Sinosteel Midwest Corporation

Practitioner Restoration Manual

BOTANIC GARDENS & PARKS AUTHORITY

2017

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Preface (Scope and Limitation)

This restoration manual is largely a synthesis of research findings from a five year research program agreed to by the Botanic Gardens and Parks Authority (BGPA) and Sinosteel Midwest Corporation (SMC) and undertaken from March 2012 to March 2017 at SMC's Koolanooka and Blue Hills tenements in the mid-west region of Western Australia. While a large of this this restoration manual was developed for restoration works that maybe carried out in the future on SMC tenements, other sources of broadly relevant information are cited.

The manual was produced from three sources of information:

(1) Primary source for restoration recommendations was based on the five year research program undertaken at Koolanooka and Blue Hills locations.
(2) Secondary sources are relevant restoration research publications located in scientific research journals and grey literature (clearly indicated with an appropriate citation).
(3) Alternative guidelines/recommendations based on unpublished collective knowledge and experience of the authors (i.e. to be taken as advice only and recommend further research to test its validity).

The recommendations in this manual will be applicable to the broader restoration community, particularly to the Midwest and Pilbara bioregions, similar style mining operations and other areas of similar habitat or vegetation structure. It is important to note that this manual is based on best current knowledge of restoration activities carried out on SMC's tenements. The manual will require updates and amendments based on the use adaptive management practices in response to additional research outcomes on these tenements.

This manual could not have been created without the dedicated work of staff and students, from organising on site support to assisting with the heavy field research involved in this project. We would like to thank staff and students from SMC (Paul Hogan, Stephen Neill, Stuart Griffiths, Wayne Ennor), BGPA (Davide Abate; Arielle Fontaine; Rachel Omodei; Sonja Jakob; Anthea Challis; Ellery Mayence; Matt Barrett; Wolfgang Lewandrowski), University of Western Australia (Clare Courtauld; Sarah Boys; Erin Picken; Marlee Starcevich) and Curtin University (Kingsley Dixon) for their tireless efforts over the last five years.

Overview of Restoration Processes

The restoration of sustainable native vegetation communities using local species requires consideration of a number of key components

- identifying the community's constituents and their attributes
- identifying abiotic conditions necessary for the establishment and persistence of the community
- techniques for recreating these abiotic conditions
- techniques for successful introduction and establishment of the biotic elements of the community
- identifying and managing risks and threats to the establishment and sustainability of the community.

Optimising use of available resources including plant (topsoil, seed and plants) and soil substrate (plant growth medium and parent material) in restoration is critical. The following diagram summarises a generic outline of the restoration process (Figure 1). Restoration research aims to maximise restoration success with a minimal amount of intervention and thus reduce company investment (Miller et al., 2016).

Determining the research requirements for restoration or restoration activities themselves for individual sites involves identifying a series of constraining factors, which may include:

- those imposed by specific Ministerial conditions and the knowledge underpinning these conditions
- those imposed internal by the company (timelines and resources for restoration)
- those imposed by availability of natural resources (seed supply or soil substrate).

Addressing these constraining factors through research will provide the best opportunity for any company to establish new benchmarks in mine site restoration and achieve successful mine closure.

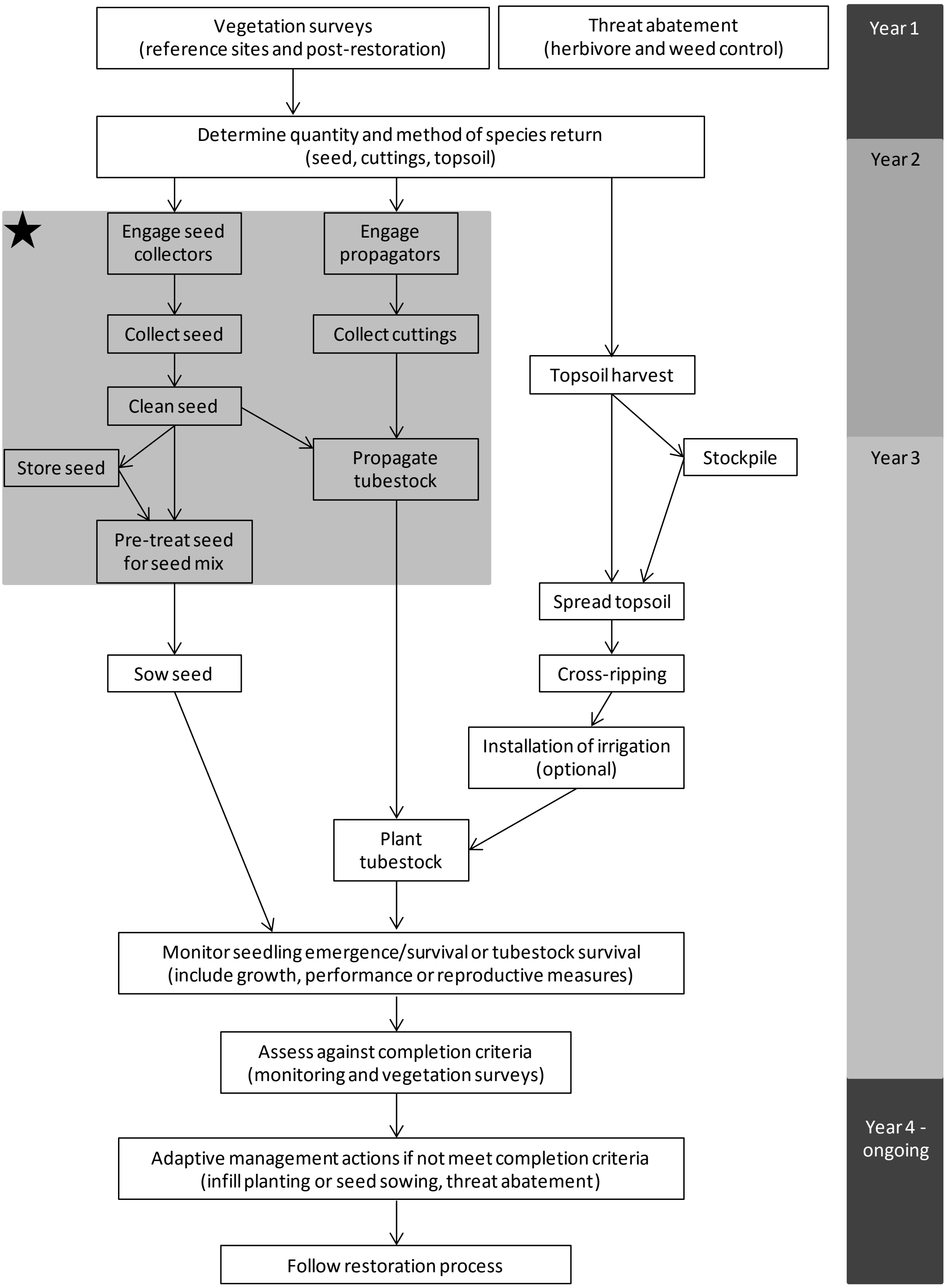


Figure 1. Generic flow chart of the restoration process from on site preparation to adaptive management, including a timeline guide for activities. ★ These activities should be carried out a minimum of two years ahead for seed and one year ahead for tubestock of before commencing the site restoration and need to be repeated (all subsequent years of the restoration program) to ensure adequate propagation resources are acquired for restoration efforts because of likely difficultly to obtain sufficient propagating material, consistently, in a highly variable rainfall environment.

Summary of Restoration Processes

(1) Define the **restoration goal** and end land use, and define **completion criteria** (see Table 1 and Table 2).

(2) **Survey vegetation** (Winter/Spring) prior to clearing.

(3) **Identify reference sites** for each mine domain and survey (Spring).
- Set up multiple permanent monitoring plots for each reference, survey and restoration sites (20x20m).
- Record each species in the plot to determine the total number of species in all plots and the average number of species per plot.
- If required, walk through an area equivalent to the size of the area to be restored and record any additional species in order to find the total number of species in that area.

(4) **Create completion criteria** based on surveys in the reference sites.

(5) **Create a ranked species list** for each reference site from the survey.
- Develop a species pool list using species lists from surrounding communities.

(6) **Undertake site and threat assessment**
- Identify potential constraints to plant growth, such as compaction, weed competition or herbivores, and identify mitigation measures.
- Measures include fencing (plot or plant scale until tall enough to be out of the browsing zone) or culling for non-native herbivores.

(7) **Maintain accurate records of restoration information**
- For each restored area, record source of seed or cutting collections, soil sources, harvest date, spreading date, seeded species and rates, seeding date, tubestock planting density (and irrigation if used), and emergence or survival data.

(8) **Start seed collections** (Spring) 1-3 years prior to clearing.
- Source from the surrounding areas as soon as possible.
- Sufficient quantities of seed may take several years to collect.
- Use the ranked species list for each reference site to inform the species and their quantities for collection.
- Ensure that the seed collectors record GPS locations of all collections, and follow best practice seed collection and cleaning techniques (see Seed collection, cleaning, quality and storage).
- For best practices, it is recommended that priority should be given to seed collectors and suppliers who are accredited by the Revegetation Industry Association of WA (see www.riawa.com.au) or request that seed collectors follow RIAWA Seed Industry Standards (see http://riawa.com.au/wordpress/wp-content/uploads/2015/05/01-RIAWA-Seed-Standards-1505201.pdf).

- Ensure the total weight of the collection and the number of seeds per gram is available, in order to assist in the calculation of seeding rates.

(9) **Harvest topsoil and subsoil** while the soil is dry.
- Topsoil contains the seedbank and is in the top 10 cm of the soil profile, and subsoil below 10 cm.
- If during the clearing of vegetation, soil is also removed, then this soil must be conserved as it contains the seed bank.
- Record vegetation condition prior to stripping – undisturbed vegetation is likely to have a larger and more diverse soil seed bank than disturbed vegetation, which may require more seed input, and vegetation with a high weed load will have a large weed seed bank.

(10) **Stockpile** topsoil and subsoil separately
- Also stockpile soil from different landforms (flats and hills) separately.
- Erect signage displaying the soil type (topsoil/subsoil), source location (GPS, and flats/hills), volume, and harvest date.

(11) **Store seed** in cool, dry conditions so that viability is maintained.
- For instance, an air-conditioned room with ambient humidity may be sufficient for up to five years.
- However, drying seed prior to storage in impermeable bags, or storing seed under low temperature (<10°C) and humidity (15%) will enable seed to be stored for longer (5-10 years)
- Exact storage longevity is species specific (Martyn et al., 2009).

(12) **Collect cuttings** or use seed **to generate tubestock**.
- Generally, growing tubestock using seed is less expensive, but when seed is not available, propagation by cuttings will be necessary.
- Species likely to be restored via tubestock may store their seed in the canopy and not in the soil seedbank or have limited seed quantities.
- Slow growing species (e.g. *Melaleuca* sp.) should be sown 12 months prior to planting, and faster growing species (e.g. *Acacia* sp.) can be sown 6 months prior to planting. Hence, for some species, seed may need to be collected 2 years before planting.

(13) **Spread soil** when it is dry (early Autumn)
- If applicable, spread subsoil first, followed by topsoil.
- If possible, spread the soil on the landform type it came from (e.g. flat areas to be returned to flat areas).
- Spread the topsoil to an optimal depth of 10cm.
- If there is an excess of topsoil, then it can be spread deeper than 10 cm. If there is a shortage of topsoil, it can be mixed with waste rock at a 3:1 ratio (topsoil:rock), but do not spread to a depth greater than 10 cm. The waste rock at Koolanooka was suitable for mixing with topsoil. There are currently no specifications for the particle size for waste rock, as long as the material is able to be spread to 10 cm once mixed with topsoil.

- Fines and ultrafines (low grade ore) are not suitable for use as a substrate.

(14) **Cross rip** flat areas, rip **slopes on the contour**, rip **plateaus above slopes** and **benches parallel to the slope**.
- Make a bund of waste rock/soil (non-dispersive material) around the edge of the plateau or bench that is tall enough to minimise runoff downslope from the plateau which could lead to erosion.
- Seek specialist advice from engineers for bund heights as they may differ depending on size of waste dump catchment and hydraulic properties of materials used to construct waste dump and bund.
- Check the bund during or at the end of the first winter to ensure that it remains intact.

(15) Develop the **seed mix for broadcast**
- If known, calculate seeding rates based on number of seeds per gram, plant densities, ranked species lists, seed quality and emergence rates.
- If unknown quality, a starting point for seeding rates is 100 seeds in the seed mix for every one plant required of a particular species.
- If unknown plant density, a starting point for seeding rates in 1000 seeds/ha
- If insufficient seeds available for the seed mix, then seedlings should generated in a nursery, and not included in the seed mix.

(16) **Seed immediately after soil preparation**
- Before rainfall causes a soil crust to be formed and therefore the break in the season (e.g. agricultural timing of crops).
- Use an air-seeder attached to the back of the ripper (recommended), an agricultural seeder adapted for use on rocky soils, or hand seeding.

(17) **If economically viable, irrigate the site**.
- Irrigate during the first winter to bet-hedge against a low rainfall year. Irrigation can be done in 'resource islands', for instance, 20 x 20 m 'nodes' to concentrate the resources.

(18) **Plant tubestock** when the soil is visibly moist (Winter) at the break in the season.
- Planting density (spacing) should reflect plant density and pattern found in reference sites.
- Water tubestock with about 1 litre of water immediately after planting to improve tubestock survival especially since rainfall can be unpredictable in a semi-arid environment.

(19) **Monitor** the restored areas according to the monitoring plan (Maia Environmental Consultancy, 2015) and assess against the **completion criteria**.

(20) Carry out adaptive management actions if not meet completion criteria
- **Additional seeding or planting**, if the restored areas have insufficient density and/or diversity. If seeding, take care to integrate the seed

into the soil, as the soil crust may prevent seeds from being integrated.

- **Additional weed control**, if the restored areas have unacceptable levels of weeds.
- **Adjust seeding rates for future restoration areas**, if plant density in the restored areas does not compare to the reference sites.

1. Background

Sinosteel Midwest Corporation (SMC) engaged the Botanic Gardens and Parks Authority (BGPA) to undertake research to underpin their restoration activities. This restoration manual is based on results from site specific research at Koolanooka Hills and Blue Hills, and best practice (SER 2004) restoration in Western Australia.

This study is of regional significance to land managers and conservation agencies with an interest in the conservation and rehabilitation of the Midwest and Pilbara bioregions (and bioregions with similar habitat or vegetation structure). The study will lead to long-term conservation benefits of international significance, and ultimately enable significant biodiversity conservation and rehabilitation in the post-mined landscape of the SMC operations with flow-on benefits in terms of:

(1) Ecosystem function and stability.
(2) Meeting best practice standards in biodiversity following mining.
(3) Contributing information towards developing a scientifically robust means for establishing completion criteria for rehabilitation programs.

2. Definition of restoration

Restoring a self-sustaining, resilient ecosystem.

Ecological restoration is defined as 'the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed' (SERI Science & Policy Working Group, 2004). An ecosystem is considered restored when its structure (density and distribution of life-forms) and function (e.g. nutrient cycling and carbon fixation) is self-sustaining, that is, it no longer needs further inputs. The ecosystem will be resilient to disturbance (the ability to regain structure and function following natural disturbance such as fire or drought). The ecosystem will interact through abiotic and biotic exchange (e.g. water, nutrients and organisms) with surrounding ecosystems in the landscape (SERI Science & Policy Working Group, 2004). The national standards for ecological restoration have been designed to encourage all restoration and rehabilitation projects in Australia to reach their highest potential and are available here: http://www.seraustralasia.com/standards/contents.html

3. Restoration goal and completion criteria

Completion criteria are a set of measurable benchmarks against which rehabilitation indicators can be compared to determine whether the objectives are being met.

Ministerial statement 811 outlines one completion criteria: To re-establish flora and vegetation with not less than 70 percent of the known original species diversity.

Goals are essential for restoration projects, as they provide a direction for restoration activities and completion criteria ultimately enable the project to be evaluated. The restoration requirements for disturbed areas following mining at Koolanooka Hills and Blue Hills (Mungada East and West) within the shires of Morowa and Perenjori are described in Ministerial statement 811.

Ministerial statement 811 requires that the projects shall:

a) minimise the disturbance to, or loss of, the Threatened Ecological Community “Plant assemblages of the Koolanooka System” and the “Blue Hills vegetation complex” Priority Ecological Community,

b) re-establish flora and vegetation with not less than 70 percent of the known original species diversity and

c) develop a rehabilitation strategy to ensure that the characteristics of the constructed waste dumps optimise rehabilitation outcomes.

These are some of the highest objectives set for restoration of natural communities and, will represent leading practice in mining rehabilitation. Approaches outlined throughout this document encompass leading research techniques and technologies developed by Botanic Gardens and Parks Authority to underpin rehabilitation success at two SMC sites (Koolanooka and Blue Hills). It is a restoration practitioner’s manual for SMC environmental staff to assist with the implementation of scientific findings for on-ground restoration. Hence, this document will form part of the rehabilitation strategy, as requested by Ministerial statement 811.

Completion criteria are a set of specific targets against which restoration success can be measured. These criteria must be SMART – Specific, Measurable, Attainable, Relevant and Timebound. They measure various aspects of the restored community to ensure that the goal is met (Table 1: Koolanooka Hills and Table 2: Blue Hills). These criteria compare aspects of the restored site with a reference site. Completion criteria should be assessed during ongoing restoration monitoring to ensure that the site is progressing satisfactorily.

Table 1. Closure criteria for Koolanooka Hills.

Aspect	Objectives	Completion criteria	Measurement tools
Flora and Vegetation	Impacted areas are returned to self-sustaining vegetation communities that reflect pre-disturbance state.	• Rehabilitation conducted as per BGPA research program. • Compliance with Ministerial conditions (species richness, weeds). • Flora and vegetation are re-established with not less than 70 percent composition (not including weed species) of the known original species diversity. • Weed coverage no more than that in undisturbed bushland in the area or less than 10%, whichever is the lesser.	• Annual vegetation monitoring programs and weed surveys; • Comparison of vegetation density and diversity with agreed analogue communities;

Table 2. Closure criteria for Blue Hills.

Aspect	Objectives	Completion criteria	Measurement tools
Flora and Vegetation	Impacted areas are returned to self-sustaining vegetation communities and fauna habitats that reflect pre-disturbed state. Weed species cover does not increase, relative to pre- mining condition.	• Within five years post closure, flora and vegetation has been re-established to at least 70% composition of original known diversity, as per Ministerial Condition 13-3 (a). Baseline diversity levels are those referred to in the ATA 2004 report, titled "Vegetation and Flora Assessment, Koolanooka, Midwest Corporation Limited, and ecologia's 2008 report titled "Koolanooka/Blue Hills Flora and Vegetation Survey". • Within five years post closure, weed coverage represents no more than in undisturbed bushland or less than 10%, whichever is the lesser, in accordance with Ministerial Condition 13-3 (b).	• Rehabilitation conducted as per BGPA research program at Koolanooka: • Deep ripping has been conducted in rehabilitation areas. • Flora species have been identified for use in rehabilitation and seed collection, and reflect principles of vegetation succession. • Annual weed surveys and vegetation health assessments. • Comparison of vegetation density and diversity with agreed previous. • Annual flora surveys.

4. Reference sites

Vegetation surveys in reference sites in the undisturbed vegetation are essential to define the species in the community and enable development of completion criteria.

Reference communities for each restoration domain in the mine have been suggested and species lists provided.

The number of species is dependent on the area surveyed. To replace 70% of species in a given area, a reference survey should be undertaken in an area of the same size.

A 7 ha area has been surveyed in the Koolanooka Threatened Ecological Community (TEC) to define the number of species required to achieve 70% replacement in the 7 ha TEC offset. This type of survey will need to be undertaken to determine the target number of species for the remaining mine domains (see Figure 1).

