

Regional considerations might include:

- Availability, type, number, proximity, and quality of native remnant communities (e.g. reference and seed harvest potential).
- General climatic characteristics (e.g. average rainfall, rainfall seasonality, winds, absolute minimum temperatures, extreme temperatures).
- Access to restoration infrastructure, expertise, and capacity.
- Prevailing public attitudes (e.g. interest or opposition).

Site preparation

No matter what the scale of a seeding project, appropriate site preparation is a key prerequisite for success. At the point of sowing, seeds require appropriate soil-to-seed contact, oxygen, water, temperatures and amounts of light or dark (provided by planting depth), plus reduced competition from other plants (weeds or other). These requirements essentially translate to weed free or weed reduced conditions, moist friable soils, niches or opportunities for burial to suitable depths and appropriate soil temperatures.

Some soils present challenges for direct seeding. These include those that are highly compacted, cracking, water repellent or saline, or have low water holding capacity or contain excessive or too few nutrients. Techniques used to improve unsuitable soil conditions may include:

- Soil removal (using various forms of scalping equipment).
  - To reduce weed loads, reduce excessive nutrient loads (especially phosphorus).
- Soil inversion (e.g. periodic 8-10 years) (with scalpers or mouldboard ploughs).
  - To bury weed loads, nutrients, water repellent topsoils.
- Soil capping or topsoil spreading (e.g. placing of transported soil strata onto soil surface).
  - To create more suitable nutrient and/or seedbank settings.
- Addition of amendments (e.g. composts, mulches, gypsum, lime, green manure).
  - To improve soil structure, increase soil carbon, increase biological activity, reduce dispersion, alter pH, increase water retention.
- Soil mounding (e.g. using m-profiler).
  - To create a raised M-shaped mound to sow seed into. This configuration captures rain which then drains into mound taking away or diluting salts.
- Soil imprinting (e.g. Clary 1989, Dobrowolski 2019).
  - Machine imprinting of soil surfaces with geometric patterns to hold seed and moisture.
- Nutrient stripping (e.g. cut and bale, saw dust, sugar, species drawdown (e.g. *Themeda triandra*), fire, grazing).
  - To reduce nutrient loads – especially nitrogen.
- Ripping – deep (Figure 4) or shallow.
  - Deep ripping can be used to fracture heavy, compacted or hard pan soils to enhance moisture penetration and promote early root growth (Dalton 1993). Shallow ripping can be used on contours to slow water movement down slope and to increase moisture penetration into soils.
- Cultivation – to create niches for seeds and moisture accumulation.
- Use of residual herbicides.
  - Keeps weeds suppressed while sown plants mature. Seed is sown into an area where residual herbicide has been removed mechanically (Carr et al. 2009).

In highly modified arable landscapes, high residual weed seed and bud loads often dominate emergent native species at seeding sites. Therefore, practitioners should also aim to suppress weeds for a period in which sown natives can germinate, emerge, establish and become competitive. Poor weed control is one of the main reasons for failure of direct seeding projects in some environments (Carr et al. 2009). Weeds can be treated by a variety of means including chemical herbicide controls (e.g. pre- or post-emergent, selective, knockdown, systemic, residual (note chemical controls should always be undertaken after investigation of suitability and in compliance with label directions and stipulations), mechanical controls (e.g. tilling, hoeing, scalping, inversion, capping) or by other means (e.g. fire, steam, grazing, biological agents, soil covering agents). At some sites pre-seeding treatment or control of herbivores may also be necessary (e.g. red legged earth mites). Ideally, weed control should start at least 12 months prior to seeding in order to control the whole annual suite of weeds.

Figure 4. Large machinery such as graders can be used for site preparation including ripping, especially at mine sites and quarries. (Photo: L. Commander)

Seeding Machinery

There are many types of seeding machinery available (Figure 5, Figure 6, Figure 7). The type selected may depend on a range of factors including the scale of the sowing project, the type of species being sown (trees, shrubs, grasses, forbs), topography of the seeding area (e.g. flat, rocky, hilly), soil types (e.g. heavy, light, dry, cracking, wet, moist, saline), the volumes of seed involved, the type and state of seed to be used (e.g. shape, size, weight, cleaned, chaff, mixture, coated/ pelletised), timelines and available budgets. Seeding can be undertaken using tractor-drawn seeders (e.g. pasture drill seeders, air grain seeders, slot seeders and super spreaders), 4WD-drawn machines (e.g. purpose built native seeders such as Rodden seeders, Burford seeders, Hamilton seeders, Rippa seeders, Egadd Seeder, ComVeg Seeder and Eco seeders) (Figure 5; Figure 6) and even large bulldozer-drawn seeders (e.g. at mine sites or quarries).