A reference site is essential to both plan and evaluate restoration. Attributes of the site's composition, structure and function must be measured to enable the development of completion criteria (Miller et al., 2016). Information that is necessary for benchmarking restored communities to the level required in project plans and ministerial statement include:

- a full list of species for the community
- clear delineation of communities, including species whose presence/absence or variation in abundance defines each community
- the appropriate spatial scale at which to assess communities
- the range of variation for species richness and cover that can be expected
- the relative abundance of the most important species in each.

A reference site can be the pre-cleared site, or it can be an analogue site in a nearby community. Pre-clearing surveys are extremely useful for determining the above ground vegetation, which is related to the species present in the soil seed bank. However, given that mining alters landforms, the former community may not be the most appropriate community to restore. For instance, if a sand plain is cleared to make way for a waste rock dump, a nearby banded ironstone community may be a more appropriate reference for the rock dump than a sand plain. Therefore, analysis of the soils and topography in the site to be restored will assist in identification of a suitable reference site. Hence, when choosing reference sites for each of the domains at Koolanooka and Blue Hills, we have tried to recommend reference ecosystems that are matched to the altered site conditions.

As species naturally vary in abundance within plant communities and most have spatially patchy distributions the definition of communities requires recognition of spatial and temporal variation. Specifically, communities vary in density (they are patchy), and in composition (not all species will be found in any one sample) over a range of spatial scales. Ecologists recognise that the number of species identified in a community increases with the dispersion of surveyed plots as well as with the total sampled area, but at a diminishing rate. A variety of techniques - based on species-area curves - exist to identify appropriate sampling area for assessing species richness. Adequate sampling for definition of vegetation communities would include replicated plots of this appropriate size in which the presence and density and/or cover of species present is assessed. The number of such plots will depend on the inherent variability of the community but must be sufficient to accurately identify the average values for species richness and vegetation cover / density, and to capture a representative amount of their variation. Finally, a useful target definition of a plant community should also include a species list that is as complete as possible for the entire area (i.e. also outside of sampled plots).

A full species list including identification of dominant (framework) species and species that differentiate individual communities was generated for all impacted communities. Methods used to generate the species list includes analysis of existing consultants data supplemented by vegetation surveys, and seed bank audits to understand species richness and composition of the latent system (see Topsoil management) for sites where topsoil use is available. Target densities and frequencies of individual species was determined for mature vegetation on a scale suitable for restoration monitoring (i.e. 7 ha). **Key traits for individual species** that were determined include:

- **Growth form** (tree, shrub, annual herb)
- **Ecological strategy** (annual, long-lived perennial, disturbance perennial)
- **Ecological amplitude** (widespread, restricted)
- **Regeneration strategy** (soil seedbank, canopy seedbank)
- **Restoration approach** (topsoil seedbank, collected seed, cuttings)
- **Target range of densities** (and number of individuals for the area) corresponding to reference (intact undisturbed) community.

Recommendations for reference site surveys:

(1) Define and survey reference sites early (first) in restoration planning
  - o Pre-clearing surveys or appropriate analogue site nearby

(2) For 70% species reinstatement, recommend scale-dependent surveys to account for spatial and temporal variation in environmental conditions
  - o Surveys should be scaled to be the same for both the area of restoration targeted and reference sites to enable accurate comparisons to be made.
  - o The same method of survey and sampling intensity is essential for accurate comparisons

(3) **Recommend comprehensive description of species diversity, composition (abundance/density) and structure of reference sites**
   - Enables development of a species list to inform the species selection for restoration and seed collection efforts
   - Enables development of appropriate seeding rates from abundance/density estimates in surveys

4.1. Plant community targets for Koolanooka

The Koolanooka Mine Closure Plan has detailed that the site has been divided into six specific domains, based on landforms or infrastructure that has similar rehabilitation requirements (Figure 2). The domains and their potential reference communities are outlined in Table 3, along with a description of each in Table 4.

To achieve 70% species re-instatement and to ensure robust restoration targets were established, diversity at the species level must be adequately described in existing communities (see section 2.3.1 in the Research Proposal for further information).

- To develop the appropriate methodology to define the restoration targets, BGPA developed targets for Domain 4.
- Vegetation surveys and analysis of previous data (Meissner and Caruso, 2008, Maia Environmental Consultancy, 2010) were conducted by BGPA. An effective and ecologically appropriate species composition target for the 7 ha TEC (Threatened Ecological Community) offset was defined.
- DEC (Department of Environment and Conservation) community 3 was chosen as the reference community. In 7 ha of this reference community, 84 species were found, hence, 59 species should be restored to achieve 70% of the pre-existing species diversity in a 7 ha TEC offset. A species list has been provided for this community (Appendix 1).
- With the methodology for determining restoration targets being established, using Domain 4 as an example, additional surveys may be required to define the appropriate number of species for the corresponding area of restoration for the remaining domains (see Table 3).

Methodology for defining 70% replacement in Domain 4, the TEC offset

(1) As species richness is area dependent, **the diversity target should be based in an area similar to the area to be restored**. As the TEC offset area (Domain 4) is 7 ha (Figure 3), the same area in the reference community was selected to identify the target plant species diversity.

(2) Within this 7 ha, **vegetation surveys** of ten 20 x 20 m plots (TRS 1-10, Figure 2&3) in DEC's community type 3 (co-incident with ATA Environmental consultant's (ATA) community 6, Figure 4) were conducted to use as a reference site for the TEC offset area. In addition to these surveys, we walked

through the 7 ha site to record any additional species that were not identified during the survey of the plots (Figure 4&5).

(3) With this **methodology (10 plots and 7 ha walk)** we found 84 species. Therefore, a 70% target richness based on 84 species should be 59 species. However, this target number of species could be achieved from the larger pool of species than just those found in the 7 ha, by including the species found in previous surveys from DEC and Maia in DEC's community type 3 (106 species). A complete list of the species pool is shown in Appendix 1.

Table 3. Domains with similar rehabilitation requirements and reference communities for each domain at Koolanooka.

Domain	Description	Reference community
1	Infrastructure and ore stockpile areas (flat ground)	DEC Community 5
2	Waste dumps: detritals, south-fold and ultra-fines	DEC Community 3 (as per Domain 4) or 4 (adjacent to south-fold waste dump)
3	Former waste dump footprint (flat ground)	ATA Community 15
4	Environmental Offset Area (establish TEC vegetation)	DEC Community 3
5	Historical WMC waste dump and public lookout site	DEC Community 3 or 4
6	Pits (historical WMC, current south-fold and detritals), backfill and historic Train Load-out site	None required

Table 4. Description of vegetation types in reference communities at Koolanooka.

Community	Vegetation description
DEC 3	*Allocasuarina* Low Open Woodland on Upper slopes and a minor gully on banded and non-banded ironstone
DEC 4	*Acacia* High Open Shrubland on west facing moderate slopes and at the base of a gully with a surface layer of laterised banded ironstone rocks on the southern side of the range
DEC 5	*Eucalyptus* Low Open Woodland on footslopes and gravelly flats to the south-west of the range
ATA 15	Tall to Tall Open Shrubland dominated by *Acacia acuminata* and *Acacia aneura* with scattered *Eucalyptus loxophleba* subsp. *loxophleba*

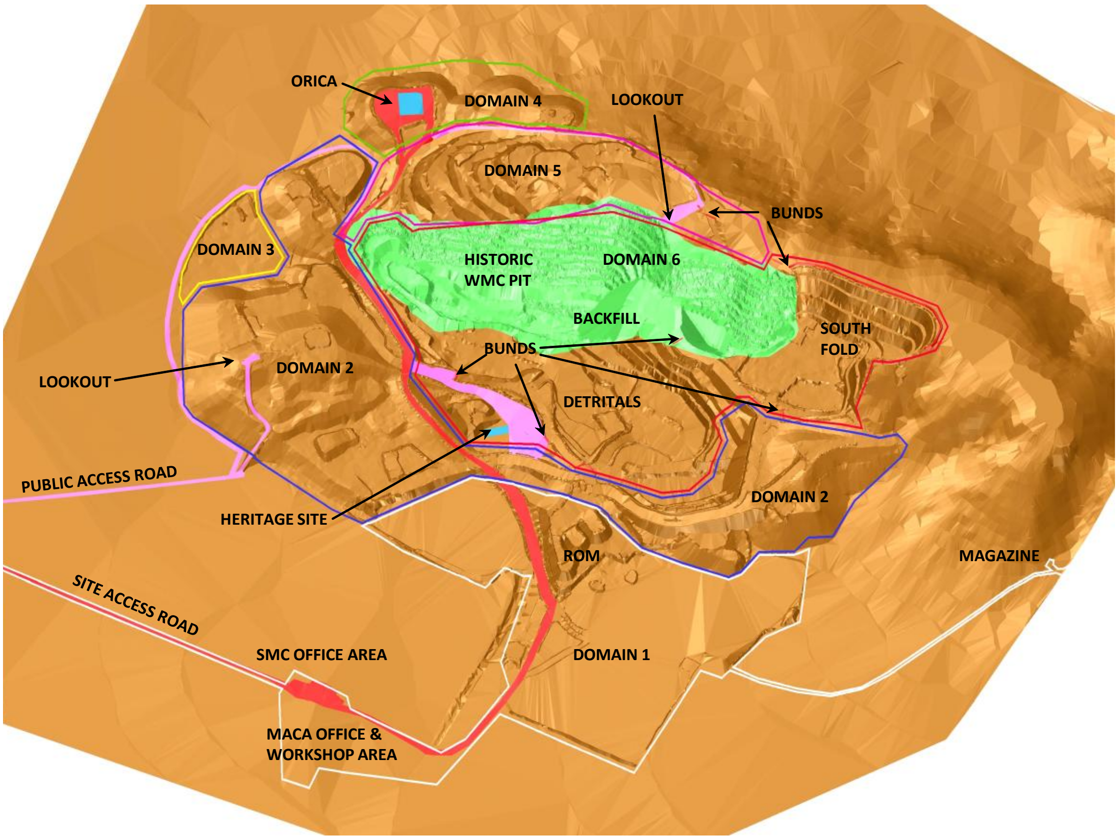


Figure 2. Closure Domains at Koolanooka (Source: Koolanooka Iron Ore Project Mine Closure Plan, p 33.)

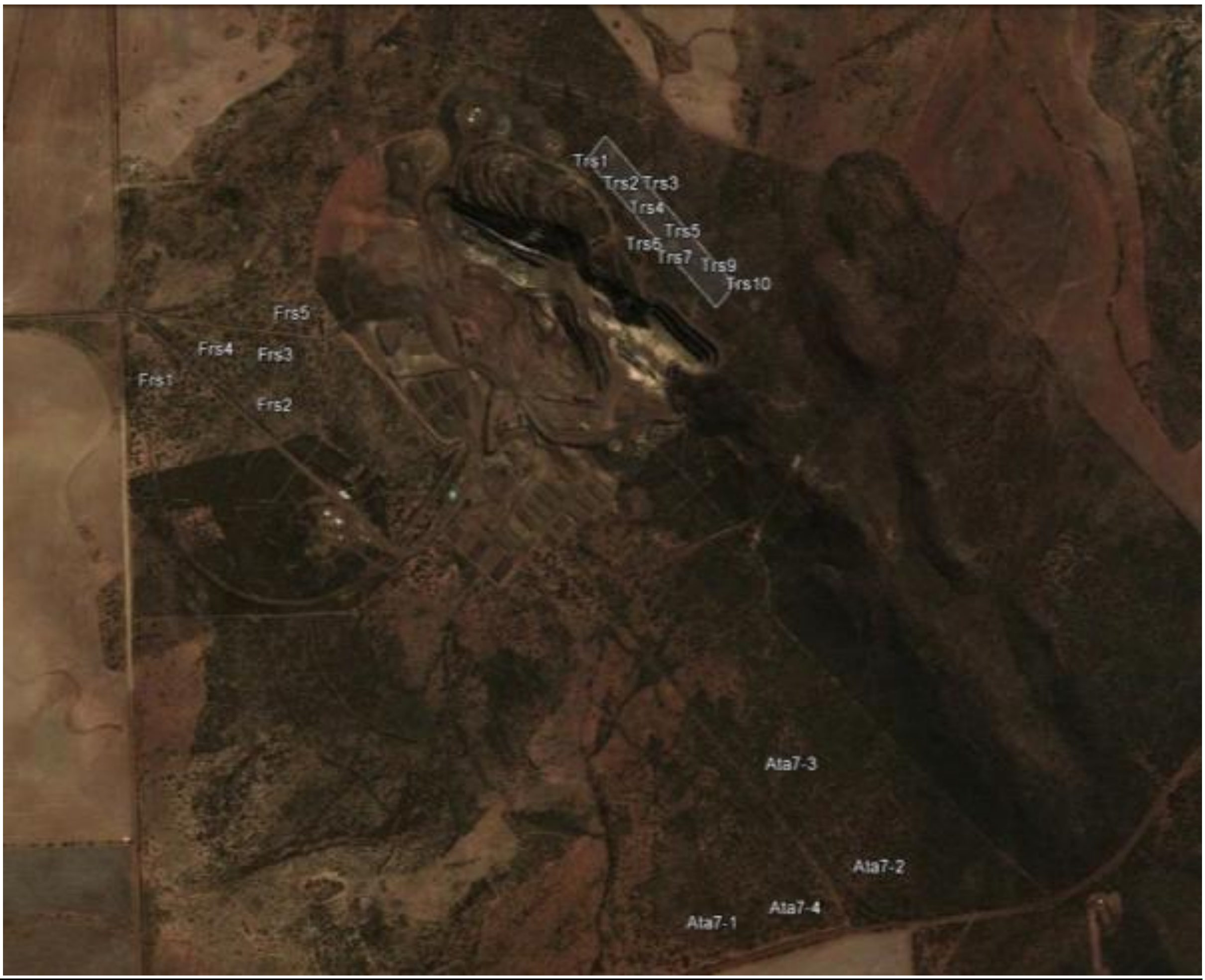
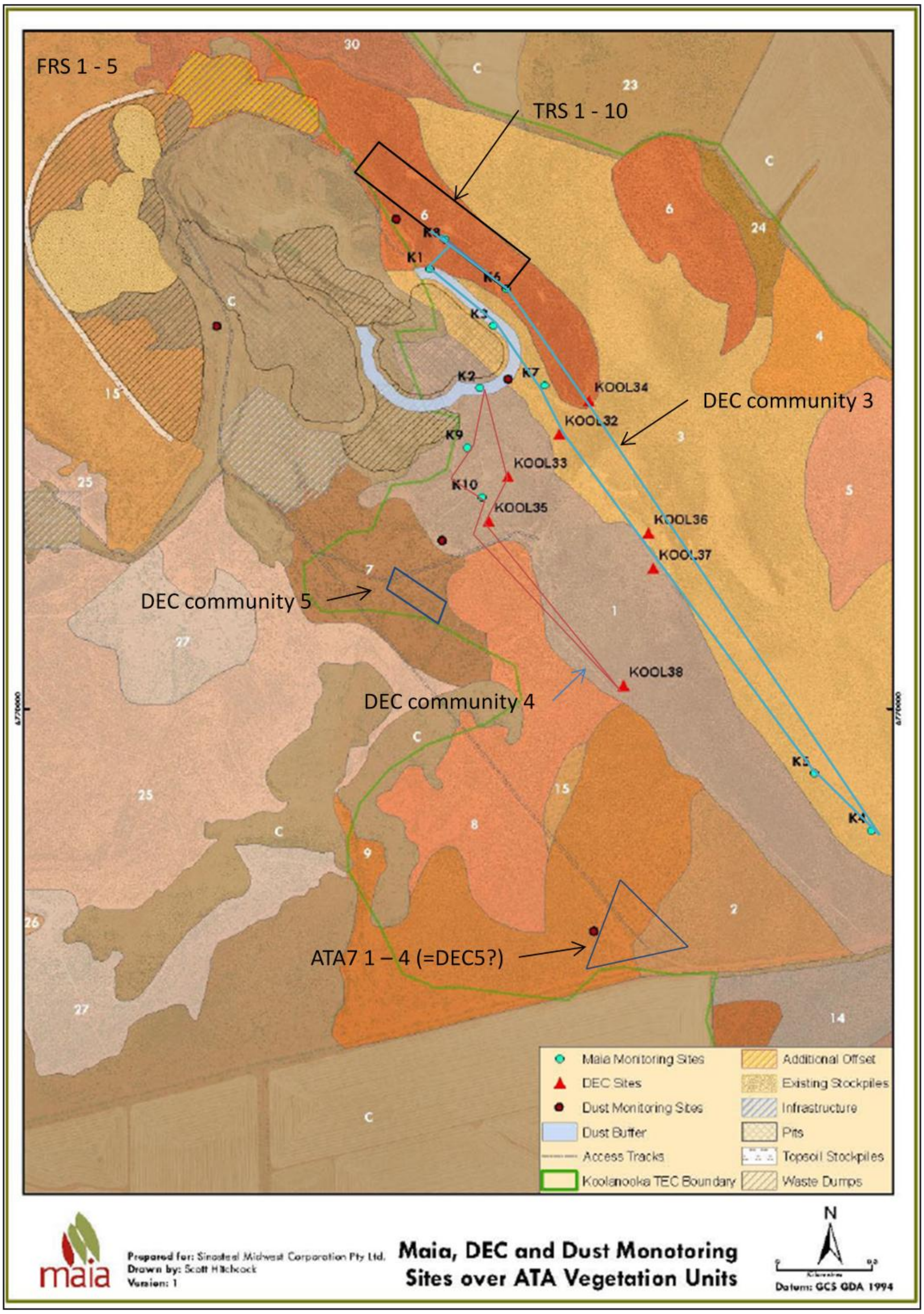


Figure 3. Botanic Gardens and Parks Authority vegetation survey plot locations. The map shows the area covered by the vegetation survey and the location of the 20 x 20 m plots located randomly on the TEC (Trs 1-10) within DEC community 3, the area adjacent to the former waste dump footprint (Frs 1-5) within ATA community 15 and the area around the south fold waste dump (Ata7 1-4).



Community	Number of 20x20m quadrats	Average number of species per quadrat	Total number of species in all quadrats
ATA 7 1-4	4	21	51
DEC 3	19	24	91
DEC 4	7	20	44
DEC 5	5	21	45
FRS	5	20	43

Figure 4. Vegetation communities at Koolanooka, and DEC, Maia and BGPA survey locations, (Source: SMC Koolanooka Project: Vegetation Monitoring Program, Maia, 2010, p 9.) and the average number of species per quadrat and total number of species.

4.2. Plant community targets for Blue Hills

The area impacted by mining activities at Blue Hills Mungada East and West mine sites (Figure 5) cover seven floristic community types (FCT: 1a, 2, 4, 12, 13, 14 and 17) according to Woodman (2008) or six vegetation communities (Arr, Ew, El, Aan, ApCp and AaPo) according to Bennett (2004) classification systems. Floristic community types 12 or Arr are likely to be suitable for restoration to waste rock dumps as they are found on flats to mid-upper slopes of Banded Ironstone Formation (BIF) ranges with ironstone gravel soils (Figure 5). Also, FCT 12 or Arr are the largest community types impacted by mining and will also provide the main source of topsoil and hence contain the soil seed bank of the species to be restored.

Quadrats were chosen from existing vegetation survey data collected by Bennett (2004), Ecologia (2008), Maia (2012) and Markey and Dillon (2006) within or adjacent to the mine foot print proposed in “Attachment 3 to Ministerial Statement 811 - Section 45C change to proposal”. A total of 112 species, subspecies and varieties were identified in 12 quadrats (20 m x 20 m) at Mungada East and 12 quadrats at Mungada West mine sites (Figure 5). A total of 84 plant taxa were identified for each site with 56 species common to both sites. Of the 112 taxa identified at both sites, 40 herbs and 2 grasses were annuals (37.5% of all taxa).