Figure 5. Burford type seeder. (Photo: P. Gibson-Roy)

Figure 6. Moose seeder, which is an update of the Burford seeder. (Photo: T. Zwierson)

Figure 7. Various types of agronomic air-seeders able to apply cleaned and flowable seed at large scales. (Photos: D. Carr)

In recent years, some trialling of large agricultural seeders has been undertaken (e.g. John Deere MaxEmerge planters), the benefit of which is the scale of the restoration achieved in short time periods (whereas small-scale native seeders might only sow 5-15 ha per day). However, such seeders require pure cleaned and coated seed, which increases project costs and complexity (i.e. coating brings the seeds up to standard sizes to pass through plates with set hole sizes, see Module 12 – Seed Enhancement Technologies). Modified versions of smaller scale off-the-shelf agricultural and horticultural seeders are becoming more widely used for restoration of native ground layer communities (and many are also successful with trees and shrubs). These machines often combine niche and broadcast approaches (e.g. seed is broadcast as a 'curtain' rather than through tubes, onto prepared soils) (Figure 8). Purpose-built grassland seeders are also available from North America which have been successfully used under Australian conditions for species that have similar seed-types to prairie species (e.g. Great Plains Seeder, Grassland Seeder or Truax Seeder).

Figure 8. Grassland seeder developed by Paul Gibson-Roy for the Grassy Groundcover Restoration Project. It utilises a First Products Aerovator from the USA. The seed box is modified to deliver as many species as wanted. It does not use drill lines but drops seed as a curtain. (Photo: P. Gibson-Roy)

Many seeders have standard gravity fed seed boxes (where seed can bridge before exit points and fail to pass onto the ground) while others employ live seed boxes (with internal agitation that aims to eliminate bridging) or fan-forced seed flow (which eliminates the need for bulking agents). Seeders must be properly calibrated to ensure the flow of seed per unit area or linear distance matches the target seeding rate (as determined in project planning stages). The method of calibration will to some degree depend on the type of equipment being used, but broadly speaking it involves quantifying the amount of seed passing through a machine over a set time period and distance or manipulating a seed drive-wheel for defined number of revolutions (determined by the drive wheel circumference) to ensure that the quantity of seed per unit area or linear meter is as planned.

Malfunctioning seeding machinery can disrupt projects to varying degrees, with minor setbacks impacting activities on a day and major mechanical failures potentially delaying seeding for extended periods. For these reasons, practitioners should always ensure equipment is properly serviced and maintained. Machinery should also be properly stored and re-checked for operation and safety prior to use. Machine operators must also remain vigilant for minor issues while seeding, which if not recognised or left unchecked, can have deleterious impacts on outcomes (such as improper plant densities or vegetation composition).

Some issues that might arise while seeding are:

- Drill line blockages (e.g. stalks or appendages blocking seed flow, moist seed clogging lines).
- Seed bridging (i.e. wedging near to the exit point of a seed box creating an air cavity with no seed passing through the exit points).
- Inconsistent seed flow (e.g. large seed falling while small seed is held back or vice versa, more seed moving through a down-slope section of a seeder when working across slopes).
- Intermittent seed flow (e.g. when seeding over bumpy or cracking terrain).
- Excessive or insufficient seed flow (e.g. machines are not properly calibrated to desired flow rates).

Drill Seeders

Agricultural drill seeders normally operate on tilled soils free of vegetation, to place and cover seed in linear rows at precise spacings and soil depths. Native tree and shrub drill seeders do likewise, but often use offset discs to scalp a discrete band of soil in advance of the drill line. This action removes weed seedbanks and unwanted nutrients from the drill zone and in some instances helps harvest and direct water to the seeded zone. They then deposit seed into a defined sowing line niche along the cleared band at set spacings (e.g. 200-300 mm). Native seeders also typically utilise multiple seed hoppers for seed of different sizes and weights which direct flows through separate drill-lines set at differing soil depths. These native tree and shrub seeders generally sow in the range of 10 to 15 ha per day, or for linear seeding at 30 km to 45 km per day (i.e. 1:3 ratio of ha to km).

Drill seeders typically use cleaned seed which flows through drill tubes (by gravity or air-forced) and into the soil, before being press-wheeled to achieve good seed-to-soil contact (Figure 9; Figure 10). Some drill seeders are designed to address the issue of saline or waterlogged conditions by mounding or raising soil profiles to ensure sown seed lays above deleterious conditions. Examples of mounding seeders include Kimseeders and Kerang SaltBush Seeders (both of which were designed for seeding saltbushes (i.e. *Atriplex*, *Rhagodia*, *Einadia*, *Enchylaena*, *Chenopodium*) but which have also been used successfully with other species).

Figure 9. Row seeder. (Photo: P. Gibson-Roy)

Figure 10. A seeder used in Utah, USA. (Photo: L. Commander)

Slot seeders

Slot seeding is similar to drill seeding except it does not require cultivation and is typically used in no- or low-till farming. Slot seeders are primarily used to rejuvenate agricultural pastures but could be equally effective for native pastures (although this is yet to be tested widely). Slot seeding is generally undertaken in open or reduced swards where the sowing mechanism deposits seed into thin slots cut into in the soil surface. Where weeds dominate a site, a discrete band of herbicide can be sprayed in advance of the seeding line.

Hydro seeding/mulching

Hydro-seeding or hydro-mulching involves adding seed and/or other amendments (such as cellulose fibre, straw, paper, bitumen and/or binding agents) to an aqueous solution which is distributed in a quick and uniform manner (Figure 11) (Buchanan 1989). It is also very effective for spreading seeds of different sizes and/or shapes. There is also a possible hydro-priming effect that could result in faster and more synchronous germination for some species (see Module 12 – Seed Enhancement Technologies). This technique is most often used in situations where terrains are steep, hostile, or inaccessible for conventional seeding equipment (e.g. steep slopes on mine sites, road or rail batters) and a number of commercial operators offer these services. The approach entails blending the seed and other materials (such as binding agents, nutrients, organic mulches) with water in a purpose-built mixing tank. The aqueous solution is then sprayed over the soil surface by an operator using a high-pressure pump. Ideally, roughened soil surfaces provide suitable niches for the seed to germinate. When applied without mulches, seed is typically held in place using binding agents that form thin short-term crusts. When applied as hydro-mulches or with artificial crusts these components form more stable surface that protects seed, keep soils stable, retains moisture, reduces erosion (i.e. from wind and water) and retards weed emergence (Dobrowolski 2019).

Another form of seeding which uses hydro-approaches is 'glob' seeding (Buchanan 1989). Here seed is combined with bulking, amendments and coagulating agents and ejected by high pressure jets to specific hard to reach locations.

Figure 11. Hydroseeding of road batters. (Photos: P. Gibson-Roy)

Aerial seeding

Aerial seeding involves spreading seed (and amendments) from an aerial device (e.g. plane, helicopter, drone) (Novikov and Ersson 2019). It is typically used in highly inaccessible landscapes (such as alpine forests following timber removal), to regenerate remote or degraded sites after impacting events (e.g. logging, overgrazing or bushfires) or to reseed vegetation onto steep re-formed landscapes (e.g. post-mined landforms). Aerial seeding is less commonly used in arable landscapes where conventional seeding is possible. A clear advantage of aerial seeding is that large areas in often inaccessible or inhospitable locations can be sown in a short amount of time. Its drawbacks include that the fate of broadcast seed is often unpredictable, especially given a large proportion of seed may fall onto inappropriate settings and perish or be predated resulting in low establishment outcomes (especially when distributed from plane or helicopter).

In recent years, drone technology has developed to a stage where specialised machines can deposit small 'packets' of seed into specific locations across sites with high degrees of accuracy (creating new opportunities in mining rehabilitation and forestry) although battery life limitations currently inhibits 'airtime' and hence the potential of this approach (Elliott 2016). Drone technology is likely to develop further, and detailed monitoring and reporting of outcomes from such projects will help to increase confidence in its potential.

Figure 12. A hand seeder. (Photo: D. Carr)

Hand seeding

Direct seeding can be undertaken at small scales where seed is broadcast across an area by hand or using a handheld spreader (of the type sold in garden centres) or is sown into specific niches (i.e. openings) by hand or handheld implements (e.g. spot sowing). For the best results, these methods involve distributing seed in combination with bulking agents (e.g. sand, vermiculite) onto moist, weed free and cultivated surfaces. Techniques that create discrete canopy openings for seeding within vegetated areas involve herbicide spraying or mechanical interventions (e.g. rakes or hoes). These methods are generally low cost and ideal for establishing plants at small scales over a range of terrains.

Seed Balls

Small amounts of seed can be mixed with clay and rolled into balls which, once dry, can be dropped (e.g. helicopter, drone) or thrown (by hand or mechanically) into difficult to access sites where people or machinery cannot operate (such as rocky substrates, steep batters, hillsides or mountainous settings and some riparian zones) (Naizy 2020). The balls are constructed using dry powdered clay mixed with compost or seed-raising mix at 50:50 ratio and cleaned seeds. Water is added to create a damp mix which can be rolled into balls around 1cm in diameter. Additives such as inoculants, fertiliser and predator-deterrents (such as chilli powder) can also be incorporated to improve establishment success. When lodged in the landscape, and exposed to sufficient rainfall, the re-wetted balls become the substrate for seedling germination and emergence. See also Module 12 – Seed Enhancement Technologies.