Two separate lists were created for selecting suitable species for restoration of the waste rock dumps at Mungada East (Appendix 2) and Mungada West mine sites (Appendix 3). Mean species richness/quadrat was 15.1 ± 3.7 for Mungada East and 17.1 ± 1.2 at Mungada West. A difference in species richness between sites is due to a larger number of Ecologia quadrats, which did not record annual species, used in analysis for Mungada East. To restore a vegetation community that is most similar to undisturbed sites, species targeted for restoration should be selected on the basis of frequency of occurrence i.e. 100% of very common taxa should be targeted for restoration, 80% of the common taxa and 60% or 55% of uncommon taxa.

Recommendations for vegetation restoration and reference sites:

(1) **For new areas of restoration outside of existing mining footprints, a similar method to that taken at Koolanooka (Domain 4 TEC offset; Section 4.1) is recommended**
   - We have demonstrated that it is necessary to perform vegetation surveys in reference communities with an area equivalent to the area to restore to define the diversity targets appropriate for each restoration domain area.

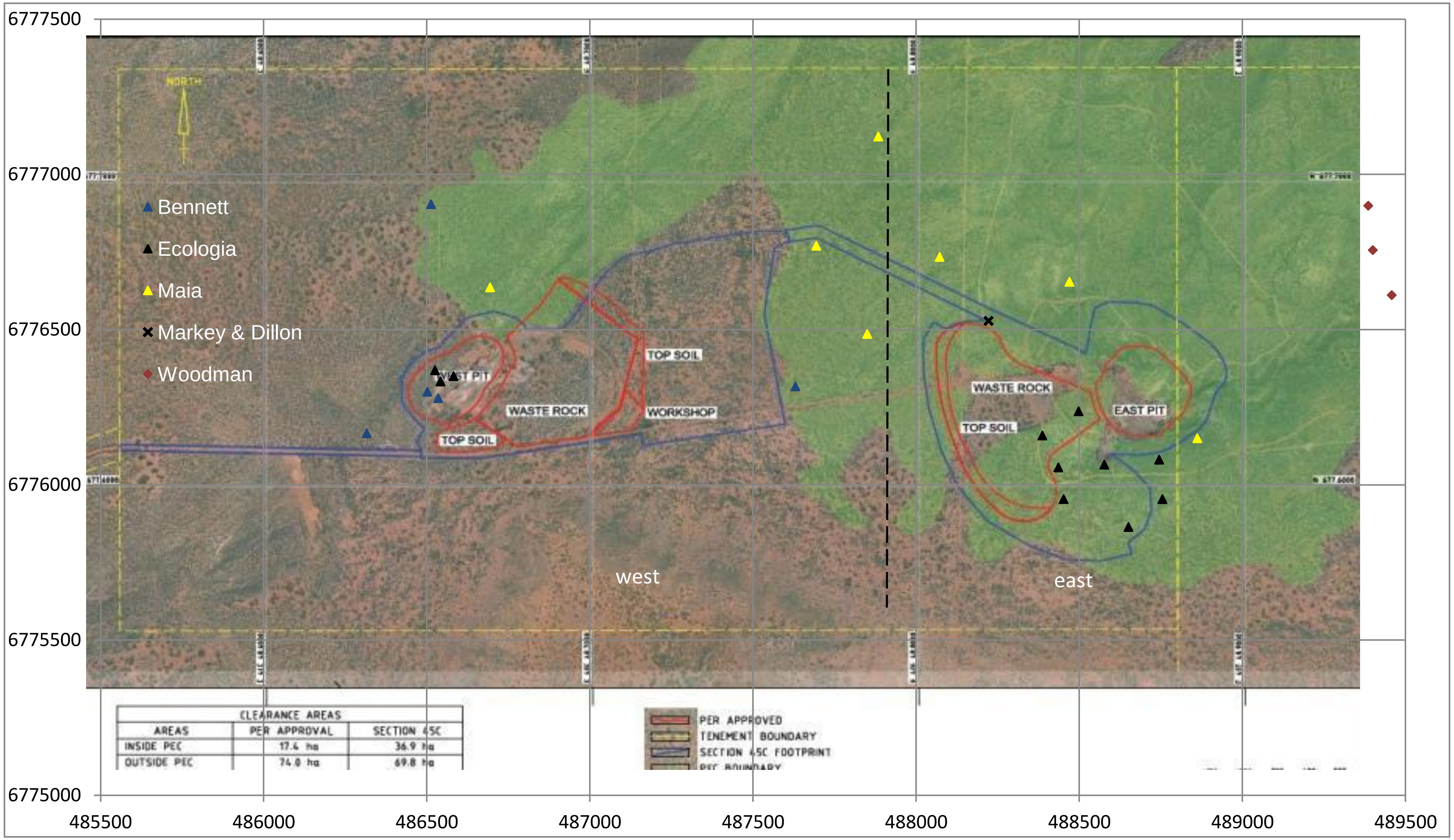


Figure 5. Location of vegetation survey quadrats by Bennett (2004), Ecologia (2008), Maia (2012), Markey and Dillon (2006) and Woodman (2008) at Mungada West and East mine sites.

5. Site and threat assessment

Prior to restoration, each site should be assessed, and any threats should be identified and alleviated. Threats to restored communities include continued mechanical disturbance, erosion / sedimentation (dust), chemical pollution (salinity or toxicity), weed or pest outbreaks, excessive herbivory, altered hydrology and inappropriate fire regime (Miller et al., 2016).

Twelve weed species were recorded as present in the Koolanooka restoration trial (TEC offset area 2016; Table 5) and there were six species in common with the vegetation surveys in the TEC undisturbed areas. The abundance of weed species varied across the restoration trial plots, with plots on the slopes, which received minimal topsoil cover, had a higher abundance of weeds particularly, *Rumex vesicarius* and *Silene nocturna*, than the plots on the flat plateaus. In general, the number of plots in the TEC offset area that had weeds present was greater than what was recorded in undisturbed TEC vegetation (Table 5). Minimal (scattered plants) or no weed species were recorded on the drill pads at Blue Hills (2016).

Table 5. Frequency of plots where weed species were recorded as present in the 1) TEC undisturbed vegetation surveys (19 plots); 2) restoration trials on the TEC offset slope areas (12 plots); and 3) restoration trials on the TEC offset flat plateau areas (18 plots).

Family	Weed species	TEC undisturbed	TEC offset Slopes	TEC offset Flats
Aizoaceae	**Cleretum papulosum*	0%	0%	6%
Aizoaceae	**Mesembryanthemum nodiflorum*	0%	100%	67%
Convolvulaceae	**Cuscuta planiflora*	47%	0%	0%
Poaceae	**Pentaschistis airoides subsp. airoides*	32%	100%	61%
Polygonaceae	** Rumex vesicarius*	16%	100%	89%
Brassicaceae	**Sisymbrium erysimoides*	11%	0%	0%
Caryophyllaceae	**Silene nocturna*	11%	67%	28%
Asteraceae	**Arctotheca calendula*	5%	75%	72%
Asteraceae	**Hypochaeris glabra*	5%	100%	94%
Asteraceae	*Hypocharis-like sp.	0%	0%	11%
Asteraceae	**Monoculus monstrosus*	5%	0%	0%
Asteraceae	**Sonchus asper*	0%	17%	6%
Asteraceae	**Sonchus oleratus*	0%	42%	61%
Caryophyllaceae	**Petrorhagia dubia*	5%	0%	0%
Caryophyllaceae	**Polycarpon tetraphyllum*	5%	0%	0%
Caryophyllaceae	**Spergula pentandra*	5%	83%	17%
Fabaceae	**Medicago minima*	uncommon	0%	0%
Fabaceae	**Trifolium sp.*	0%	0%	1%
Poaceae	**Avena fatua*	uncommon	0%	0%
Poaceae	**Bromus rubens*	uncommon	0%	0%

Weed abundance in TEC offset areas varied across plots – see BGPA Final Report 2017.

Recommendations for site and threat assessment:

(1) Recommend early and continual monitoring and control of weeds during active mining and across all areas to ensure large weed seedbanks do not develop prior to commencement of restoration

(2) Recommend weed control occur before or while species are flowering
  - Department of Agriculture and Food advices on legislation, policies, programmes and coordination of control activities in Western Australia (https://www.agric.wa.gov.au/pests-weeds-diseases/weeds)

(3) Recommend weed control and quarantine of topsoil stockpiles to minimise the impact and spread of weeds

(4) Recommend application of topsoil in restoration to minimise emergence of weed species
  - Weeds emerged from existing seedbank on the waste rock surfaces at Koolanooka mine site that was not covered with topsoil. In contrast very few weeds were found emerging from topsoil.

(5) Recommend vulnerable tubestock be protected from herbivore pressure through fencing (plot size or individual plants) until plants are above grazing height
  - Rabbits and goats have been identified (observations) at Koolanooka mine site and suspect kangaroos (scat type) at Blue Hills who have had impacted tubestock survival and growth.
  - Species planted as tubestock found to be targeted by herbivores included *Acacia tetragonophylla*, *Allocasuarina acutivalvis*, *Calycopeplus paucifolius*, *Eremophila clarkei*, *Grevillea levis*, *Grevillea paradoxa* and *Hakea recurva*.

(6) Recommend emerging seedlings be protected from herbivore pressure through pest management (non-natives only)
  - Alternatives to fencing or pest management that would need additional research (i.e. not tested in this project) could include: a) planting more mature tubestock, as a larger size may increase survival from herbivory pressures; b) planting tubestock at greater densities than required to minimise impact to all tubestock from herbivore pressure; c) using unpalatable species to protect seedlings (i.e. planted amongst broadcast seedlings preventing access to herbivores)

6. Landscape connectivity

Restoration areas should be designed so that they have the **capacity to exchange resources with the adjacent land**. These exchanges could include pollen, seeds, water and fauna. Hence, the interface between restored and undisturbed areas is important to link the two areas, so there should not be any major physical barriers. The physical barrier of isolation, where the distance from the restoration area to adjacent vegetation is greater than the capacity of these exchanges to occur (e.g. >1km for some insects; Byrne et al., 2008), will impede the integration of the restoration area into the landscape leading to a slower or lower rate of initiating the development of complex ecosystem processes (e.g. establishment of pollinator communities) post-restoration efforts. When non-natural physical barriers are in place to enhance restoration success (e.g. herbivore proof fences), they will eventually need to be removed once the threat or reason for placement has been alleviated, allowing the exchange of other resources (e.g. seed dispersers like emus).

Recommendations for landscape connectivity:

(1) Recommend monitoring of restoration to determine integration into the surrounding landscape, including:
   - pollination levels (seed production or mating systems)
   - recruitment capacity (next generation seedlings; development of seedbank)
   - hydrology (infiltration or runoff)
   - or soil function (microbial community)

7. Soils, hydrology, runoff and erosion

The **soil substrate dictates plant establishment, growth and survival** and is correlated with the distribution of many plant species / communities (for example the Blue Hills Priority Ecological Community (PEC) is linked directly with the BIF). The soil substrate can be defined by the three categories; topsoil, subsoil and mine waste (waste rock, fines). Topsoil is the top 10cm of the soil profile that contains valuable amounts of seed, organic matter, and soil nutrient reserves. Underlying the topsoil is the subsoil where roots access water sources and nutrient pools that support juvenile and mature plant growth and survival. Supporting the entire system is the underlying substrate (commonly waste rock in restoration), that amongst other things dictates sub-surface hydrology. Therefore, characterisation of physiochemical properties of substrates used in reconstructing soil profiles and comparison with the reference site is crucial to identify any potential chemical or physical properties in substrates that may impede seedling emergence, survival and plant establishment (Marrs, 2002).

Recommendations for growth media:

(1) Recommend topsoil as the soil cover growth media

- Optimal seedling emergence was observed in topsoil growth media

(2) Recommend cross ripping even with the addition of topsoil

- For heavily compacted areas, analysis showed higher infiltration relative to single ripping or non-ripping treatments

(3) Recommend restoration commence during (seed broadcast) or immediately after (tubestock planting) application of growth media

- Soil surface crusts increase significantly with time, impeding seedling emergence

(4) Not recommended to use fines, ultrafines or fines/ultrafines with the addition of rock

- This is not a suitable growth medium, as seedling emergence and survival was lower than the topsoil or topsoil and rock growth media

(5) Not recommended to use topsoil from flats around the BIF to restore TEC areas

- Flats topsoil showed reduced water storage capacity than BIF topsoil

(6) Not recommended to mix topsoil with waste rock on waste dump plateau

- There is reduced numbers of emergent seedlings from the topsoil seed bank when topsoil is mixed with waste rock on the waste dump plateau

8. Replacing plants

Topsoil seed banks, broacast seed and planted tubestock are three methods of plant replacement and the best method will be species specific.
Best method for plant replacement for each species is documented (Table 8; Appendix 1)

8.1. Choosing the most cost effective method of replacement

Species differ in the ease with which they can be established in restoration. This results from factors such as their abundance in the environment, seed production, viability and predation rates, dormancy mode and requirements for breaking dormancy, natural regeneration strategy (e.g. soil- or canopy-stored seed banks) and sensitivity to the altered environment of restored substrates.

Soil seedbanks have many advantages as sources of material for restoration, they are species rich, genetically representative of original populations, and may be relatively easy to manage (if some specific requirements are met). If soil seed banks are insufficient or unavailable for particular species or communities (i.e. very low density or low seed production), then restoration from collected seed is often the next most effective approach. Appendix 1 lists many species which have been shown to return from topsoil seedbank. Assessment of topsoil seedbanks is a straightforward exercise but requires time to grow plants to sufficient stage for identification. **Seed collections** work well for many species but for others it can be limited by the availability of good quality seed, suitable quantities of seed (difficult and expensive to collect) or lack of knowledge of mechanisms for overcoming dormancy. As a last resort, the production and **planting of tubestock** may be required to overcome some of these problems. Appendix 1 and Table 8 lists the known methods of plant replacement, either through natural recruitment (dispersal via wind, birds or animals), seeds within topsoil, collected seeds, seedlings or cuttings as tubestock.

Rare and threatened species may need special considerations for replacement. Despite restoration of rare and threatened species being beyond the scope of this study, Appendix 4 contains important information for beginning a restoration program for *Acacia woodmaniorum*, a threatened species occurring at Blue Hills.

8.2. Topsoil management

The topsoil seed bank is considered the most valuable source of propagules for restoration purposes (Bellairs and Bell, 1993, Koch and Ward, 1994, Rokich, 1999). In addition to providing seed, topsoil also contains the appropriate fungal and bacterial symbionts required for promoting the successful establishment of many plant species (Bell et al., 1993, Muñoz-Rojas et al., 2016). However, **the value of the topsoil seedbank is highly dependent on topsoil harvesting, handling and storage** which can affect the size and species composition of the soil seed bank (Golos and Dixon, 2014, Rokich et al., 2000, Koch et al., 1996).

The topsoil seedbank is concentrated in the top 5 to 10 cm of soil, hence stripping and harvest should be targeted at this depth to minimise dilution of the soil seedbank. Before topsoil is cleared it is the usual practice to clear vegetation cover. However, clearing of vegetation can result in the removal of the most valuable layer of the topsoil seed bank with the woody debris. Subsequent stripping will result in harvesting of subsoil that will contain a much lower concentration of seeds. Subsoil can provide a valuable growth medium for covering waste rock dumps when there is limited.

Recommendations for topsoil management:

(1) Recommend topsoil be harvested when conditions are dry and stockpiled dry

- Moisture negatively affects the longevity of the soil seedbank and increases the risk of seed loss

(2) Recommend that vegetation (and woody debris) be included in topsoil harvest

- This minimises the loss of the first 5-10cm of topsoil seedbank where seed is concentrated.

(3) Recommend that areas on Banded Ironstone Formations be single stripped and areas on flats be double stripped

- There is not enough topsoil available for BIF formations to be double stripped
- Content of double stripping should be stored separately because the first strip contains the soil seedbank (re-spread last) and the second strip contains the growth media for plants (re-spread first).
- <u>Avoid</u> a single deep strip or combining the content of the two strips as it will dilute the soil seedbank.

(4) Recommend topsoil stockpiled for the shortest period possible

- This minimised the loss of seed viability in the topsoil seedbank
- For example, after 2 years stockpiling seedling emergence from the topsoil seed bank declined by 48%

(5) Recommend appropriate signage for topsoil management

- Dates and provenance are important because restoration success can be landform specific

(6) Recommend topsoil (or topsoil and waste rock media) be spread at ≤ 10cm

- Very few seeds can emerge when buried greater than 10 cm, hence spreading topsoil greater than 10 cm is a waste of a valuable but limited resource

(7) Recommend cross ripping or ripping after topsoil has been spread

- There was higher seedling emergence from broadcast seed on sites that had been ripped before surface sowing of seeds.

(8) With limited topsoil resources, waste rock can be blended with topsoil to increase coverage at a ratio of 3:1 topsoil to waste rock.

- However, this will dilute the topsoil seedbank
- This blend did not significantly reduce seedling emergence from sown seed
- To enable spreading of topsoil rock:armour mixture at 10 cm depth then largest rock size should be <10cm but >than fines) produced during mining operations at Koolanooka was suitable for revegetation on slope trials at Koolanooka as it minimised the formation of voids and reduced erosion.
- Optimum particle size distribution of rock/topsoil blend for restoration requires additional research (i.e. not tested in this project)
- <u>Avoid</u> increasing the ratio of waste rock above the recommended in the blend. It will increase runoff rates because the addition of waste rock decreased infiltration rates in the rainfall simulation experiments.

(9) Recommend supplementing topsoil re-spreading with other restoration efforts (broadcast seeding and/or tubestock planting)

- Topsoil replacement alone will not achieve the target of 70% species replacement.
- Tubestock (seed or cuttings) planting is the most efficient method for species with seeds that are difficult to collect or germinate (Table 8; Appendix 1)
- Seed broadcasting is the most efficient method for species that are easy to collect and may require pre-treatment before seeding (Table 8; Appendix 1)

(10) Recommend seed broadcasting be done during or immediately after ripping

- Air-seeding during ripping (or broadcast immediately after with a seeder drill) will help shallowly bury seeds, increasing germination and emergence through greater soil contact and protection.
- Soils would not have formed a physical crust that would increase the risk of seed loss from the area, through wind or water movement, ants or predation

8.3. Seed management

Topsoil replacement alone is unlikely to achieve the target of 70% species replacement; hence broadcast seeding is required to enhance species diversity and seedling density.
Each of the steps in the seed management chain must be understood and optimised.
Seed quality (the number of live seeds per gram) must be known in order to develop the seeding rates.
Seed pre-treatments such as hot water and smoke water can increase seed germination.
Air-seeding at the same time as ripping is the best method of seed delivery

Knowledge of seed germination optimisation is complex when dealing with biodiverse plant communities, such as those found in the Midwest and Pilbara regions. Whilst in a broad sense the vegetation assemblages across the Midwest are similar, at the local scale there are differences at the species level. **Species-specific information on seed use must, therefore, be tailored to site-specific needs for effective seed use in rehabilitation**. Past failures in the effective use of seed (Table) can be linked to the need to develop site-specific, bioregional approaches to seed utilisation that address the core issues of timing of collection, quality of seed, viability of seed, dormancy release and site delivery techniques.

Table 6. Factors limiting the efficient and effective use of seeds in mine site rehabilitation.