Seed hay / Brush matting

Seed which is held in the canopy can also be distributed as seed hay (e.g. herbaceous species – Cole and Lunt 2005) or brush matting (e.g. woody species – Buchanan 1989, Dobrowolski 2019). While this approach is typically a lower cost method, it is sometimes less (although not always) successful than mechanised seeding in terms of plant establishment. The seed hay method is typically focussed on herbaceous species, such as native grasses and forbs, which are suited to cutting/slashing and baling (usually using agronomic equipment) at or near to near to the time of ripening. Brush matting entails the use of cut or mulched branches from woody/shrubby material which has intact fruits containing seeds held within. Seed hay and brush matting can be hand or mechanically spread onto pre-prepared (i.e. cultivated, roughed-up or furrowed) or unprepared surfaces. Following spreading, the suspended seed is released and falls to the ground surface over time while the vegetative material it is held within offers the benefits of a mulch through continued retention of moisture, protection for the seed and/or seedlings (e.g. wind, herbivores), and surface stabilisation (erosion – wind, water, hooves).

With good planning and on-ground protocols in place, salvaged brush or mulched matting from pre-mining cleared vegetation can be an important seed resource. Where this represents material from high diversity and quality native vegetation which is subsequently spread on to furrowed (i.e. to retain/protect seed and trap moisture) and stabilised (e.g. tackifiers, crusts) post-mine surfaces this approach has been shown as highly effective in restoring post-mine landforms (DFAT 2016, Dobrowolski 2019).

For seed hay, drying the cut material to appropriate moisture levels prior to baling, and then again of bales prior to long-term storage, is critical to prevent losses to fungi. Thus, the timing of these actions is often a skill that experienced farm contractors acquire over years, and for this reason it is often wise to consult or engage specialists. Indicators of improper drying and fungal activity include sweet aromas, heat within the material, and powdery fungal coverings.

Agricultural balers are suited to processing large amounts of material, and so native sites should be large enough to warrant their use. This equipment is also best suited to open and even surfaces (e.g. with ample room to manoeuvre). They commonly produce large round bales that can be rolled out onto bare cultivated sites as seed mulches, although their size and weight makes them difficult to manoeuvre or move from site to site without proper equipment. Alternatively, small-scale mechanised balers (i.e. towed by ride-on mowers) which cut small rectangular bales that are very easy to manage are available from the hobby farming sector. Because they are suited to working on smaller areas, they are potentially very suitable for cutting seed hay in small grasslands and grassy woodlands.

A drawback of the seed hay technique (and to a much lesser extent brush matting) is that the seed of undesirable (or non-target) species will almost certainly be harvested within the bales and introduced onto a new site. Therefore, the composition and extent of weeds at the cutting site should be carefully assessed to determine if the harvest is justified. In some situations, a relatively light weed load may be tolerated.

Machinery for post-mined landscapes

Depending on the type (e.g. open cut or strip mining) and scale of the mine operation, post-mining landscapes can be highly variable. Landscapes range from very steep (angle of repose) waste rock landforms to flat, even surfaces (e.g. strip-mining mineral sands). Nevertheless, because of the scale and the expectations for success (i.e. by regulators, communities, mine operators), direct seeding is an important component of restoration at mine sites. In some settings topsoil containing native seed or bud banks are also available for respreading onto reformed landforms to take advantage of natural regeneration (Figure 13), but this often entails further seed addition by over-sowing (e.g. additional species or cover crops) which is typically undertaken prior to rains to minimise compaction of the spread topsoil. In large scale mine operations, seeding on steep slopes is often undertaken using bulldozer-mounted seeders. Bulldozers are ideal in these conditions because they can safely handle steep slopes (20% to 25% grades), while ripping ground surfaces and integrating soil layers as they proceed. They are also able to traverse over rock and/or timber mulch placed on batter slopes for landform stability. In many settings, D7-D8-D9 sized bulldozers have been demonstrated to provide the appropriate combinations of ripping depth, power and agility for mine sites (larger bulldozers, while available, are heavy and cumbersome resulting in increased compaction and unnecessary operational costs). There are numerous examples of commercially designed mine-ready seeders used on steep slopes (Figure 14), e.g. Ellworx and Gessner Engineering. As described earlier, drone technologies are also increasingly being used for seeding difficult post-mine landforms.

Figure 13. Spreading topsoil on a waste rock dump slope at a mine site. (Photo: L. Commander)

For less challenging post-mine landforms, such as when aiming to restore grazing pasture on flat or gently sloping landforms, agronomic seeders and equipment are more often used. In other instances, brush matting or mulching has proved effective (Figure 15).