Factors Limiting Seed Use	Impacts on Rehabilitation
Limited understanding of the phenology of seed development and maturation, and the provenance variation for these factors leading to inappropriate timing of seed collection.	Incorrect seed collection timing leading to reduced seed viability, storage life and ability to germinate.
Unresolved seed dormancy alleviation and germination techniques for many species, including those of key families Amaranthaceae, Goodeniaceae, Myoporaceae, Poaceae.	Failure of seed restoration programs attributed to inability to release dormancy.
Poor seed banking procedures that do not consider the required storage duration or designated end use of seeds.	Inadequate storage leading to significant loss of seed viability and poor germination through inappropriate temperatures, seed moisture levels and predation.
Lack of knowledge of storage requirements and germination characteristics of seed.	Low seedling establishment (<10%) from broadcast seeds and inadequate biodiversity representation in rehabilitation
Lack of development of integrated rehabilitation methodologies to link seedling recruitment and establishment to episodic rainfall events.	Failure of seed broadcast methods in post-mining rehabilitation as seed not suitably cued to germinate and establish in remade soils at the appropriate time.

8.3.1. Seed collection, cleaning, quality and storage

Seeds are essential for mine restoration as they are the main component in re-establishing vegetation. Knowledge of seed biology greatly assists restoration practitioners and ensures that restoration is achieved in an efficient manner (Jiménez-Alfaro et al., 2016). **Seed use is a chain, in which each of the steps must be fully understood and optimised to obtain the best restoration outcome** (Figure 6). The first important component of seed use is seed collection. Seeds must be collected when mature so that they have the capacity to germinate. Second, seeds must be cleaned correctly to remove unwanted material. Seed quality must be assessed to ensure that only pure, live seeds are used in restoration. Seeds must then be stored to maintain viability (keep them alive) until use. An understanding of the environmental conditions needed for seed germination is essential. Seeds that do not germinate under optimal environmental conditions may be dormant, and an understanding of how dormancy is lost may assist with the development of seed pre-treatments, or an understanding of how dormancy may naturally be overcome in the soil seed bank. Seeds can be delivered to restoration areas via topsoil, directly seeded, or used to propagate seedlings which are then planted as tubestock.

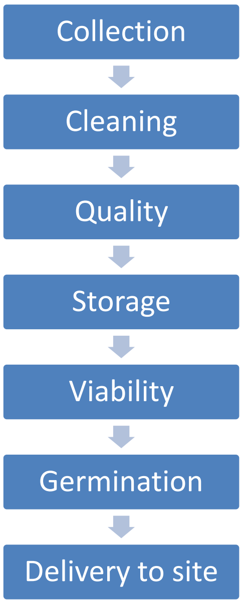


Figure 6. The chain of seed use (Merritt and Dixon, 2011).

Seed collection

Seeds must be collected at maturity. If seeds are collected too early they may not be able to germinate or may be shorter lived in storage. Indicators that seeds are ready for collection include: changes in seed and fruit colour (e.g. seeds may turn from green to brown), fruits rattle as they are full of dry seeds (e.g. *Senna*) or start to split (e.g. *Acacia*), fruits and seeds are dry, seeds/fruits have started to disperse, seeds/fruits disperse when lightly touched. At Koolanooka and Blue Hills, the main seed collection season is October –

January, however, for species which store their seeds in the canopy (e.g. *Eucalyptus* sp.), seeds may be collected all year round. Seed collection contractors will be aware of the timing of seed collection for many species.

Seed cleaning

Seeds and fruits of Australian species come in many shapes and sizes. Seeds develop inside fruits and at maturity the fruits open and disperse the seeds (dehiscent fruits), such as, *Acacia* and *Grevillea* species. Alternatively seeds develop inside dry fruits, but the fruits do not open to release the seed and the fruit is the dispersal unit (indehiscent fruits), such as, *Aluta* species. Fruits can be fleshy, such as *Solanum* species where the fruit, a berry, contains multiple seeds. The type of dispersal unit a plant possesses determines how it is processed after collection, for instance, seeds are generally removed from dehiscent fruits, as they are naturally dispersed as seeds, however seeds are generally not removed from dry indehiscent fruits. Alternatively, seeds may need to be removed from fleshy fruits immediately after collection so that the seeds do not become mouldy in storage.

Seed collections may contain unwanted material such as empty dehiscent fruits, leaves, sticks or insects (may predate seed collections). Seed collections can be cleaned using a variety of methods:

- the material can be sorted by hand, sieves can be used to separate material of different sizes
- an aspirator can be used to separate material of different weights (such as lighter leaves or unfilled seeds)
- winnowing or rolling seeds across an inclined plane or using a gravity separation table
- using a thresher, or by rubbing them across a corrugated rubber mat, however care must be taken not to damage the seeds

Ideally, it is **best to clean seed collections to pure seed to reduce the volume of the collection for storage and to more accurately determine seed quantities for restoration**. However, if non-seed material remains in the collection, then the seed purity should be determined to accurately calculate the contents of a seed mix. Seed batch purity can be calculated on a subsample of the batch using the following equation:

$$\boldsymbol{Purity}\ (\%) = \frac{\boldsymbol{weight\ of\ pure\ seeds\ in\ the\ sample}}{\boldsymbol{weight\ of\ entire\ sample}} \times \mathbf{100}$$

To remove insects, seeds can be placed in an impermeable container, and the container filled with carbon dioxide, sealed and left for 24-48 hours. Alternatively, seeds can be dried and placed in a freezer where the freezing temperature will kill the insects.

Seed quality

In order to germinate, **seeds must contain a viable (live) embryo**. The embryo consists of a radicle (root) and one or two (or more) cotyledons (leaves). Seeds may or may not also contain endosperm, which is the food reserve for the germinating seed. Seeds that contain an embryo/embryo+endosperm are termed 'filled'. To determine whether seeds are filled, they can be dissected using a scalpel and forceps or assessed with x-ray analysis. Dissection is destructive and time consuming but low cost, whereas x-ray analysis is non-destructive and fast, however the equipment is expensive. Unfilled seeds can either be removed from the seed collection with further cleaning, or the seed fill percentage accurately calculated and taken into account when seeds are used for direct seeding or propagation. To calculate seed fill, a subsample of each seed collection batch (as quality can vary from species to species and year to year) should be quality tested, and the average seed fill can then be used to calculate the seed mix for the seed batch used.

Seed storage

Seeds for restoration activities often need to be stored between collection and use, and storage time may be less than one year or many years. As seeds are metabolically active, they need to be kept alive during storage. The length of time that seeds will remain alive (their longevity) depends on the storage temperature, the seed moisture content, initial seed quality and the species (Royal Botanic Gardens Kew, 2011, Probert, 2003, Martyn et al., 2009). **As storage temperature decreases, seed longevity increases**. Storage temperature is relatively easy to control and monitor, with seed storage options ranging from room temperature for short term storage (≤ 5 years), to 1-10°C for medium term storage (5-10 years) and -18°C for long term storage (> 10 years).

Lowering seed moisture content also increases longevity. Seed moisture content depends on the relative humidity of the surrounding air. Most seeds are hygroscopic, which means that they are able to absorb moisture from the air, if the water potential of the air is higher than that of the seed, until they are in equilibrium with the air. Seeds are also able to lose moisture if the surrounding air is drier than the seeds. The relative humidity of air that is in equilibrium with the seed is known as the equilibrium relative humidity (eRH). Understanding seed moisture content is crucial for seed storage, because **as seed moisture content decreases, longevity increases**. The general effects of storage eRH on seed longevity are presented in Table 7.

Temperature and relative humidity of the storage environment can be easily measured. For instance, a thermometer can be placed in the seed store to determine the current temperature. To monitor both temperature and eRH in the seed store over a long period of time, a data logger could be used. Equilibrium relative humidity of seeds prior to, during, and after storage can be measured with a hygrometer, self-indicating silica gel, or moisture indicating strips (Royal Botanic Gardens Kew, 2011).

Table 7. Seed survival over a range of equilibrium relative humidity's (eRH). For further information see Royal Botanic Gardens Kew (2011).

eRH%	Seed Survival
70-85%	Seeds at risk of rapid loss in viability
50-70%	Suitable for short term storage
30-50%	Suitable for medium term storage
10-30%	Suitable for long term storage

Guidelines for the collection, cleaning, testing and storage of seeds

A "checklist" of equipment, facilities, and biological considerations important for collecting seeds has been provided below. Some further guidelines outlining the principles of seed collection can also be found in Sweedman and Merritt (2006) and Offord and Meagher (2009).

Essential infrastructure and equipment:

Seed collection

- Collection books to record information
- GPS
- Tags to label collections
- Plant press to collect herbarium specimens
- Camera to photograph plants to add to herbarium specimens
- Plant identification books
- Maps of roads and known plant populations
- Large buckets / bins, calico bags, paper bags, secateurs

Seed cleaning and quality testing

- An enclosed area to protect people and seeds from the elements (sun/wind/rain), and an air-conditioned room to ensure that seeds are not exposed to extreme temperatures during processing and drying
- Large trays on which to dry seeds
- Sieves to separate seeds by size from non-seed material
- A vacuum separator (aspirator) to separate seeds by weight and shape from non-seed material and empty seeds
- Corrugated rubber mats and rubber blocks to remove seeds from fruits
- A sink to rinse seeds from fleshy fruits
- A dissecting microscope and dissecting kit to assess seed quality
- Permeable shelving (e.g. wire)
- A balance for weighing seeds

- A computer and spreadsheet/database to record all collection, cleaning, quality and storage information

Seed storage (short term, <5 years)

- A room in which to dry seeds
- An air-conditioned room in which to store seeds
- Shelving on which to store herbarium specimens
- Data loggers for recording temperature and relative humidity
- Airtight bags for seed storage (e.g. laminated aluminium foil bags)
- A heat sealer to hermetically seal storage bags

Training required for team leader and collecting staff:

- Plant identification and correct plant vouchering and lodgement of herbarium specimens
- Seed collection techniques – timing, seed maturation, harvesting techniques and technology
- Seed cleaning techniques – post harvest handling and treatment
- Seed quality testing

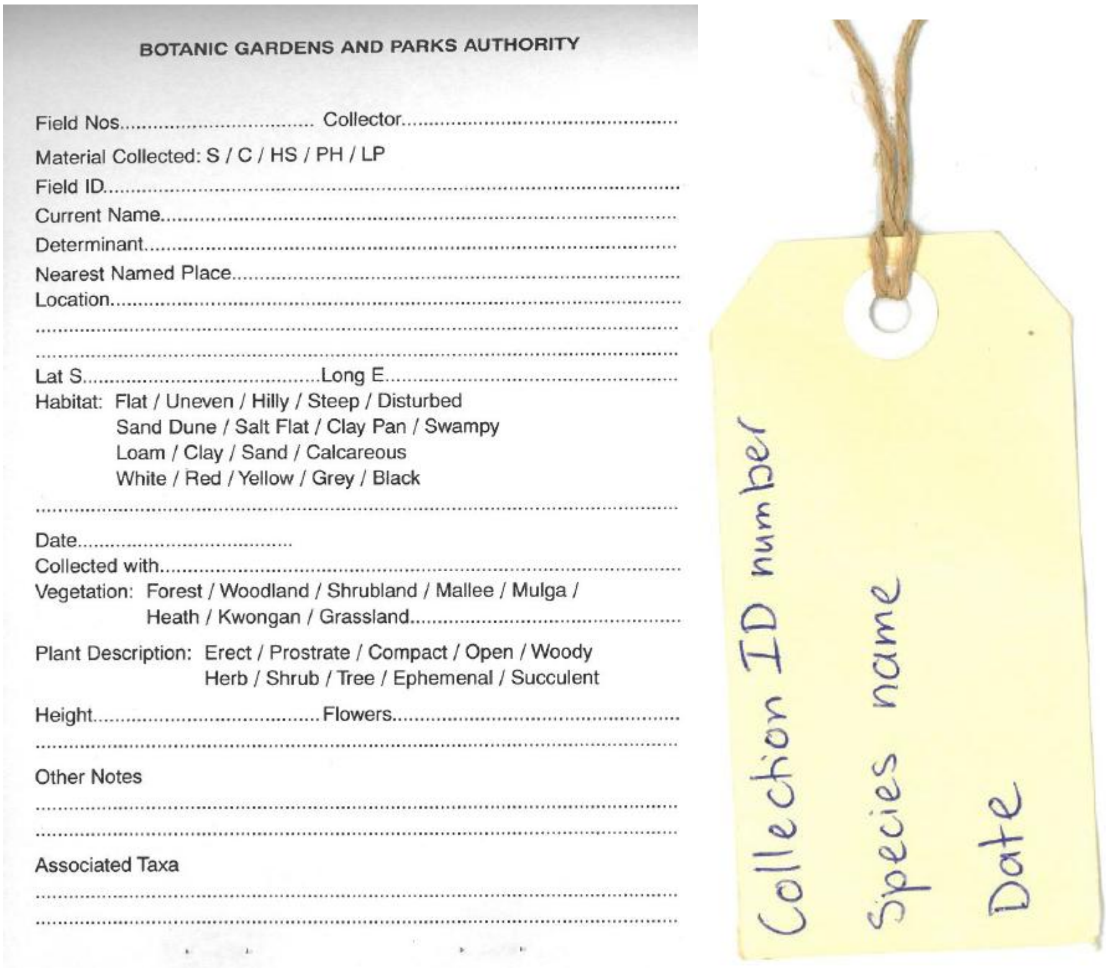
The chain of seed use (Figure 6):

- Planning seed collection
    - Ensure the appropriate permits and permissions are obtained.
    - Decide on a provenance zone for the mine.
    - Decide on target species for collection and seed quantities required for restoration.
    - At flowering time (winter/early spring), assess the area within the provenance zone and record GPS coordinates of the areas where the target species occur. Record where there is prolific flowering of target species. Collect herbarium specimens and photos when plants are flowering.
    - Regularly return to areas where plants are flowering to track seed maturation. Return visits could be undertaken 2-weekly during and immediately after flowering, then weekly or several times a week as the seeds approach maturity.
- Collecting seed and voucher specimens
    - Spread collection over the largest possible number of widely dispersed trees.
    - Avoid sites where seed crops are sparse or heavy crops are restricted to isolated plants.
    - Collect across the range of site conditions.
    - Record GPS location, collection date, number of trees collected from, position in landscape, etc. in a collection book, and label each collection with a reference number (Figure 7).

    - Collect seeds or fruit when mature with secateurs, but the seeds have not yet dispersed.
    - Store collections in permeable such as calico bags.
    - Collect voucher specimens and press between newspaper in a plant press.
- Post-harvest handling
    - Remove leaf material to reduce bulk and moisture prior to transport.
    - Store seeds in permeable (calico or paper) bags or on trays prior to and during cleaning
    - Keep collections in dry conditions where possible.
- Seed drying
    - To release the seeds from dehiscent mature fruits, collections can be stored in dry conditions at room temperature for a few weeks, or until seeds are released.
    - Once seeds are released, the collections can be stored in cool dry conditions (e.g. 15% RH, 15°C) until cleaning.
- Seed cleaning
    - Use the rubber mats, sieves and aspirator to separate seeds from non-seed material (including insects) to reduce bulk before storage.
- Determining seed quantity (weight and number) and quality (purity, fill and viability)
    - To determine seed purity and seed quantity use the following steps
        - Weigh the entire seed batch (A)
        - Remove and weigh a small sub-sample (B) (or several replicate sub-samples)
        - Separate seeds from non-seed material in the sub-sample, and count (C) and weigh (D) all of the seeds
        - Then use the following calculations:
            - Purity of the seed batch (%) = (D / B) × 100
            - Total weight of seeds in the seed batch = A × (Purity of the seed batch / 100)
            - Individual seed weight = D / C
            - Total number of seeds in the seed batch = Total weight of seeds in the seed batch / Individual seed weight
    - Seed fill (whether or not the seed contains an embryo and/or endosperm) can be determined by x-ray analysis or a cut test
    - Seed viability (whether or not the seeds are alive) can be determined by a cut test or a germination test (as these seeds are non-dormant)
        - X-ray analysis will show filled seeds as bright white, whereas unfilled seeds will be greyish, or just the outline of the seed coat will be visible. This test is fast (undertaken in seconds) and non-destructive, but expensive equipment is required.

        - Seed fill % = (number of filled seeds / total number of seeds) × 100
    - To perform a cut test, firstly imbibe the seeds in water (usually on moist filter paper in a petri dish), then cut open each seed using a scalpel and inspect the embryo inside under a dissecting microscope. Seeds may either have an embryo present (filled) or absent (not filled) Turgid and white tissues indicate viable seed, soft or liquid, grey, brown or black tissues indicate non-viable seed. This test can be undertaken within a day, but is destructive.
        - Seed fill % = (number of filled seeds / total number of seeds) × 100
        - Seed viability % = (number of viable seeds / total number of seeds) × 100
    - To perform a germination test, place seeds on moist filter paper or germination test paper in a petri dish and incubate between 15-25°C for 4 weeks, then count the number of seeds that have germinated. Seeds that germinate are considered viable. A cut test can be performed on the ungerminated seeds to determine their viability, but given that these species are non-dormant, if incubated under the correct conditions, a germination test may estimate viability. Ensure that an adequate subsample is tested, for instance, 4 replicates of 100 seeds. This test takes longer than the others, but more information can be gained.
        - Germination % = (number of germinated seeds / total number of seeds) × 100
  - Seeds should be supplied with information about seed quality (purity, fill and viability). Seed supplied to SMC by commercial collectors has mostly had high seed fill, except for *Dodonaea inaequifolia*, *Conospermum* sp., *Acacia sclerosperma* var. *cuthbertsonii*, *Allocasuarina campestris*, *Eremophila miniata* and *Sida calyxhymenia* which showed less than 50% seed fill (x-ray analysis), and *Senna artemisioides* ssp. *helmsii* which had <15% seed fil (x-ray analysis).
- Storing seeds
  - Dry seeds under appropriate conditions. This can include a purpose-built drying room that maintains relative humidity below 50%, and ideally at 15%; or the appropriate use of silica gel or other desiccant.
  - Storage conditions
    - If seeds are to be used within 2-3 years of collection, seeds may be stored in a cool, dry place. Ideally, relative humidity should be maintained at 15-20%. Ensure the relative humidity does not exceed 50% and the temperature does not exceed 25°C.

        - If seeds are to be stored for 5-10 years before use, store seeds at a temperature ≤5°C. Ensure seeds are dried first at 15-20% RH and sealed in air-tight packaging prior to storage. If seeds are not hermetically sealed they will absorb moisture from a cool atmosphere.
        - If seeds are to be stored for > 10 years before use, they should be dried at 15-20% RH, hermetically sealed in air-tight containers and stored at -18°C.
        - Drying and/or storage conditions can be displayed and recorded using a data logger which is capable of measuring temperature and relative humidity, such as T-TEC 7-1C, Tinytag View 2 or HOBO UX.
    - Storage containers
        - Examples of air-tight storage containers include glass containers with rubber seals or tri-laminate foil bags (which can be sealed with a heat sealer).
    - Labelling
        - Each collection should be labelled with a reference number, species name, collection date, collection location, storage date, initial number of seeds and current number of seeds (if subsamples of the collection are withdrawn for testing or restoration) (Figure 7).
    - Data management
        - A spreadsheet recording the collection details, reference number, seed quantity and quality information and current location (drying or storage) of each collection should be maintained.
    - Re-testing
        - After a period of storage, seeds may need to be re-tested for quality, particularly if they are stored for longer than their intended period. See the guidelines for seed quality testing above.


BOTANIC GARDENS AND PARKS AUTHORITY

Field Nos.................................. Collector...

Material Collected: S / C / HS / PH / LP

Field ID..

Current Name...

Determinant..

Nearest Named Place...

Location...

....

....

Lat S...Long E...

Habitat: Flat / Uneven / Hilly / Steep / Disturbed
Sand Dune / Salt Flat / Clay Pan / Swampy
Loam / Clay / Sand / Calcareous
White / Red / Yellow / Grey / Black

....

Date.......................................

Collected with...

Vegetation: Forest / Woodland / Shrubland / Mallee / Mulga /
Heath / Kwongan / Grassland...

Plant Description: Erect / Prostrate / Compact / Open / Woody
Herb / Shrub / Tree / Ephemenal / Succulent

Height..Flowers...

....

Other Notes

....

....

Associated Taxa

....

....

Figure 7. An example of a seed collection information sheet (left) and an example of a suitable label for seed collection (right).

Recommendations for seed collection, cleaning, quality and storage:

(1) Recommend seeds are collected at maturity

- Seed collection should commence 1-3 years prior to clearing

(2) Recommend seed batches be cleaned to remove non-seed material such as leaves, insects, and empty dehiscent fruits

- Seed batches will then take up less space in storage and are less likely to be subject to predation

(3) Recommend seed quality be assessed on a sub-sample of each seed batch

- Quality assessment will allow for accurate seed mix calculations

(4) Recommend seeds are stored at a temperature and relative humidity appropriate for their intended length of storage time

- Storing at low temperature and low relative humidity will help maintain seed viability between collection and use

8.3.2. Seed pre-treatment

Seeds require water, oxygen and appropriate temperature conditions for germination. However, seed that do not germinate under conditions that would otherwise be appropriate are termed dormant. An understanding of the type of seed dormancy a species possesses, and how it is alleviated, can firstly be used to:

- understand how seed dormancy is naturally alleviated in the soil seed bank
- direct research for species that do not reliably germinate under laboratory conditions or in restored areas
- develop effective seed treatments for efficient *ex-situ* propagation or for seed pre-treatment prior to seed broadcasting

The two main types of dormancy most likely to be present are physical and physiological dormancy. Some species are non-dormant, and do not require pre-treatments to enable reliable germination in the field. Seed germination may also be related to a species recruitment strategy and therefore indicate what alternative pre-treatments can be applied to species. For example, seed germination stimulated by smoke may indicate fire following species and is of particular importance for restoration, as this smoke cue may need to be delivered to seeds prior to seed broadcasting. An interaction between physiological dormancy loss and a fire cue has been found in several species from fire-prone and non fire-prone environments. To pre-treat seeds that require smoke for germination, smoke can be pumped through water to form an aqueous solution, termed smoke water. Seeds can be soaked in smoke water then dried prior to seeding. Smoke contains many compounds, and one of these, karrikinolide, is able to promote seed germination of many species. Seeds with physiological dormancy lack the growth potential to overcome the constraint of the structures surrounding the embryo (i.e. endosperm, seed coat or fruit). The mechanism of overcoming dormancy may be currently unknown, in which case, seeds may be removed from their covering structures, and grown as tubestock.

Recommendations for seed pre-treatments:

(1) Recommend seeds with physical dormancy be pre-treated with a short treatment of wet or dry heat, or physical scarification

- Physical dormancy is present in seeds with a water impermeable seed or fruit coat.
- A short treatment of wet or dry heat using hot water or an oven, can overcome physical dormancy.
- Recommend hot water (95°C for 1-2 mins) was effective at overcoming physical dormancy of *Acacia, Senna* and *Dodonaea* spp.
- Species with physically dormant seeds are commonly found in 16 families, including the Fabaceae (*Acacia* spp.), Malvaceae (*Sida* spp.) and Sapindaceae (*Dodonaea* spp.)

(2) Recommend seeds with physiological dormancy be pre-treated by exposure to growth hormones or chemicals

- Fire responsive species can be pre-treated with karrikinolide or smoke water (commercial scale)
- In our laboratory trials, germination of the following species was increased with karrikinolide: *Lawrencella davenportii, Myriocephalus guerinae, Brunonia australis, Grevillea levis, Velleia rosea, and Grevillea paradoxa*
- For nursery propagation of *Grevillea* spp. using seed, germination can be increased by 'nicking' the seed (cutting off part of the seed coat without damaging the embryo. Although time consuming, if seeds are valuable, then this may be a cost effective method of propagation

Appendix 1 indicates the type of seed dormancy (PY=physical, PD=physiological, MPD=morphophysiological, ND=non-dormant; non-dormant and physical dormant species being most easy to germinate)

8.3.3. Seed mix

The selection of species for the seed mixes for each domain should be based on the list of species in the reference community for that domain. Additional species from adjacent communities can also be used to increase the diversity**. Seeding rates should be based on seed quality (fill and viability), seedling emergence, plant survival and required plant density**. For example, Figure 8 shows how 2000 seeds/ha of a hypothetical species can result in only 108 seedlings/ha, when arbitrary values of seed fill, viability, germination and emergence are taken into account. These values are all species specific, and can vary from year to year so need to be assessed on each seed batch. Appendix 1 contains the recommend seeding rates for species at Koolanooka and Blue Hills.

What to do if there are too few seeds

For some species, only a small number of seeds may have been collected, in which case these collections are too valuable for direct seeding. If collections are fewer than can be seeded at 1,000 seeds/ha. For those species, the perennials could be propagated as seedlings, and the annuals could either be sown in discrete patches at high density. Alternatively, seeds from those species may need to be collected over several years to obtain a sufficient number of seeds for broadcasting.

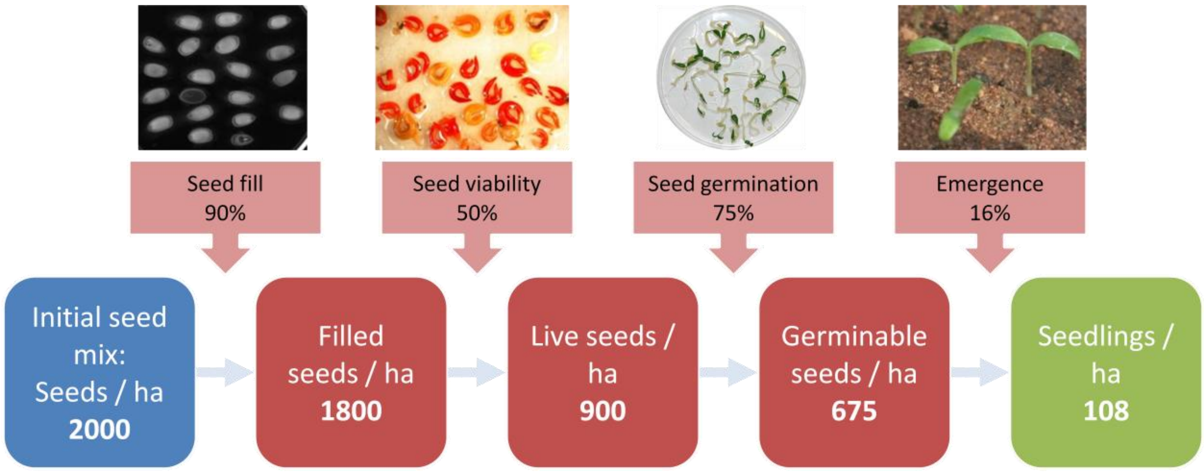


Figure 8. The effect of low seed fill, low seed viability, low seed germination and/or low seedling emergence on the actual number of seedings established in restored areas (hypothetical species as an example).

An example of a seed mix used at Koolanooka.

Appendices 5 and 6 represent examples of seed mixes used at Koolanooka. Seed supplier (Red Dirt Seeds) provided the list of species and seed quantities for the 2013 restoration seed mixes for Koolanooka. Seed weights allowed calculations of seed number and therefore an estimate to be placed in the seed mix (Appendices 5&6). The weight of seed per 100g was determined either from seeds provided by the supplier (Red Dirt Seeds), from the Seed Information Database (http://data.kew.org/sid/), or from the BGPA seed store. The number of seeds per ha or per m^2 allows comparisons to be made with the number of seedlings per unit area, as determined in the restoration monitoring program. These worked calculations of seed mixes shows how information for seed mixes can be recorded.

Calculating the seeding rate

Seeding rate should be calculated on the basis of live seeds per unit area (e.g. per ha), rather than by weight, as seed weight of different species varies widely. For example, the number of seeds per gram varies as widely as 33,000 (*Cephalipterum drummondii*), 582 (*Allocasuarina campestris*) and 11 (*Acacia ramulosa*) per gram.

From our research, we have determined that once dormancy is overcome, seedling emergence is the bottleneck to recruitment. Our lab trials have ascertained that for the species that we have worked on, germination is high (often >90%), but emergence is much lower (<1% in a low rainfall year, <10% with irrigation). Survival in the TEC offset is around 10% (in a low rainfall year). These ball park figures (which of course vary annually, between species and between growth media), together with the plant density information we collected during the vegetation survey, have enabled us to estimate seeding rates to achieve target plant densities (Appendix 1). If emergence is estimated to be 10%, and survival is estimated to be 10%, 100 seeds should be sown for every 1 plant required. This assumes that seed fill and viability is high, if not, seeding rates need to be adjusted accordingly. For species without density data, seeding rates could be estimated using information on plant frequency (Appendix 1), with very common species seeded at a higher rate than common and uncommon species. To start with, perennial species without density information could be sown at 1,000 seeds/ha. For annual species with unknown density, start by using a seeding rate of 30,000 seeds/ha. Annual plant density was not determined during the study, however, annual species are likely to be in higher density than perennials, although their numbers fluctuate from year to year due to annual rainfall variation. Although annual species may not be present in the required density in the first year after seeding, if they set seed, then plant density may increase over time.

The suggested seeding rates are based the assumption that the restored areas are connected to the undisturbed areas of the landscape. Hence, we assume there will not be any issues with minimum population numbers, and therefore founder effects. Also, it is essential that the seeding rate is recorded (see section 14) to enable adaptive management. The seeding rates suggested in this report are a starting point for continual improvement.

Recommendations for developing the seed mix:

(1) Recommend undertaking quality assessment on each seed batch

(2) Recommend calculate species specific seeding rates based on:
- number of seeds per gram (Appendix 1)
- plant species densities in reference sites (Appendix 1) or ranked species lists of abundance from vegetation surveys
- seed quality (a property of each seed batch)

(3) Recommend a starting point for seeding rates at 100 seeds in the seed mix for every 1 plant required if no suitable information available
- This includes a generic (not species specific) estimate of 50% mortality of emergent seedlings in an arid environment

(4) Recommend for species with known plant density, seeding rates range from 1,100 to 34,400 seeds/ha

(5) Recommend for perennial species with unknown density, start by using a seeding rate of 1,000 seeds/ha, and for annual species with unknown density, start by using a seeding rate of 30,000 seeds/ha
- If insufficient seeds of a perennial species are available for the seed mix (i.e. <1,000 seeds/ha), then they should be used to generate seedlings in a nursery, and not included in the seed mix.

- If insufficient seeds of an annual species are available for the seed mix, then they should be sown separately in concentrated patches on site, rather than added to the broadcast seed mix.

(6) Recommend that the vegetation monitoring program assess plant density in restoration after 1-2 years and implement an adaptive management approach by adjusting seeding rates accordingly for each species in successive restoration efforts

8.3.4. Seed delivery

Seeds can be delivered by hand or by machinery. Hand seeding may be necessary in small areas or areas with limited access. When hand seeding, it may be difficult to apply seed at the correct rate, so that you don't either run out of seed, or have seed left over. To ensure an even seeding rate, divide up the area to be seeded on a map, and peg it out. Then divide up the seed mix accordingly (i.e. if seeding 12 units, then divide the seed mix by weight into 12 bags). **Machinery will be more efficient in larger areas with suitable access**. We used the Aitchison MiniSeeder A260 in the 2013 field trials (Figure 9). Alcoa used a purpose built air seeder which is attached to a dozer with tines, so that they rip and seed in the one pass (Figure 9).

Our experiments found that seeds of *Acacia* sp. had higher emergence when buried, whereas *Allocasuarina acutivalvis* and *Waitzia nitida* had higher germination on the surface, indicating that for some species, likely those that have very small seeds or those that require light, surface seed broadcasting is preferable to seed burial but the number of these species were few.

Recommendations for delivering seed to site:

(1) Recommend seed broadcasting be done during or immediately after ripping

- Air-seeding during ripping (or broadcast immediately after with a seeder drill) will help shallowly bury seeds, increasing germination and emergence through greater soil contact and protection
- Soils would not have formed a physical crust that would increase the risk of seed loss from the area, through wind or water movement, ants (up to 23% removal) or predation
- If possible, (for instance if a seeder drill can seed different species at different depths) seeds of some species may benefit from being surface sown (*Allocasuarina acutivalvis* and *Waitzia nitida*)

Figure 9. Seeding process with the direct seeder at Koolanooka (top left); close-up detail of the seed burial process with the direct seeder (bottom right) and an example of an air-seeder which is attached to a dozer with tines (right; courtesy of Alcoa, photo taken from http://www.alcoa.com/australia/en/info_page/mining_air_seeding.asp).

8.4. Planting

For species that **do not set sufficient seed** to collect for broadcasting, or have **low emergence rates** must be raised under nursery conditions and the species introduced to site via **tubestock planting** (see Appendix 1). Production of plants under nursery conditions can fall under two broad propagation strategies, traditional seed based and vegetative propagation. Vegetative propagation (i.e. cuttings) is beneficial when seed propagation is difficult, large nursery stocks are required in a short time period, specific genotypes and / or disease free plants are required. The disadvantages of the system include greater production costs, a reduction in the amount of genetic diversity, and investment in propagation infrastructure. After plants are successfully produced via vegetative propagation methods they can move into traditional nursery production. Propagation information developed during this research program including seed pre-treatments, optimum germination temperatures and strike rates of cuttings should be provided to the nursery to maximise their success. Planting density (spacing) should reflect plant density and pattern (clumps) observed in reference sites.

Cutting propagation techniques
Plants from cuttings have been successfully generated for 10 species from Koolanooka. The methodology for producing plants from cuttings is as follows. Take tip or semi hardwood cuttings from healthy plants. Softwood cuttings have been more successful than hardwood cuttings. Wrap cuttings in damp newspaper and seal in plastic bags for transport, then store in a refrigerator overnight. Dip cuttings in clonex rooting gel (3g/L indole-3-butyric acid) before planting into punnets containing 30% peat moss, 30% coarse sand, and 30% native potting mix. Place punnets inside plastic incubators to reduce water loss and increase humidity then place onto heat mats (set at 30^{o}C soil temperature) and water every 2-3 days. Once roots are formed, transplant the plants into forestry tubes containing 1:1 native potting mix and Koolanooka TEC topsoil.

All seedlings and cuttings must be grown in an accredited media that is free of pathogens (e.g. *Phytophthora*), pests and invasive species.

Planting techniques
Tubestock can be carried around site in kidney buckets and planted using potiputkis (Figure 12). Planting may be done in the same year as seeding, or infill planting may be done 2 or 3 years after planting when surveys have determined which species are absent, or in low density. Planting should be undertaken when the soil profile has been sufficiently moistened at the break of the season.

Genetic variability

When establishing a new population of plants, care should be taken to ensure that a sufficient number of genetic individuals (not clones) are planted and subsequently survive post-planting, so to avoid the potential of a 'founder effect'. This effect occurs when there are too few individuals in the new population to maintain the levels of genetic diversity, resulting in its decline in the new population (Espeland et al., 2017, Miller et al., 2016). In addition, plants or seeds should be sourced from multiple individuals, which are spread across the entire population (or multiple populations), that are local to the where the new population is to be established. This is to avoid the effects of inbreeding (i.e. poor plant fitness) in the new population, which occurs when too few genetic individuals are sourced for collection resulting in the capture of low genetic variability, and increases the risk of the new population not surviving (Weeks et al., 2011). At Koolanooka and Blue Hills the reference ecosystems are mostly adjacent to the restoration sites, allowing multiple individuals from local populations to be sourced for material. With the gradual initiation of natural processes (after the reduction of threats) in restoration sites, it is expected that there will be exchange of genetic material between the two sites, through pollination and seed dispersal, thus providing landscape connectivity that maximises population survival and minimises any potential 'founder effects'.

Costs

Approximate quotes (2015) for generating tubestock are approximately as follows:

- Seedlings = $1.50 to $1.75 +GST ea
- Cuttings = $1.75 to $1.99 + GST ea
- SMC to supply seed and cutting material
- To cover the sowing costs: $25 +GST per propagation tray for seed and $50 per propagation tray for cuttings.

Recommendations for planting:

(1) Recommend use of accredited nurseries to propagate tubestock from seed or cuttings for semi-arid native plants
    - Source cuttings near to restoration site around late winter/early spring
    - Select semi-hardwood material for striking

(2) Recommend planting density (spacing) reflect the density and pattern (e.g clumps) observed in reference sites.
    - Plant species densities as in reference sites (Appendix 1) or ranked species lists of abundance from vegetation surveys
    - To account for approximately 50% tubestock mortality after planting, double the number of plants should be planted

(3) Recommend planting tubestock propagated in standard forestry pots

- Optimum size for transport and planting.

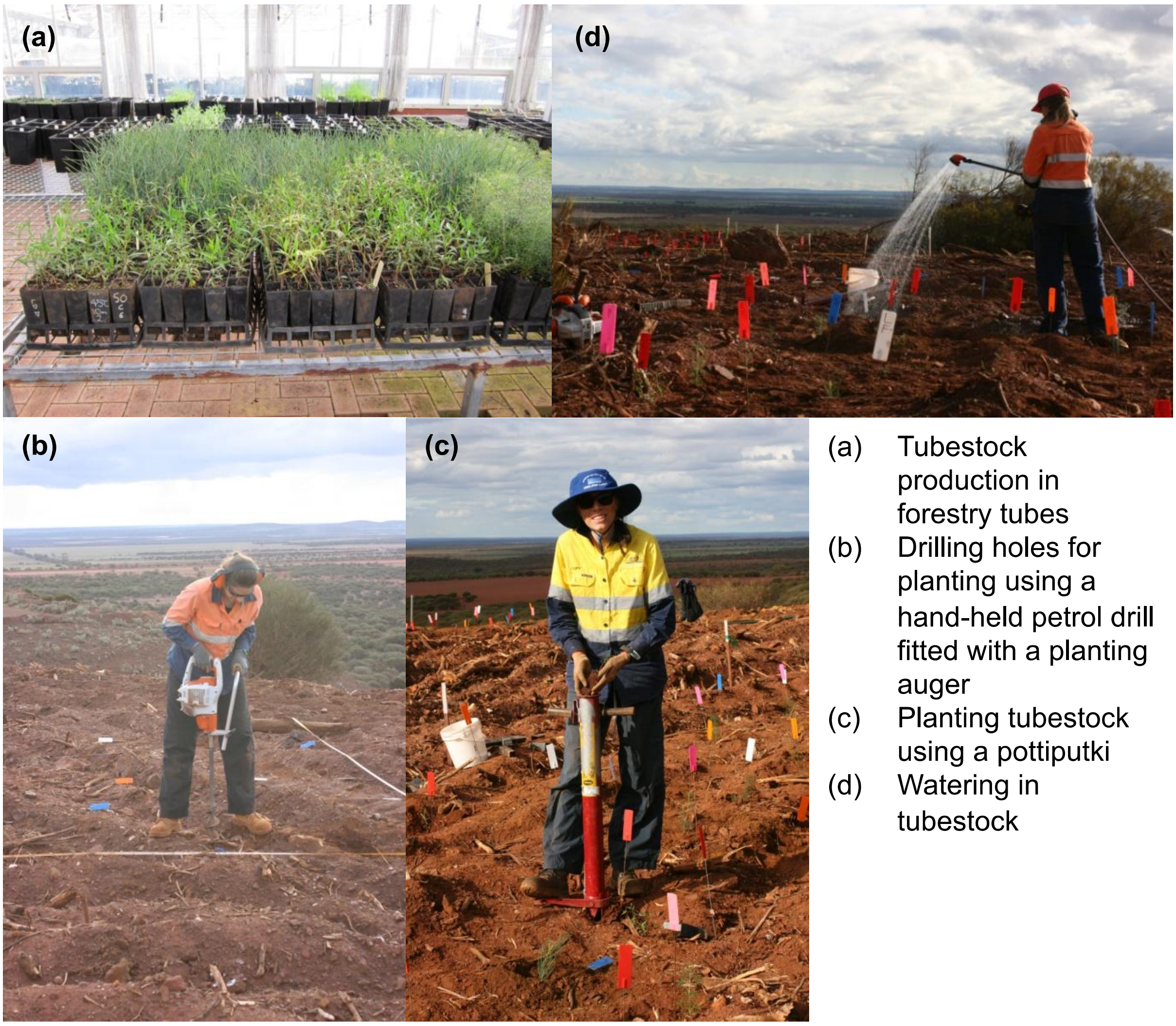
(4) Use a petrol driven auger (70mm diameter for standard pots) to dig holes

(5) Plant tubestock and form a saucer-shaped depression around plants

(6) Immediately water (1 litre) tubestock after planting

(7) After watering inspect tubestock to determine if root ball needs to be re-covered with additional soil after it has settled, then water again

- This method ensures good soil contact for the tubestock root ball and increases the soil moisture available to the tubestock after planting



(a) Tubestock production in forestry tubes
(b) Drilling holes for planting using a hand-held petrol drill fitted with a planting auger
(c) Planting tubestock using a pottiputki
(d) Watering in tubestock

Figure 10. Planting activities on restoration site, showing processes.