Figure 14. Air seeder attached to the back of a D9 for use on rocky soils and slopes up to 20 degrees, capable of metering a large range of native seeds. (Photos: N. Ellwood)

Figure 15. Cutting and spreading mulch at a mine-site. (Photo: Iluka Resources)

Seeding Rates

Calculating seeding rates is critical to ensure that seed is used efficiently, and that the targets, goals, and objectives of the project are met. Seeding rates that are based on sound information of seed lot characteristics will increase the probability that seed is distributed at a rate that leads to target plant establishment densities, while incorrect seeding rates may have the opposite effect (plants may be too dense or too sparse) and some species may dominate.

Seeding rate calculations are based on the area of the site to be sown, the composition of the seed lot (single or multiple species), seed quality of the seed lot, target plant densities, and predictions about how the species will establish in the field. For ecological restoration, target plant densities are typically based on field survey information from existing or historic reference plant communities (see Module 1 – Introduction). For projects where other outcomes are sought (e.g. wind breaks, firewood-lots, fodder, ground stabilisation, visual amenity), target densities are often determined by pragmatic considerations (e.g. projected plant number and cover, biomass production, aesthetics). Target plant densities are generally described as the number of plants per unit area (e.g. plants per square metre or hectare) or the number per linear distance (e.g. plant per kilometre).

The type of information used in seed rate calculations can influence the soundness of the derived seeding rates. For example, seed rates can consider information about seed quality and seed germination (see Module 10 – Seed Quality Testing and Module 11 – Seed Germination and Dormancy).

If only germination data is used, seeding rate calculations will not account for any viable dormant seed (because germination tests only report the percentage of seed that germinates under test conditions/periods). Thus, while germination data is useful for calculating seeding rates for nursery propagation, it presents obvious limitations for field restoration where dormant seeds may in fact eventually germinate. Therefore, if germination % of the seed lot is very high (i.e. little dormant seed component), or the goal is to sow for rapid establishment of the germinable seed component (i.e. any dormant component is viewed as a backup), then germination data alone could be used to calculate rates.

Where viability information is available, its inclusion in seed rate ensures calculations take into account both germinable and dormant seed components of the seed lot. Thus, if there is some reliance on the dormant seed component to provide security over early germination losses and to make up target plant numbers, using viability information may be preferred over germination data. It should also be remembered that the accuracy of the germination or viability estimates can/will vary depending on the method and quality of testing (i.e. cabinet vs nursery germination tests, tetrazolium testing vs cut-test – see Module 10 – Seed Quality Testing and Module 11 – Seed Germination and Dormancy) and using representative and unbiased sampling. Hence, so can the accuracy of the seed rate calculation.

Key parameters for a seed lot used to derive seeding rates are:

- Purity %.
- Germination % or Viability %.
- Pure Germinable Seed % (PGS %).
- Pure Live Seed % (PLS %).
- Seed Weight – seeds per gram.
- Field Survival % – expected percentage of plants that will establish in the field, calculated from monitoring past sowings or estimated from experience.
- Target Plant Density – the number of plants per unit area (plants per m^2).
- Sowing Area – the area to be seeded (m^2).

The following section describes how these parameters are derived and the steps used to calculate seeding rates for a range of seeding scenarios and equipment types (adapted from Delpratt and Gibson-Roy 2015). Parameters can be scaled up to seeds per kilogram and areas in hectares.

Calculations

Step 1. Calculate the pure germinable seed % or pure live seed %

Pure Germinable Seed (PGS) % - derived from purity percentage of the target species seed lot and germination percentage of the target species seed lot (refer to Module 10 – Seed Quality Testing and Module 11 – Seed Germination and Dormancy).

$$Pure\ Germinable\ seed\ (PGS)\ \% = \frac{purity\ \% \times germination\ \%}{100}$$

or

Pure Live Seed (PLS) % - derived from purity percentage of the target species seed lot and viability of the target species (refer to Module 10 – Seed Quality Testing and Module 11 – Seed Germination and Dormancy).

$$Pure\ live\ seed\ (PLS)\ \% = \frac{purity\ \% \times viability\ \%}{100}$$

Step 2. Calculate the number of seeds per unit weight

Seed Weight – the number of seeds of a species per unit weight (e.g. gram). Seed weight can be calculated by weighing samples then counting the number of seeds in each sample, and deriving an average value from those samples (seeds per gram). This calculation is seed lot specific because it depends on the degree of processing that the seed lot has undergone (i.e. how much chaff, if any, the sample contains).

$$Seeds\ per\ gram\ (sample)\ = \frac{number\ of\ pure\ seeds\ in\ sample}{weight\ of\ sample\ (g)}$$

$$Seeds\ per\ gram\ (seed\ lot)\ = \frac{Sample\ 1 + Sample\ 2 + \ldots Sample\ n}{number\ of\ samples}$$