Table 8. Frequency, seed weight, seed pre-treatment, plant density, method of species replacement (natural recruitment, topsoil, seed, seedling, cutting), and seeding rates for species in DEC community 3 (summarised from Appendix 1).

Family (-aceae)	Species	Frequency	100 seed wt (g)	seeds per 100g	Required pre-treatment	Plant density (plants/ha)	Method of return	Seeding rate (seeds/ha)
Amaranth-	*Ptilotus gaudichaudii*	32					topsoil, nat. rec.	
Amaranth-	*Ptilotus obovatus*	63	0.3443	29050	none	344	topsoil, nat. rec.	
Amaranth-	*Ptilotus polystachyus*	42						
Api	*Xanthosia bungei*	21						
Api-	*Daucus glochidiatus*	5						
Apocyn-	*Rhyncharrhena linearis*	uncom.						
Arali-	*Trachymene cyanopetala*	11	0.1543	64823			topsoil	
Arali-	*Trachymene ornata*	37	0.1886	53426		56	seed	
Asparag-	*Arthropodium dyeri*	16						
Asparag-	*Thysanotus manglesianus*	11						
Aster-	*Calotis hispidula*	11						
Aster-	*Gilruthia osbornei*	5						
Aster-	*Lawrencella davenportii*	32	0.3129	31956	KAR			
Aster-	*Podolepis canescens*	47	0.0300	377407	NA			
Aster-	*Rhodanthe battii*	53	0.2472	40453	TBA			
Aster-	*Rhodanthe maryonii*	5						
Aster-	*Waitzia acuminata*	47	0.0224	447227	TBA			
Casuarin-	*Allocasuarina acutivalvis*	63	0.2439	41448	none	78	seeding	7800
Casuarin-	*Allocasuarina acutivalvis subsp. prinsepiana*	uncom.						
Casuarin-	*Allocasuarina campestris*	5	0.1609	62454	none	44	seed	4400
Casuarin-	*Allocasuarina dielsiana*	26	0.2495	40077	none	11		1100
Chenopodi-	*Dysphania melanocarpa f. melanocarpa*	5						
Chenopodi-	*Enchylaena tomentosa var. tomentosa*	11				189		
Chenopodi-	*Maireana brevifolia*	5					topsoil, nat. rec	
Chenopodi-	*Maireana carnosa*	5	0.4659	21462			topsoil, nat. rec	
Chenopodi-	*Maireana planifolia*	32	0.5274	18960	none			
Crassul-	*Crassula colorata var. acuminata*	uncom.						
Crassul-	*Crassula sp. – probably C. colorata*	5						
Cyper-	*Lepidosperma sp. Koolanooka*	uncom.						
Dilleni-	*Hibbertia arcuata*	5						
Dioscore-	*Dioscorea hastifolia*	74				56	seed	5600
Eric-	*Astroloma serratifolium*	16						
Euphorbi-	*Calycopeplus paucifolius*	63	0.0166	603136		56	cuttings	
Euphorbi-	*Euphorbia tannensis subsp. eremophila*	26						
Euphorbi-	*Ricinocarpos muricatus*	5						
Fab-	*Acacia acuminata*	53	0.8158	12504	HW			
Fab-	*Acacia andrewsii*	5						
Fab-	*Acacia assimilis subsp. assimilis*	37				22	seed	2200
Fab-	*Acacia coolgardiensis*	11	0.3474	29094	HW			
Fab-	*Acacia exocarpoides*	58	2.9587	3404	HW	133	topsoil, seed	13300
Fab-	*Acacia nigripilosa subsp. nigripilosa*	26				44	seed	4400
Fab-	*Acacia ramulosa var. ramulosa*	68	9.2027	1094	HW	267	seed	26700
Fab-	*Acacia stereophylla var. stereophylla*	11						
Fab-	*Acacia tetragonophylla*	68	1.4857	6741	HW	22	seed	2200
Fab-	*Acacia umbraculiformis*	uncom.						
Fab-	*Daviesia hakeoides subsp. hakeoides*	53				22	seed	

Family (-aceae)	Species	Frequency	100 seed wt (g)	seeds per 100g	Required pre-treatment	Plant density (plants/ha)	Method of return	Seeding rate (seeds/ha)
Fab-	*Mirbelia bursarioides*	16				44	seed	4400
Fab-	*Mirbelia microphylla*	26						
Fab-	*Senna charlesiana*	uncom.						
Fab-	*Senna glutinosa subsp. chatelainiana*	21	2.1670	4615	HW			
Gerani-	*Erodium cygnorum*	84					topsoil, nat. rec.	
Goodeni-	*Goodenia mimuloides*	5						
Goodeni-	*Goodenia pinnatifida*	16						
Goodeni-	*Scaevola spinescens*	16						
Goodeni-	*Velleia rosea*	37	0.3411	30734	KAR?			
Hemerocallid-	*Caesia sp. Koolanooka Hills P1*	5						
Hemerocallid-	*Dianella revoluta var. divaricata*	11						
Hemerocallid-	*Tricoryne elatior*	11						
Lami-	*Hemigenia sp. Yalgoo*	5						
Loranth-	*Amyema gibberula var. tatei*	5						
Malv-	*Abutilon cryptopetalum*	5						
Malv-	*Abutilon oxycarpum*	21						
Malv-	*Androcalva luteiflora*	uncom.						
Malv-	*Sida calyxhymenia*	5	0.3338	29954	TBA	11	seed or seedling	1250
Malv-	*Sida sp. dark green fruits*	89				133	cuttings	
Malv-	*Sida sp. Golden calyces glabrous*	37				78	cutting as seeds may be scarce	
Myrt-	*Aluta aspera subsp. hesperia*	uncom.						
Myrt-	*Enekbatus dualis P1*	uncom.						
Myrt-	*Eucalyptus ebbanoensis*	5						
Myrt-	*Eucalyptus sp.*	uncom.						
Myrt-	*Melaleuca barlowii P3*	uncom.	0.0140	716332	none			
Myrt-	*Melaleuca hamata*	11	0.0066	1506024	none		seedling	
Myrt-	*Melaleuca nematophylla*	37	0.0120	940503	none	133	seedling	
Myrt-	*Melaleuca radula*	11	0.0095	1056636	none		seedling	
Pittospor-	*Bursaria occidentalis*	uncom.						
Po-	*Amphipogon caricinus var. caricinus*	32			none	22		
Po-	*Anthosachne scabra*	5				22		
Po-	*Aristida contorta*	5	0.1221	81878				
Po-	*Austrostipa elegantissima*	74	0.1641	60951				
Po-	*Austrostipa hemipogon*	5						
Po-	*Austrostipa scabra*	5						
Po-	*Austrostipa trichophylla*	16						
Po-	*Austrostipa variabilis*	21						
Po-	*Cymbopogon ambiguus*	uncom.						
Po-	*Monachather paradoxus*	74						
Polygon-	*Comesperma integerrimum*	16				11		
Polygon-	*Comesperma volubile*	5				11		
Portulac-	*Calandrinia eremaea 'dull-seeded variant'*	11						
Prote-	*Grevillea levis*	5	1.6912	5913	KAR		seedling or cutting	
Prote-	*Grevillea obliquistigma subsp. obliquistigma*	5				67	seed	
Prote-	*Grevillea paradoxa*	58	1.0905	9170	KAR + nicking	189	seedling or cutting	
Prote-	*Hakea recurva subsp. recurva*	42						
Prote-	*Persoonia hexagona*	uncom.						
Pterid-	*Cheilanthes lasiophylla*	uncom.						
Pterid-	*Cheilanthes sieberi / adiantoides*	79						
Rut-	*Philotheca brucei subsp. brucei*	21						
Sapind-	*Dodonaea inaequifolia*	58	0.3497	28730	HW	56	seed	

Family (-aceae)	Species	Frequency	100 seed wt (g)	seeds per 100g	Required pre-treatment	Plant density (plants/ha)	Method of return	Seeding rate (seeds/ha)
Scrophulari-	*Eremophila clarkei*	32				33	cuttings	
Solan-	*Solanum cleistogamum*	5						
Solan-	*Solanum ellipticum*	58				100		
Solan-	*Solanum lasiophyllum*	63				33	seed	
Solan-	*Solanum sp.*	5						
Stylidi-	*Stylidium confluens*	5						
Thymelae-	*Pimelea angustifolia*	11						
Thymelae-	*Pimelea microcephala subsp. microcephala*	uncom.						
Urtic-	*Parietaria cardiostegia*	uncom.						

9. Irrigation

Irrigation of restoration sites can provide **a risk management strategy** to ensure the investment in seed sown and tubestock planted against the highly variable rainfall patterns of a semi-arid climate. Rainfall/irrigation experiment conducted at Koolanooka found very few seedlings emerged with below average ambient winter rainfall conditions compared to irrigation suppling simulated 5th or 8th decile winter rainfall (Morawa airport).

If water is limited, then the water can be concentrated to a 'resource island' concept, whereby patches (e.g. size and number can be adjusted to water availability minimum size 20x20m) within the landscape are irrigated. These islands served to concentrate limited resources instead of spreading them over a larger area which may have decreased their effectiveness. The 'resource island' concept can be used when resources such as water capacity or seed quantity are limiting.

Recommendations for irrigation:

(1) Recommend that irrigation system replicate as a minimum the 8th decile winter rainfall pattern (Morawa airport weather station) after the sowing season, which meant delivering 10 mm of water every 4 days during the winter (June to August).

- Most species are timed to germinate during the cooler winter months to avoid false breaks during summer when follow up rains are not likely and will result in death of newly germinated seedlings

(2) Tubestock watered immediately after planting and inspected

- Plant tubestock and form a saucer-shaped depression around plants and water in (~1L)
- As the soil may settle after watering, root balls may be exposed and requires soil backfilled into planting whole to cover root ball and then re-watered (~1L).
- This method ensures good soil contact for the tubestock root ball and increases the soil moisture available to the tubestock after planting
- Use a hose connected to an existing irrigation system or use of a water cart.
- Monitoring of the soil may indicate tubestock may require a repeat watering if still too dry

(3) Recommend an irrigation design of an appropriate system be undertaken by suitably qualified personnel or contractors

- Designs may include features such as soil moisture probes to monitor automatic watering or remote sensing for monitoring

- Designs should include an element of re-use, so that the infrastructure can be moved to another site the following year

(4) Water quality and information required for design of appropriate irrigation system

- E.C. value
- Quantity and frequency of supply
- Power supply gravity or pump
- Design must take into account the availability of human resources for monitoring and maintaining the irrigation system (on site versus remote system).

10. Measuring plant performance

Measuring and monitoring plant performance across seasonal stresses will demonstrate the capacity of restoration to respond to environmental factors.

To assess the performance of seedlings on restored mine sites in comparison with mature plants in undisturbed reference communities ecophysiological measurements can be undertaken. Measurements can be used to demonstrate to regulatory bodies that the vegetation in restoration sites is performing physiologically similarly (or better) to vegetation in undisturbed sites and hence is following a trajectory towards successful restoration.

Ecophysiological measurements include the assessment of plant carbon and water relations, which determines:

(1) How plants function under favourable and adverse conditions
(2) What stress levels plants experience
(3) How environmental factors impact on plant function and survival

Ecophysiological measurements involves:

(1) Pre-dawn and midday water potentials to determine the plants' water status
(2) Chlorophyll florescence measurements to assess levels of plant stress
(3) Stomatal conductance assessments and gas-exchange to assess plant function
(4) Leaf temperature assessments

Ecophysiological measurements require:

(1) A suitable reference plant or site (or control plants, either contained in a glasshouse environment or located in a natural population in the field).
(2) A good experimental design and knowledge on data analysis and interpretation, to maximise the outcomes from any monitoring program.
(3) Significant set up of equipment and onsite support to obtain the results. However, there are some portable devices available for field assessments (options of hiring equipment from speciality laboratory service or purchase).

Ecophysiology is a specialist field and these services may be found at research institutions (University or Government) or possibly environmental consultants that specialise in this type of field monitoring. For examples of datasets generated as part of the program please see Appendix 7.

11. Exploration lines and drill pads

Restoration activities in exploration areas must be undertaken during specific seasons during the year to maximise success.

Restoration of exploration areas (drill pads and exploration lines) requires the execution of appropriate topsoil management, broadcast seeding and planting of tubestock as outlined in Section 8 (Replacing plants).

Ideally all drill pad operations (clearing, topsoil stripping, drilling then rehabilitation) should be carried out when the topsoil is dry i.e. about October to March. Layout of exploration lines and drill pads should be designed to minimise runoff and hence chance of erosion especially after rehabilitation. In drill pads ensure topsoil stockpile is placed to minimise any potential runoff ponding at base of stockpile. Due to the size of drill pads and hence the size of topsoil stockpiled after stripping, it is practical to use waterproof tarpaulins to keep topsoil dry and maintain topsoil seed bank viability during storage. In one study covering topsoil stockpiles increased seedling emergence by 3.5 times after two years of storage (Golos & Dixon 2014). If the drill pad needs to be levelled, ensure topsoil stripping is carried out first and subsoil is used to level site.

Vegetation assessment of older drill pads that were stripped and replaced at Blue Hills had shown that the return of topsoil and ripping had replaced 70% of species found in adjacent reference plots on drill pads nine years after restoration (BGPA Final Report 2017). Restoration trials on younger drill pads (~two years old) showed that broadcast seeding and planting of tubestock are suitable methods for returning species to site that have not come up from the topsoil seedbank. The level of herbivory that occurred on site showed that tubestock plantings could incur a loss in growth for certain palatable species (i.e. *Allocasuarina acutivalvis* and *Acacia tetragonophylla*; see Site and Threat Assessment).

If the protocol for topsoil harvesting and storage is followed then seeding is not likely to be required for drill pads and exploration lines. However, annual monitoring should be undertaken and drill pad revegetation should be compared to adjacent reference sites. If there is any significant difference in species present or abundance then tubestock planting should be used to reach reference site targets.

Recommendations for exploration areas:

(1) Recommend exploration operations be carried out when soil is dry

- Approximately November to March which will maximise soil seedbank viability

(2) Recommend implementation of design and ripping to minimise surface runoff

- Prevents the formation of erosion gullies that negatively affect restoration

(3) Recommend topsoil stockpiles be located where water does not pond at the base and they be covered

- Prevents the input of moisture into the topsoil stockpile and minimises the decrease in soil seedbank viability over time
- A 15 m long x 3 m wide at base x 1.5 high topsoil stockpile would require a readily available tarpaulin (680 gsm ripstop PVC) from a canvas supplier (Figure 11)

(4) If topsoil harvesting and storage protocols are followed, then broadcast seeding is unlikely to be required for drill pads and exploration lines

- 70% of species replacement had been achieved with topsoil replacement alone on drill pads after nine years at Blue Hills

(5) Recommend annual monitoring to detect species loss from exploration areas

- Absent species or species lost can be replaced with tubestock

(6) If topsoil harvesting and storage protocols are not followed, recommend supplementing topsoil re-spreading with other restoration efforts

- Tubestock planting is the most efficient method for species with hard to collect or store seeds (Table 8; Appendix 1)
- Seed broadcasting is the most efficient method for species that are easy to collect and pre-treat before application (Table 8; Appendix 1)

(7) If seed broadcasting, recommend it be done during or immediately after ripping

- Air-seeding during ripping (or broadcast immediately after with a seeder drill) will help shallowly bury seeds, increasing germination and emergence through greater soil contact and protection
- Soils would not have formed a physical crust that would increase the risk of seed loss from the area, through wind or water movement, ants (up to 23% removal) or predation
- Soils formed a physical crust similar to the reference site in drill pads that were nine years old (high soil impedance). Younger drill pads (~ two years old) had lower soil impedance, but this was still significantly higher than the simulations for recently spread topsoil (few days)

(8) If planting tubestock, recommend once off watering in at time of planting

- To allow for 50% tubestock mortality, double the number of tubestock that should be planted according to density estimates

- Important for tubestock survival, particularly in low rainfall years
- Plant tubestock and form a saucer-shaped depression around the plant and water in (~1L)
- As the soil may settle after watering, root balls may be exposed and requires soil backfilled into planting hole to cover root ball and then re-watered (~1L)
- This will increase the soil moisture available to the tubestock, reducing water stress as it settles after planting shock and puts out new roots to search for moisture.

Figure 11. A TEC sub-community topsoil store. The topsoil was collected dry and immediately tarped to ensure moisture could not interact with the seedbank. This is this one of the first examples of the practice in Western Australia, and potentially represents leading practice on a global scale. Photo: Stephen Neill SMC, 2010

12. Timing of restoration activities

Restoration activities such as surveys, soil movement, seeding and planting must be undertaken during specific seasons of the year to maximise success.

The timing of restoration activities is critical, due to the seasonal nature of the work, and forward planning is necessary for planning works and engaging contractors. The following chart (Table 9) will facilitate restoration planning.

Vegetation surveys should be undertaken during late winter/early spring when plants are flowering and annuals are present, to enable plants to be identified. If vegetation surveys are undertaken during summer, identification of some perennial species may be challenging, and annuals will not be present. Seed must be collected when it is mature and before it disperses. Cuttings need to be collected in spring for the propagation of tubestock for planting the following year. Fast growing species, such as Acacias, may need a minimum of 6 months before planting. Whereas slow growing species, such as *Melaleuca* sp., may need a minimum of 12 months before planting so they are at a suitable development/growth stage for planting. Soil containing the seed bank should be stripped and respread when dry. Seeding should occur immediately after soil is respread and before the breaking rains. Tubestock should be planted when the soil has sufficient moisture.

Scheduling these activities around operations can be challenging, but not impossible (Table 9). For instance, if exploration drilling is due to be commenced in winter, clearing the exploration lines and topsoil return should not be done immediately before and after the drilling. However, the site can be cleared and topsoil stockpiled prior to rainfall, and after drilling in winter, soil can be then be returned in summer.

Table 9. The timing of restoration activities during the season. For planning of most restoration activities, consideration is required months in advance. For example, seed collection activities would be needed to be completed a year before plant propagation can occur. In addition, plant propagation needs to be started at least nine months before planting in the field.

Activity		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Surveys	Vegetation surveys (reference or restoration sites)							dark grey	dark grey	dark grey			
Seed collection	Engage seed collectors		dark grey	dark grey	dark grey								
	Seed collection	dark grey						light grey	light grey	light grey	dark grey	dark grey	dark grey
Plant propagation	Engage propagators			dark grey	dark grey	dark grey							
	Collect cuttings							dark grey	dark grey	dark grey			
	Commence propagation						dark grey	dark grey	dark grey				
Topsoil	Topsoil harvest	dark grey	dark grey	dark grey	dark grey							dark grey	dark grey
	Respread of topsoil and ripping	dark grey	dark grey	dark grey	dark grey							light grey	light grey
Restoration	Installation of irrigation		light grey	dark grey	dark grey	light grey							
	Broadcast seeding			light grey	dark grey								
	Planting tubestock					light grey	dark grey	dark grey					
	Mature-whole plant translocation (from field)						dark grey	dark grey					
	Weed control (first signs of flowering)						light grey	dark grey	light grey				
	Vertebrate control		dark grey	dark grey	dark grey								

dark grey represents optimal time for activity

light grey represents an optional extension for activity, usually dependent on the break in season or species-specific development during the season.

13. Record keeping of restoration activities

Detailed record keeping is essential for adaptive management.

Keeping records of restoration activities can ensure the retention of knowledge within the company and assist with adaptive management (such as adjusting the seeding rate, changing the type of ripping). In addition, these records may help to identify differences in monitoring outcomes between sites. Individual records should be kept for each restoration area, i.e. each area with unique site characteristics and restoration history (Figure 12).

<table>
<tr><th colspan="2">Restoration record</th></tr>
<tr><th colspan="2">Site</th></tr>
<tr><td>Site reference:</td><td>Location (GPS):</td></tr>
<tr><td>Site preparation:</td><td>Machinery used:</td></tr>
<tr><td>Slope angle:</td><td>Aspect:</td></tr>
<tr><td>Topography:</td><td>Total area (ha):</td></tr>
<tr><td colspan="2">Type of area: waste dump, road, cleared area, infrastructure, excavated area, other</td></tr>
<tr><td colspan="2">Domain:</td></tr>
<tr><td colspan="2">Physical properties (parent material, texture etc.) and chemical properties (C, N, P, organic carbon, pH, EC) (attach to record)</td></tr>
<tr><th colspan="2">Topsoil</th></tr>
<tr><td colspan="2">Topsoil source (GPS and community type):</td></tr>
<tr><td colspan="2">Species list at topsoil source (attach to record)</td></tr>
<tr><td>Date of topsoil stripping:</td><td>Date of topsoil spreading:</td></tr>
<tr><td>Storage duration:</td><td>Stockpile height:</td></tr>
<tr><td colspan="2">Spreading depth:</td></tr>
<tr><td colspan="2">Physical properties (texture etc.) and chemical properties (C, N, P, organic carbon, pH, EC) (attach to record)</td></tr>
<tr><th colspan="2">Ripping</th></tr>
<tr><td>Ripping date:</td><td>Machinery:</td></tr>
<tr><td>Type (single, cross rip):</td><td>Spacing:</td></tr>
<tr><td colspan="2">Depth:</td></tr>
<tr><th colspan="2">Organic material</th></tr>
<tr><td>Type (mulch, woody debris):</td><td>Application rate:</td></tr>
<tr><td>Source location:</td><td>Species at source location:</td></tr>
<tr><th colspan="2">Seed</th></tr>
<tr><td colspan="2">Species sown, collection location, supplier, seed quality, seed germination (if known), seed pre-treatment, application rate of each species (seeds/ha) (attach list)</td></tr>
<tr><td>Seeding date:</td><td>Seeding method (hand, machinery):</td></tr>
<tr><th colspan="2">Tubestock</th></tr>
<tr><td>Source material (seed or cuttings):</td><td>Source collection location:</td></tr>
<tr><td>Tubestock age:</td><td>Tubestock size:</td></tr>
<tr><td>Planting date:</td><td>Planting method:</td></tr>
<tr><td colspan="2">Planting density:</td></tr>
<tr><th colspan="2">Threats</th></tr>
<tr><td>List of weed species present (attach to record)</td><td>Weed management undertaken:</td></tr>
<tr><td colspan="2">Presence of herbivores (domesticated, feral):</td></tr>
<tr><td colspan="2">Herbivore exclusion undertaken (fencing, culling):</td></tr>
<tr><td colspan="2">Presence and control of feral predators:</td></tr>
<tr><th colspan="2">Rainfall</th></tr>
<tr><td colspan="2">Rainfall between topsoil spreading, seeding and planting and 31 December of the same year:</td></tr>
<tr><th colspan="2">Completion criteria</th></tr>
<tr><td colspan="2">List the completion criteria and indicate the reference community for the restoration area (attach)</td></tr>
</table>

Figure 12. An example of the variables recorded at a restoration site to ensure adequate maintenance of data collected.

14.Restoration monitoring and evaluation of completion criteria

Once appropriate community targets / completion criteria have been established, restoration monitoring can commence to determine whether the areas that have been subject to restoration activities are progressing towards the target, and to therefore determine if intervention is required.

Maia Environmental Consultancy has drafted a rehabilitation monitoring plan outlining the monitoring protocols. They have recorded the following:

- Tree species density, diversity and height
- Tree and shrub canopy and basal cover
- Coarse woody debris
- Native shrub, grass, forbs species richness and weed cover
- Rock and litter cover
- Erosion

In addition, monitoring could record the reproductive status of the plants, i.e. whether they are flowering and/or seeding. Seeding will indicate that the site is on its way to becoming self-sustaining. The presence of secondary recruitment (i.e. the offspring of the initial recruits) should also be recorded if observed. Secondary recruitment would indicate that the site is self-sustaining, although that may take several years, depending on the species.

15. Adaptive management

Adaptive management in restoration can allow changes to the methods used for restoration as monitoring assesses restoration success. It also allows remedial action to be made if the site trajectory looks like it will not meet the completion criteria. The ability to take early action on the criteria will largely depend on careful record keeping, following restoration recommendations, regular monitoring (early and annually) of restoration progress (emergence, survival, plant cover), and continued maintenance of the existing threat abatement measures. For instance, if weed cover is found to be above the target, weed control should be undertaken as early as possible before the weeds can set another crop of seed. If initial species richness is less than 70%, tubestock (cuttings and seedlings) of additional species could be planted and monitored for survival, and in future, additional species could be added to the seed mix. Tables 10 and 11 list potential remedial actions for Koolanooka and Blue Hills ,that can be undertaken in an adaptive management response.

Table 10. Closure criteria for Koolanooka Hills and the remedial action that may be required if completion criteria are not achieved

Aspect	Objectives	Completion criteria	Measurement tools	Remedial action

Flora and Vegetation	Impacted areas are returned to self-sustaining vegetation communities that reflect pre-disturbance state.	• Rehabilitation conducted as per BGPA research program.
		• Compliance with Ministerial conditions (species richness, weeds).
		• Flora and vegetation are re-established with not less than 70 percent composition (not including weed species) of the known original species diversity.
		• Weed coverage no more than that in undisturbed bushland in the area or less than 10%, whichever is the lesser.
			• Annual vegetation monitoring programs and weed surveys;
			• Comparison of vegetation density and diversity with agreed analogue communities;
				• Absent species from restoration areas
				  ○ Infill planting of these species
				  ○ Include larger quantities of absent species in the seed mix or planting list for future restoration areas
				• Weed coverage greater than undisturbed bushland or 10% coverage
				  ○ Undertake weed control before plants have set seed and monitor annually
				  ○ Ongoing weed control required if a weed seedbank has already established
				• Species with inadequate density
				  ○ Infill planting of perennials to increase stem density
				  ○ Increase seeding density of perennials and annuals in future restoration areas
				• Site is unstable or has higher erosion than that of pre-disturbance
				  ○ Ensure bunds at the top of the slopes are intact
				  ○ Assess and modify ripping procedures and battering of slopes or possibly slope angle
				  ○ Consider different soil coverage
				• Ecosystem not self-sustaining (i.e. function not that of pre-disturbance state)
				  ○ Ensure threats have been controlled
				  ○ Assess connectivity of restoration to surrounding vegetation (i.e. not isolated)
				  ○ Identify the specific function that is not present and works towards reinstating it

Table 11. Closure criteria for Blue Hills and the remedial action that may be required if completion criteria are not achieved

Aspect	Objectives	Completion criteria	Measurement tools	Remedial action
Flora and Vegetation	Impacted areas are returned to self-sustaining vegetation communities and fauna habitats that reflect pre-disturbed state. Weed species cover does not increase, relative to pre-mining condition.	• Within five years post closure, flora and vegetation has been re-established to at least 70% composition of original known diversity, as per Ministerial Condition 13-3 (a). Baseline diversity levels are those referred to in the ATA 2004 report, titled "Vegetation and Flora Assessment, Koolanooka, Midwest Corporation Limited, and ecologia's 2008 report titled "Koolanooka/Blue Hills Flora and Vegetation Survey". • Within five years post closure, weed coverage represents no more than in undisturbed bushland or less than 10%, whichever is the lesser, in accordance with Ministerial Condition 13-3 (b).	• Rehabilitation conducted as per BGPA research program at Koolanooka: • Deep ripping has been conducted in rehabilitation areas. • Flora species have been identified for use in r ehabilitation and seed collection, and reflect principles of vegetation succession. • Annual weed surveys and vegetation health assessments. • Comparison of vegetation density and diversity with agreed previous. • Annual flora surveys.	• Absent species from restoration areas o Infill planting of these species o Include larger quantities of absent species in the seed mix or planting list for future restoration areas • Weed coverage greater than undisturbed bushland or 10% coverage o Undertake weed control before plants have set seed and monitor annually o Ongoing weed control required if a weed seedbank has already established • Species with inadequate density o Infill planting of perennials to increase stem density o Increase seeding density of perennials and annuals in future restoration areas • Site is unstable or has higher erosion than that of pre-disturbance o Ensure bunds at the top of the slopes are intact o Assess and modify ripping procedures and battering of slopes or possibly slope angle o Consider different soil coverage • Ecosystem not self-sustaining (i.e. function not that of pre-disturbance state) o Ensure threats have been controlled o Assess connectivity of restoration to surrounding vegetation (i.e. not isolated) o Identify the specific function that is not present and works towards reinstating it

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Appendices

Appendix. 1. TEC offset reference community species list (DEC Community 3: *Allocasuarina* Low Open Woodland) and additional species in DEC Communities 4 and 5, and ATA Community 15. Species frequency is recorded for DEC 3 and 4, and presence in DEC 5 and ATA 15, noting whether seed has been collected, its seed dormancy class (PY=physical, PD=physiological, MPD=morphophysiological, ND=non-dormant; non-dormant and physical dormant species being most easy to germinate), whether it has been observed emerging from the topsoil seed bank in situ, whether it returns through natural recruitment (i.e. wind/bird/animal dispersal determined by its presence on substrates not containing topsoil) and whether seed and/or cuttings have been collected, and the required pre-treatment (HW=Hot water 90°C for 1-2 minutes, KAR=karrikinolide or smoke, nicking=remove the seed coat from the radicle end of the seed). Data for DEC 3 was compiled from DEC plots KOOL32, KOOL 34 and Maia plots K1, K3, K4, K5, K6, K7, K8, Botanic Gardens and Parks Authority plots TRS 1-10 and TRS walk.

Family (-aceae)	Species	Topsoil or natural recruit	Seed collected	Cuttings collected	Life form	DEC 3	DEC4	DEC5	ATA 15	100 seed wt (g)	seeds per 100g	Control max germination (%)	Treated max germination (%)	Dormancy	Required pre-treatment	Plant density (plants/ha)	Method of return	Seeding rate (seeds/ha)
Amaranth-	*Ptilotus gaudichaudii*	topsoil, nat. rec.	yes		annual herb	32								PD?			topsoil, nat. rec.	
Amaranth-	*Ptilotus obovatus*	topsoil, nat. rec.	yes		shrub	63		*		0.3443	29050	96	93	ND/PD	none	344	topsoil, nat. rec.	
Amaranth-	*Ptilotus obovatus var. obovatus*	topsoil			shrub				*									
Amaranth-	*Ptilotus polystachyus*	nat. rec.	yes		annual or perennial herb	42		*						PD?				
Api	*Xanthosia bungei*				shrub	21	86							ND/PD/MPD				
Api-	*Daucus glochidiatus*				annual herb	5								ND/PD/MPD				
Apocyn-	*Alyxia buxifolia*				shrub			*										
Apocyn-	*Rhyncharrhena linearis*				shrub or climber	uncom.												
Arali-	*Trachymene cyanopetala*	topsoil	yes		annual herb	11				0.1543	64823			ND/PD/MPD			topsoil	
Arali-	*Trachymene ornata*		yes		annual herb	37			*	0.1886	53426			ND/PD/MPD		56	seed	
Asparag-	*Arthropodium dyeri*				perennial herb	16	71	*						ND/PD/MPD				
Asparag-	*Thysanotus manglesianus*		yes		perennial herb	11	86	*										
Asparag-	*Thysanotus pyramidalis*				perennial herb		29											
Aster-	*Calotis hispidula*	topsoil			annual herb	11								ND/PD				
Aster-	*Cephalipterum drummondii*		yes		annual or perennial herb				*					ND/PD				
Aster-	*Cratystylis spinescens*				annual or perennial herb				*									

Family (-aceae)	Species	Topsoil or natural recruit	Seed collected	Cuttings collected	Life form	DEC 3	DEC4	DEC5	ATA 15	100 seed wt (g)	seeds per 100g	Control max germination (%)	Treated max germination (%)	Dormancy	Required pre-treatment	Plant density (plants/ha)	Method of return	Seeding rate (seeds/ha)
Aster-	*Gilruthia osbornei*	topsoil, nat. rec.	yes		annual herb	5								ND/PD				
Aster-	*Lawrencella davenportii*	topsoil	yes		annual herb	32				0.3129	31956	4	7	PD	KAR			
Aster-	*Myriocephalus guerinae*	topsoil								0.3988	30783	2	8	PD	KAR			
Aster-	*Olearia humilis*				shrub			*										
Aster-	*Podolepis canescens*	topsoil	yes		annual herb	47				0.0300	377407	99	98	ND	NA			
Aster-	*Podolepis lessonii*				annual herb				*					ND/PD				
Aster-	*Rhodanthe battii*	topsoil	yes		annual herb	53				0.2472	40453	19	10	PD	TBA			
Aster-	*Rhodanthe humboldtiana*									0.3598	27796	1	0	PD	TBA			
Aster-	*Rhodanthe maryonii*		yes		annual herb	5								ND/PD				
Aster-	*Schoenia cassiniana*	topsoil								0.4980	20080	91		ND			seed	
Aster-	*Waitzia acuminata*	topsoil	yes		annual herb	47			*	0.0224	447227	0	0	PD	TBA			
Aster-	*Waitzia nitida*									0.0354	348296	100	100	ND	none			
Casuarin-	*Allocasuarina acutivalvis*		yes		shrub/small tree	63	29	*		0.2439	41448	100	100	ND	none	78	seed	7800
Casuarin-	*Allocasuarina acutivalvis subsp. prinsepiana*				shrub/small tree	uncom.								ND				
Casuarin-	*Allocasuarina campestris*		yes		shrub	5	29			0.1609	62454	99	100	ND	none	44	seed	4400
Casuarin-	*Allocasuarina dielsiana*		yes		tree	26				0.2495	40077	100		ND	none	11		1100
Chenopodi-	*Atriplex codonocarpa*	nat. rec.								0.0952	105020	75	51	ND	none			
Chenopodi-	*Atriplex isatidea*									0.1196	83612	90	85	ND	none			
Chenopodi-	*Atriplex semilunaris*	topsoil, nat. rec.								0.1463	68353	100		ND	none		topsoil, nat. rec.	
Chenopodi-	*Dysphania melanocarpa f. melanocarpa*	topsoil			annual herb	5								PD?				
Chenopodi-	*Enchylaena lanata*				perennial shrub			*						PD?				
Chenopodi-	*Enchylaena tomentosa var. tomentosa*				shrub	11		*	*					PD?		189		
Chenopodi-	*Maireana brevifolia*	topsoil, nat.	yes		shrub	5								ND/PD			topsoil, nat. rec	

Family (-aceae)	Species	Topsoil or natural recruit	Seed collected	Cuttings collected	Life form	DEC 3	DEC4	DEC5	ATA 15	100 seed wt (g)	seeds per 100g	Control max germination (%)	Treated max germination (%)	Dormancy	Required pre-treatment	Plant density (plants/ha)	Method of return	Seeding rate (seeds/ha)
		rec.																
Chenopodi-	*Maireana carnosa*	topsoil, nat. rec.	yes		shrub	5		*		0.4659	21462			ND/PD			topsoil, nat. rec	
Chenopodi-	*Maireana georgei*		yes		shrub			*		0.2788	35873	6	11	PD	TBA			
Chenopodi-	*Maireana planifolia*		yes		shrub	32		*		0.5274	18960	99	99	ND	none			
Chenopodi-	*Maireana tomentosa*	topsoil								0.4598	21749	89	67	TBA	TBA			
Chenopodi-	*Rhagodia drummondii*		yes					*		0.3971	25184	93	97	ND	none			
Chenopodi-	*Sclerolaena densiflora*									0.3261	30665	7	6	PD	TBA			
Chenopodi-	*Sclerolaena diacantha*							*										
Chenopodi-	*Sclerolaena microcarpa*	topsoil								0.1347	74250	19	32	PD	TBA			
Crassul-	*Crassula colorata var. acuminata*				annual herb	uncom.												
Crassul-	*Crassula sp. – probably C. colorata*				annual herb	5												
Cyper-	*Lepidosperma sp. Koolanooka*				perennial herb	uncom.	14							PD				
Dilleni-	*Hibbertia arcuata*				shrub	5	71	*						MPD				
Dioscore-	*Dioscorea hastifolia*		yes	yes	climber	74	14							PD		56	seed	5600
Droser-	*Drosera macrantha*				perennial herb or climber		86											
Eric-	*Astroloma serratifolium*				shrub	16	86							PD/MPD				
Euphorbi-	*Calycopeplus paucifolius*	topsoil	yes	yes	shrub	63				0.0166	603136			PD?		56	cuttings	
Euphorbi-	*Euphorbia tannensis subsp. eremophila*				annual or perennial herb/shrub	26								PD?				
Euphorbi-	*Ricinocarpos muricatus*		yes		shrub	5	29							PD?				
Fab-	*Acacia acuminata*		yes		shrub/ tree	53	14	*	*	0.8158	12504	19	99.5	PY	HW			
Fab-	*Acacia acuminata (subsp burkittii)*									2.9860	3349	21	100	PY	HW			
Fab-	*Acacia andrewsii*		yes		shrub	5		*						PY				
Fab-	*Acacia aneura*				shrub/ tree				*							11		
Fab-	*Acacia*		yes		shrub			*		1.3401	7519	17	99.5	PY	HW			