Step 3. Calculate the number of seeds required

Target Seed Number - calculated using Target Plant Density (plants per m^2) and Sowing Area (m^2), adjusted for the Field Survival %. If field survival has not been determined by a field trial, it should be in the range of 5-20%, with lower numbers for smaller seeds. To convert to target seeds per hectare, multiply by 10,000.

$$Target\ Seed\ Number = \frac{Target\ Plant\ Density\ (plants\ per\ m^2) \times Sowing\ Area\ (m^2)\ \times 100}{Field\ Survival\ \%}$$

Step 4. Calculate the weight of seeds required

Sowing Weight (g) - the total weight of the seed lot required to achieve a target plant density at a sowing site. The calculation can use either PGS % or PLS %, depending which parameter is being used. To convert to kilograms, divide by 1,000.

$$Sowing\ Weight\ (g)\ (PGS\ method)\ =\frac{Target\ Seed\ Number\ \times 100}{Seeds\ per\ gram\ \times PGS\ (\%)}$$

or

$$Sowing\ Weight\ (g)\ (PLS\ method)\ =\frac{Target\ Seed\ Number\ \times 100}{Seeds\ per\ gram\ \times PLS\ (\%)}$$

Box 1. Example inputs and calculation

Species: *Themeda triandra* (Kangaroo Grass)

- Purity = 80%
- Germination = 40%
- Viability: 60%
- Seed Weight = 300 seeds per g
- Field Survival: 10 %
- Target Plant Density = 20 plants per m^2
- Target Sowing Area: 10,000 m^2 (1 ha)

Step 1. Calculate the pure germinable seed % or pure live seed %

$$Pure\ Germinable\ Seed\ (PGS\ \%) = \frac{80\ \times 40}{100} = 32\%$$

or

$$Pure\ Live\ Seed\ (PLS\ \%) = \frac{80\ \times 60}{100} = 48\%$$

Step 2. Calculate the number of seeds per unit weight = 300 seeds per g

Step 3. Calculate the number of seeds required

$$Target\ Seed\ Number = \frac{20 \times 10{,}000\ \times\ 100}{10} = 2{,}000{,}000$$

Step 4. Calculate the weight of seeds required

$$Sowing\ Weight\ (kg)\ (PGS\ \%\ method) = \frac{2{,}000{,}000\ \times\ 100}{300 \times 32 \times 1000} = 20.83\ \mathrm{kg}$$

or

$$Sowing\ Weight\ (kg)\ (PLS\ \%\ method) = \frac{2{,}000{,}000 \times 100}{300 \times 48 \times 1000} = 13.89\ \mathrm{kg}$$

Linear Seeding Calculations

Seeding into single or multiple rows (linear seeding) can be undertaken by hand or by a wide range of seeding machines (see Seeding Machinery, above). Seed is sown in prepared rows, in contrast to broadcast seeding. Sowing targets are expressed as plants per area (e.g. square metre or hectare) or plants per row length (e.g. metre or kilometre). Once the target number of plants has been determined, the number and weight of seeds to be sown to achieve this target can be calculated using the formulae in Steps 1 to 4 above.

Calculating target plant numbers

Formula 1. Calculating plants per ha for a row sowing of a target number of plants per metre and at known between row spacing (m).

$$Plants\ per\ hectare = \frac{Plants\ per\ metre\ \times\ 1{,}000\ \times\ 10}{Between\ row\ spacing}$$

Example calculations

Target plants per metre: 3
Between row spacing: 2 m

$$Plants\ per\ hectare\ = \frac{3\ \times\ 1{,}000\ x\ 10}{2}\ =\ 15{,}000$$

To plant an area of 0.8 ha (8,000 m^2):

$$Plants\ per\ sowing\ area\ = Plants\ per\ hectare\ x\ sowing\ area = 15{,}000\ \mathrm{x}\ 0.8 = 12{,}000$$

Formula 2. Calculating plants per row length (m) to establish a target number of plants per ha at a known between-row spacing.

$$Plants\ per\ row\ length\ (m) = \frac{Plants\ per\ hectare\ \times\ Between\ row\ spacing\ \times\ Row\ Length}{10{,}000}$$

Example calculation

Plants per ha: 15,000
Row length: 800 m
Between row spacing: 2 m

$$Plants\ per\ row\ length\ (m) = \frac{15{,}000\ \times\ 2\ \times\ 800}{10{,}000}\ =\ 2{,}400$$

Box 2. Linear seeding example inputs and calculations

Species: *Acacia pycnantha* (Golden Wattle)

- Viable seeds per gram in seed lot: 30
- Field Survival: 40%
- Target sowing rate: 3 plants per m of row
- Plants per hectare (see example calculation above): 15,000

To sow 8,000 m^2 of Golden Wattle at a target rate of 3 plants per m^2 row, in rows that are 2 m apart, an expected field survival of 40% and 30 viable seeds per g in the seed lot – what weight of the seed lot is required?

$$Seed\ weight\ (kg) = \frac{Target\ plants}{Seeds\ per\ gram}\ x\ \frac{100}{Field\ survival\ \%}\ x\ \frac{1}{1000}$$

$$Seed\ weight\ (kg) = 15{,}000\ x\ \frac{8{,}000}{10{,}000}\ x\ \frac{100}{40}\ x\ \frac{1}{1{,}000} = 30\ kg$$

Bulking Agents

For many types of seeding equipment (mechanical seeders or when hand broadcasting) and/or seed-types, seed is used in conjunction with bulking or spreading agents (Figure 16). The prime reasons for using these include:

- Helping spread the seed more consistently and accurately.
- Bulking out a seed lot to ensure that seed is spread over all the target area.
- Ensuring that seeds of different size and morphology are evenly mixed and suspended.
- Assisting in making seed more flowable through drill lines or seed boxes.
- Being able to identify the area over which seed has been sown.

Commonly used bulking agents include:

- Sawdust.
- Rice hulls.
- White rice.
- Sand.
- Cat litter (spongelite granules).
- Vermiculite.

For some species (or mixed seed lots), fine chaff (e.g. from eucalypts) or coarse mulched chaff (e.g. herbaceous stems and attachments) associated with the seed or collections may be used to provide bulking, which saves on processing time. The choice of bulking agent is typically dictated by cost, availability, effectiveness, convenience of use, weight and transportability.

Figure 16. Seed mixes can contain a bulking agent. (Photo: L. Commander)

Seed treatments

In many instances, seed requires some form of treatment prior to its use in restoration. There are a range of reasons why this might be the case, including:

- To alleviate dormancy or stimulate germination (e.g. overcome water impermeability, after-ripening, stratification, smoke, hormones) (see Module 11 – Seed Germination and Dormancy).
- To coat seed with an outer layer or remove covering structures, such as flaming to remove awns of grasses (i.e. to increase uniformity, size, flowability through machinery, or add amendments) (see Module 12 – Seed Enhancement Technologies).
- To increase the speed or uniformity of germination (i.e. priming) (see Module 12 – Seed Enhancement Technologies).
- Other (e.g. inoculation, fungicides, insect deterrence, moisture-holding) (see Module 12 – Seed Enhancement Technologies).

Practitioners must weigh up the benefits achieved by whatever seed treatments are used against the added costs associated of the treatment itself (e.g. money, time, logistics). Some treatments are relatively inexpensive and simple, and so suitable for treating large batches of seed before sowing. For instance, the use of hot water to overcome a water-impermeable seed coat (i.e. *Acacia* sp.), although if very large quantities of seed are treated with hot water, there may not be sufficient space to dry the seeds. Other treatments require specialised equipment (such as scarification machines) and/or expertise to assemble additives and employ coating technologies and the added associated costs of those treatments must be reckoned for in early planning and budgets. Field trials may be useful to test the efficacy and cost effectiveness of treatments.

Sowing Mixes

Often direct seeding aims to introduce more than one species to a site and designing a seed mix that best suits a project's goals can be challenging. For ecological restoration, species selection is most often informed by the representation of a species in a reference community (e.g. sub-dominant, dominant, number per unit area, annual, perennial), while other selection factors are used to guide species choices for functional restoration (e.g. stature, drought resistance, floral attributes, persistence, seed availability and cost). Local expertise can often help further inform choices about what species are appropriate, their availability, seeding methodologies, species proportions in a mix and overall seeding rates (see Module 1 – Introduction). Experimental trials or adaptive management approaches are always informative where time and resources permit. Simple small-scale pre-works seeding trials under prevailing or similar-to site conditions (and replicated where feasible) or formal assessment of current and earlier seeding outcomes, can be used to judge whether future sowing rates or seed mix compositions should be modified, and so are potentially powerful tools to refining knowledge and improving restoration outcomes.

Other factors that might influence species choice in a mixture include:

- The availability of seed (e.g. cost, quantity, quality).
- The range of species obtainable (e.g. from the wild, seed production, seed suppliers).
- Species germination or establishment characteristics.
- Visual or functional characteristics of species.
- Competitive characteristics of the species (e.g. dominance or sub-dominance).
    - Potential for dominance of nitrogen-fixers (e.g. rule of thumb no more than 1/3 of woody seed mix from nitrogen fixers such as *Acacia* spp.).
    - Potential for dominance of ground layer vegetation by some grasses (e.g. *Themeda triandra*).
    - Ability to grow rapidly enough to compete with weeds.
- Establishment or persistence characteristics of the species (e.g. pioneers, perennials, annuals).
- Life-form characteristics (e.g. herbaceous, woody, climber, geophyte).
- Dormancy class and germination requirements (i.e. need for treatments, what treatments).
- Suitability for seeding approaches (e.g. seed morphology, suitability to equipment).
- Habitat attributes (i.e. value to other trophic levels e.g. soil fauna, invertebrates, mammals, reptiles, birds).
- Biotic interactions (e.g. are pollinators and seed dispersers present in the area).
- State and territory licensing requirements (e.g. threatened species, protected species, threatened communities).

It is unlikely that information on all these points will be available, but all available information should be considered.

Post-seeding management

Once a site has been sown, there are many factors that continue to influence the success of emerging or establishing plants and which may require management interventions (see also Monks et al. 2018). These may include the need for:

- Follow-up weed control (e.g. selective herbicides, wick wiper herbicide, hooded sprayers, mechanical removal).
- Pest/herbivore control/exclusion (e.g. red-legged earth mites, ants, grasshoppers, snails, rabbits, hares, wallabies, kangaroos, deer, goats, camels, horses).
- Manipulating vegetation structure or composition.
  - Increasing species or functional diversity (e.g. supplementary patch seeding, infill tubestock planting).
  - Increasing plant densities (e.g. supplementary seeding, planting).
  - Reducing species dominance (e.g. biomass reduction of grasses to enhance forb persistence).
  - Adjusting plant densities (e.g. tree or shrub thinning).
  - Contingency seeding/planting following extreme or unforeseen events (e.g. fire, flood, vandalism).
- Supplementary watering (e.g. targeted watering of high value species/plants, broadscale watering).

Ensure that post-seeding management is included in the project budget and plan and ascertain who is responsible. Outline also who is responsible for site management once project funding ceases.

Monitoring

Well planned and executed monitoring allows practitioners to properly determine if/when the project goals have been achieved (SERA 2016). Monitoring the establishment outcomes of seeding programs is essential to assess outcomes against project goals and to report outcomes for clients or funders. Monitoring is also critical for assessing outcomes of field trials when using adaptive management frameworks or for contingency planning (in response to failures or extreme events).

Monitoring is often undertaken only during establishment phases and while this is beneficial in assessing short term outcomes, longer term monitoring (where feasible) will pick up fluctuations and variation over years caused by stochastic events (such as changing weather patterns).

Many aspects of a seeding site can be monitored but not all are useful, feasible or cost effective. For this reason, project planning should aim to clearly identify which parameters are of most interest (e.g. to ascertain success, to meet reporting goals) and which are feasible within project budgets. Some post-seeding parameters which are commonly measured include species/plant number per linear unit or per unit area, species/plant number per unit time, stem counts per unit area, percentage cover, biomass. The information collected from monitoring can be used to adapt future seeding projects to improve germination, species relative abundance and density. Photo monitoring is also useful, so consider setting up permanent photo monitoring points. There are several templates and established methods for tracking progress and monitoring outcomes (e.g. see Carr et al. 2009, Zimmer et al. 2018). Which one is most suitable will depend on the project type, the species or plant group/s used, the type of seeding method, budget and staff skill levels.

Including monitoring plans in the project plan prior to starting the project is essential. It is important to consider who will do long term monitoring if the project goals are not reached during the budgetary/funding period, and to develop a contingency plan to enact should the monitoring reveal that the site is on a trajectory where goals are not likely to be reached.

Record keeping and reporting

Effective and timely recording of project details and on-ground actions is critical to interpreting success or otherwise (see also Module 4 – Record Keeping, and SERA 2016). Key areas where good record keeping is beneficial include:

- Project parameters (e.g. scope, goals, budgets, timing).
- Reference site/community information (e.g. maps, surveys).
- Seed collection (e.g. locations, species, collection practices & details).
- Seed processing (e.g. drying details, cleaning methods/outcomes, storage conditions and period) .
- Seed testing (e.g. quality and germination).
- Site assessment (e.g. detail characteristics before, during and after seeding, sowing plans, maps).
- Trials (e.g. seeding, site prep, equipment).
- Seeding information (e.g. date of sowing, weather at sowing, soil moisture at sowing, sowing mix composition, seeding rates, seed treatments, seeding conditions/timing).
- Seeding outcomes (e.g. emergence characteristics, timing, period).
- Post seeding management (e.g. weed control, biomass manipulation, herbivore control).

Effective record keeping is critical to assembling the information required to determine if goals have been achieved (i.e. for reporting purposes, communications, promotion) and/or to inform future projects. Consistent tracking of project actions and outcomes (across projects and over time) will help practitioners to build up valuable baseline information on various factors that aid or impede success, enabling adaptive management. Where such information is available to be shared, reporting enables others to build on knowledge, thereby benefiting others in the local area and the broader restoration community.

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Online resources

Ellworx
https://ellworx.com.au/

Gessner Engineering
https://gessner.com.au/

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