Family (-aceae)	Species	Topsoil or natural recruit	Seed collected	Cuttings collected	Life form	DEC 3	DEC4	DEC5	ATA 15	100 seed wt (g)	seeds per 100g	Control max germination (%)	Treated max germination (%)	Dormancy	Required pre-treatment	Plant density (plants/ha)	Method of return	Seeding rate (seeds/ha)
	anthochaera																	
Fab-	*Acacia assimilis*									0.2758	36360	8	99	PY	HW			
Fab-	*Acacia assimilis subsp. assimilis*		yes		shrub	37	86	*	*					PY		22	seed	2200
Fab-	*Acacia colletioides*									0.7216	13857	7	96	PY	HW			
Fab-	*Acacia coolgardiensis*		yes		shrub	11	29	*		0.3474	29094	7	100	PY	HW			
Fab-	*Acacia erinacea*		yes		shrub			*		3.2718	3304	30	83	PY	HW			
Fab-	*Acacia exocarpoides*	topsoil	yes		shrub	58	14		*	2.9587	3404	6	93	PY	HW	133	topsoil, seed	13300
Fab-	*Acacia longiphyllodinea*									1.2949	7723	7	100	PY	HW			
Fab-	*Acacia microbotrya*									2.8140	3554	2	98	PY	HW			
Fab-	*Acacia murrayana*									2.3031	4342	3	99	PY	HW			
Fab-	*Acacia neurophylla*									0.6019	16615	2	99	PY	HW			
Fab-	*Acacia nigripilosa subsp. nigripilosa*				shrub	26		*	*					PY		44	seed	4400
Fab-	*Acacia ramulosa*									9.3374	1071	8	39	PY	HW			
Fab-	*Acacia ramulosa var. linophylla*									4.1670	2400	16	68	PY	HW			
Fab-	*Acacia ramulosa var. ramulosa*		yes		shrub	68			*	9.2027	1094	30	79	PY	HW	267	seed	26700
Fab-	*Acacia resinimarginea*									0.7215	13860	2	100	PY	HW			
Fab-	*Acacia sclerosperma spp. var or cuthbebrtsonii*									14.0363	712	5	23	PY	HW			
Fab-	*Acacia stereophylla var. stereophylla*		yes		shrub	11	86							PY				
Fab-	*Acacia tetragonophylla*		yes		shrub	68		*	*	1.4857	6741	7	84	PY	HW	22	seed	2200
Fab-	*Acacia umbraculiformis*		yes		shrub	uncom.								PY				
Fab-	*Daviesia hakeoides subsp. hakeoides*		yes	yes	shrub	53	71							PY		22	seed	
Fab-	*Mirbelia bursarioides*				shrub	16								PY		44	seed	4400
Fab-	*Mirbelia microphylla*				shrub	26	86	*						PY				
Fab-	*Senna artemisioides subsp. filifolia*									1.6528	6050	49	86	PY	HW			

Family (-aceae)	Species	Topsoil or natural recruit	Seed collected	Cuttings collected	Life form	DEC 3	DEC4	DEC5	ATA 15	100 seed wt (g)	seeds per 100g	Control max germination (%)	Treated max germination (%)	Dormancy	Required pre-treatment	Plant density (plants/ha)	Method of return	Seeding rate (seeds/ha)
Fab-	*Senna artemisioides subsp. helmsii*									3.9346	2542	25	84	PY	HW			
Fab-	*Senna artemisioides subsp. sturtii*									1.7776	5626	33	98	PY	HW			
Fab-	*Senna charlesiana*				shrub	uncom.		*						PY				
Fab-	*Senna glutinosa subsp. chatelainiana*		yes		shrub	21				2.1670	4615	18	34	PY	HW			
Fab-	*Senna pleurocarpa*									1.3683	7308	84	100	PY	HW			
Gerani-	*Erodium cygnorum*	topsoil, nat. rec.			annual or perennial herb	84	43	*						PD?			topsoil, nat. rec.	
Goodeni-	*Brunonia australis*		yes		perennial herb		29	*		0.1331	75349	79	97	ND/PD	KAR			
Goodeni-	*Goodenia mimuloides*				annual herb	5								ND/PD				
Goodeni-	*Goodenia pinnatifida*		yes		herb	16								ND/PD				
Goodeni-	*Goodenia sp. (berardiana or occidentalis)*									0.1760	56818							
Goodeni-	*Scaevola spinescens*				shrub	16		*						PD				
Goodeni-	*Velleia rosea*	topsoil	yes		annual herb	37			*	0.3411	30734	60	77	PD	KAR?			
Gyrostemon-	*Codonocarpus cotinifolius*									0.2534	39564	0	0	PD	TBA			
Hemerocallid-	*Caesia sp. Koolanooka Hills P1*				perennial herb	5												
Hemerocallid-	*Dianella revoluta var. divaricata*		yes		perennial herb	11	57	*						PD?				
Hemerocallid-	*Stypandra glauca*						14											
Hemerocallid-	*Tricoryne elatior*				perennial herb	11												
Lami-	*Hemigenia ciliata*				shrub		43							PD?				
Lami-	*Hemigenia sp. Yalgoo*				shrub	5		*						PD?				
Loranth-	*Amyema gibberula var. tatei*				aerial hemiparasite	5												
Malv-	*Abutilon cryptopetalum*				shrub	5								PY				
Malv-	*Abutilon oxycarpum*				shrub	21								PY				

Family (-aceae)	Species	Topsoil or natural recruit	Seed collected	Cuttings collected	Life form	DEC 3	DEC4	DEC5	ATA 15	100 seed wt (g)	seeds per 100g	Control max germination (%)	Treated max germination (%)	Dormancy	Required pre-treatment	Plant density (plants/ha)	Method of return	Seeding rate (seeds/ha)
Malv-	*Androcalva luteiflora*	topsoil		yes	shrub	uncom.								PY?				
Malv-	*Sida calyxhymenia*		yes		shrub	5				0.3338	29954	3	8	PY?	TBA	11	seed or seedling	1250
Malv-	*Sida sp. dark green fruits*	topsoil		yes	shrub	89	14	*						PY		133	cuttings	
Malv-	*Sida sp. Golden calyces glabrous*				shrub	37								PY		78	cutting as seeds may be scarce	
Myrt-	*Aluta aspera subsp. hesperia*				shrub	uncom.	29							PD				
Myrt-	*Calothamnus gilesii*	topsoil								0.0199	502696	98		ND	none		seed	
Myrt-	*Enekbatus dualis P1*				shrub	uncom.												
Myrt-	*Eucalyptus ebbanoensis*		yes		tree	5	14							ND				
Myrt-	*Eucalyptus ewartiana*									0.0670	149165	83		ND	none			
Myrt-	*Eucalyptus horistes*							*										
Myrt-	*Eucalyptus leptopoda subsp. arctata*									0.0553	187396	100		ND	none			
Myrt-	*Eucalyptus loxophleba subsp. loxophleba*				tree				*					ND				
Myrt-	*Eucalyptus loxophleba subsp. supralaevis*		yes		tree			*		0.0331	301756	100		ND	none			
Myrt-	*Eucalyptus oldfieldii*		yes					*				90		ND	none			
Myrt-	*Eucalyptus sp.*				tree	uncom.								ND				
Myrt-	*Melaleuca barlowii P3*		yes		shrub	uncom.				0.0140	716332	98		ND	none			
Myrt-	*Melaleuca cordata*				shrub		57			0.0127	788644	98		ND	none			
Myrt-	*Melaleuca hamata*		yes		shrub	11				0.0066	1506024	99		ND	none		seedling	
Myrt-	*Melaleuca leiocarpa*									0.0110	905797	98		ND	none			
Myrt-	*Melaleuca nematophylla*		yes		shrub	37				0.0120	940503	100	99	ND	none	133	seedling	
Myrt-	*Melaleuca radula*		yes		shrub	11				0.0095	1056636	100	100	ND	none		seedling	
Orchid-	*Cyanicula amplexans*				orchid		29											

Family (-aceae)	Species	Topsoil or natural recruit	Seed collected	Cuttings collected	Life form	DEC 3	DEC4	DEC5	ATA 15	100 seed wt (g)	seeds per 100g	Control max germination (%)	Treated max germination (%)	Dormancy	Required pre-treatment	Plant density (plants/ha)	Method of return	Seeding rate (seeds/ha)
Pittospor-	*Bursaria occidentalis*				shrub/small tree	uncom.								PD?MPD?				
Po-	*Amphipogon caricinus var. caricinus*		yes		perennial grass	32	57					93	96	ND	none	22		
Po-	*Anthosachne scabra*		yes		grass	5								ND/PD		22		
Po-	*Aristida contorta*		yes		annual or perennial grass	5	29			0.1221	81878			ND?				
Po-	*Austrostipa elegantissima*		yes		perennial grass	74	86	*	*	0.1641	60951			PD				
Po-	*Austrostipa hemipogon*				perennial grass	5								PD				
Po-	*Austrostipa scabra*		yes		perennial grass	5	14							PD				
Po-	*Austrostipa trichophylla*		yes		perennial grass	16	14	*						PD				
Po-	*Austrostipa variabilis*				perennial grass	21								PD				
Po-	*Cymbopogon ambiguus*		yes		perennial grass	uncom.								PD?				
Po-	*Monachather paradoxus*	topsoil	yes		perennial grass	74	86	*						ND/PD				
Polygon-	*Comesperma integerrimum*		yes		shrub	16	14									11		
Polygon-	*Comesperma volubile*				shrub	5		*								11		
Portulac-	*Calandrinia eremaea 'dull-seeded variant'*	*topsoil*			annual herb	11												
Prote-	*Grevillea levis*	topsoil	yes	yes	shrub	5				1.6912	5913	2	21	PD?	KAR		seedling or cutting	
Prote-	*Grevillea obliquistigma subsp. obliquistigma*	topsoil	yes		shrub	5	43	*	*					PD?		67	seed	
Prote-	*Grevillea paradoxa*		yes	yes	shrub	58	71		*	1.0905	9170	12	39	PD	KAR + nicking	189	seedling or cutting	
Prote-	*Hakea preissii*				shrub				*									
Prote-	*Hakea recurva*	topsoil								1.7912	5590	100	100	ND	none			
Prote-	*Hakea recurva subsp. recurva*		yes		shrub	42		*	*					ND				
Prote-	*Persoonia hexagona*				shrub	uncom.								PD				

Family (-aceae)	Species	Topsoil or natural recruit	Seed collected	Cuttings collected	Life form	DEC 3	DEC4	DEC5	ATA 15	100 seed wt (g)	seeds per 100g	Control max germination (%)	Treated max germination (%)	Dormancy	Required pre-treatment	Plant density (plants/ha)	Method of return	Seeding rate (seeds/ha)
Pterid-	*Cheilanthes lasiophylla*				fern	uncom.												
Pterid-	*Cheilanthes sieberi / adiantoides*				fern	79	100											
Rut-	*Philotheca brucei subsp. brucei*				shrub	21	29	*						PD?				
Sapind-	*Dodonaea inaequifolia*	topsoil	yes		shrub	58	14	*	*	0.3497	28730	59	97	PY	HW	56	seed	
Scrophulari-	*Eremophila clarkei*		yes	yes	shrub	32		*	*					PD		33		
Scrophulari-	*Eremophila miniata*									5.4064	1850	0	0	PD	TBA			
Scrophulari-	*Eremophila serrulata*									3.9994	2500	0	1	PD	TBA			
Solan-	*Solanum cleistogamum*				shrub	5								PD?				
Solan-	*Solanum ellipticum*		yes		shrub	58	57		*					PD?		100		
Solan-	*Solanum lasiophyllum*	topsoil	yes		shrub	63	14	*	*					PD?		33	seed	
Solan-	*Solanum sp.*				shrub	5								PD?				
Stylidi-	*Stylidium confluens*				perennial herb	5	57							MPD?				
Thymelae-	*Pimelea angustifolia*				shrub	11		*						PD?				
Thymelae-	*Pimelea microcephala*				shrub				*					PD?				
Thymelae-	*Pimelea microcephala subsp. microcephala*				shrub	uncom.								PD?				
Urtic-	*Parietaria cardiostegia*				annual herb	uncom.												
Fab-	*Senna* sp.	topsoil																
Goodeni-	*Goodenia* sp.	topsoil																
Myrt-	*Eucalyptus* sp.	topsoil																

Appendix 2. List of species likely to be suitable for vegetation restoration of waste rock dump at Mungada East mine site, Blue Hills.

Frequency %	Family	Species	Life form
		very common species restore 100% of these species = 7 species	
67	Fabaceae	*Acacia ramulosa* var. *ramulosa*	shrub or tree
67	Myoporaceae	*Eremophila latrobei* subsp. *latrobei*	shrub
67	Rutaceae	*Philotheca brucei* subsp. *brucei*	shrub
58	Dilleniaceae	*Hibbertia arcuata*	shrub
58	Euphorbiaceae	*Calycopeplus paucifolius*	shrub
58	Proteaceae	*Grevillea obliquistigma* subsp. *obliquistigma*	shrub
50	Myoporaceae	*Eremophila clarkei*	shrub
		common species restore 80% of these species = 24 species	
42	Fabaceae	*Acacia assimilis* subsp. *assimilis*	shrub
42	Fabaceae	*Mirbelia bursarioides*	shrub
33	Araliaceae	*Trachymene ornata*	annual herb
33	Asteraceae	*Lawrencella rosea*	annual herb
25	Adiantaceae	*Cheilanthes austrotenuifolia*	perennial fern
25	Amaranthaceae	*Ptilotus obovatus*	shrub
25	Asclepiadaceae	*Rhyncharrhena linearis*	shrub or climber
25	Asparagaceae	*Thysanotus manglesianus*	twining perennial herb
25	Asteraceae	*Myriocephalus guerinae*	annual herb
25	Asteraceae	*Waitzia acuminata* var. *acuminata*	annual herb
25	Fabaceae	*Acacia aulacophylla*	shrub or tree
25	Fabaceae	*Acacia sibina*	shrub or tree
25	Rutaceae	*Drummondita microphylla*	shrub
25	Rutaceae	*Philotheca sericea*	shrub
17	Fabaceae	*Acacia caesaneura*	shrub or tree
17	Asteraceae	*Rhodanthe battii*	annual herb
17	Asteraceae	*Rhodanthe chlorocephala* subsp. *rosea*	annual herb
17	Asteraceae	*Rhodanthe maryonii*	shrubby annual herb
17	Crassulaceae	*Crassula colorata* var. *acuminata*	succulent annual herb
17	Fabaceae	*Acacia acuminata*	shrub
17	Fabaceae	*Acacia effusifolia*	shrub or tree
17	Fabaceae	*Acacia exocarpoides*	shrub
17	Geraniaceae	*Erodium cygnorum*	annual or perennial herb
17	Lamiaceae	*Prostanthera patens*	shrub
17	Myrtaceae	*Aluta aspera* subsp. *hesperia*	shrub
17	Myrtaceae	*Eucalyptus ewartiana*	mallee
17	Myrtaceae	*Melaleuca nematophylla*	shrub
17	Poaceae	*Rytidosperma caespitosum*	grass
17	Proteaceae	*Hakea recurva* subsp. *recurva*	shrub or tree
17	Sapindaceae	*Dodonaea inaequifolia*	shrub or tree
		uncommon species restore 60% of these species = 28 species	
8	Adiantaceae	*Cheilanthes adiantoides*	perennial fern
8	Apiaceae	*Daucus glochidiatus*	annual herb
8	Araliaceae	*Trachymene cyanopetala*	annual herb
8	Asparagaceae	*Thysanotus pyramidalis*	perennial herb
8	Asparagaceae	*Arthropodium dyeri*	perennial herb
8	Asteraceae	*Blennospora drummondii*	annual herb
8	Asteraceae	*Brachyscome ciliocarpa*	annual herb

Frequency %	Family	Species	Life form
8	Asteraceae	*Brachyscome perpusilla*	annual herb
8	Asteraceae	*Calocephalus multiflorus*	annual herb
8	Asteraceae	*Calotis hispidula*	annual herb
8	Asteraceae	*Calotis* sp. Perrinvale Station (RJ Cranfield 7096) P3	annual herb
8	Asteraceae	*Gilruthia osbornei*	annual herb
8	Asteraceae	*Myriocephalus rudallii*	annual herb
8	Asteraceae	*Podolepis canescens*	annual herb
8	Asteraceae	*Podolepis lessonii*	annual herb
8	Asteraceae	*Rhodanthe collina*	annual herb
8	Asteraceae	*Rhodanthe laevis*	annual herb
8	Asteraceae	*Rhodanthe manglesii*	annual herb
8	Asteraceae	*Rhodanthe polycephala*	annual herb
8	Brassicaceae	*Stenopetalum anfractum*	annual herb
8	Campanulaceae	*Lobelia winfridae*	annual herb
8	Campanulaceae	*Wahlenbergia preissii*	annual herb
8	Colchicaceae	*Wurmbea densiflora*	perennial herb
8	Epacridaceae	*Astroloma serratifolium*	shrub
8	Fabaceae	*Acacia incurvaneura*	shrub or tree
8	Fabaceae	*Acacia murrayana*	shrub or tree
8	Fabaceae	*Acacia tetragonophylla*	shrub
8	Fabaceae	*Acacia woodmaniorum* (DRF)	shrub
8	Fabaceae	*Senna artemisioides* subsp. *petiolaris*	shrub
8	Goodeniaceae	*Goodenia berardiana*	annual herb
8	Goodeniaceae	*Goodenia occidentalis*	annual herb
8	Goodeniaceae	*Velleia cycnopotamica*	annual herb
8	Goodeniaceae	*Velleia hispida*	annual herb
8	Goodeniaceae	*Velleia rosea*	annual herb
8	Haloragaceae	*Gonocarpus nodulosus*	annual herb
8	Myrtaceae	*Melaleuca leiocarpa*	shrub
8	Myrtaceae	*Micromyrtus acuta* (P3)	shrub
8	Myrtaceae	*Micromyrtus trudgenii* (P3)	shrub
8	Plantaginaceae	*Plantago debilis*	annual or perennial herb
8	Poaceae	*Austrostipa nodosa*	grass
8	Poaceae	*Austrostipa scabra*	perennial grass
8	Poaceae	*Lachnagrostis plebeia*	annual grass
8	Poaceae	*Monachather paradoxus*	perennial grass
8	Proteaceae	*Persoonia pentasticha* (P3)	shrub
8	Rutaceae	*Drummondita fulva* (P3)	shrub
8	Sapindaceae	*Dodonaea viscosa* subsp. *spatulata*	shrub
8	Solanaceae	*Solanum lasiophyllum*	shrub

Appendix 3. List of species likely to be suitable for vegetation restoration of waste rock dump at Mungada West mine site, Blue Hills.

Frequency %	Family	Species	Life form
		very common species restore 100% of these species = 6 species	
67	Fabaceae	*Acacia ramulosa* var. *ramulosa*	shrub or tree
67	Rutaceae	*Philotheca brucei* subsp. *brucei*	shrub
58	Fabaceae	*Acacia exocarpoides*	shrub
58	Myoporaceae	*Eremophila latrobei* subsp. *latrobei*	shrub
50	Asteraceae	*Waitzia acuminata* var. *acuminata*	annual herb
50	Goodeniaceae	*Velleia rosea*	annual herb
		common species restore 80% of these species = 32 species	
42	Amaranthaceae	*Ptilotus obovatus*	shrub
42	Fabaceae	*Acacia assimilis* subsp. *assimilis*	shrub
42	Myoporaceae	*Eremophila clarkei*	shrub
42	Myrtaceae	*Melaleuca nematophylla*	shrub
42	Myrtaceae	*Micromyrtus trudgenii* (P3)	shrub
42	Rutaceae	*Philotheca sericea*	shrub
42	Sapindaceae	*Dodonaea inaequifolia*	shrub
33	Adiantaceae	*Cheilanthes austrotenuifolia*	perennial fern
33	Adiantaceae	*Cheilanthes sieberi* subsp. *sieberi*	perennial fern
33	Asparagaceae	*Thysanotus manglesianus*	twining perennial herb
33	Fabaceae	*Acacia incurvaneura*	shrub or tree
33	Fabaceae	*Acacia tetragonophylla*	shrub
33	Fabaceae	*Mirbelia* sp. Bursarioides	shrub
25	Araliaceae	*Trachymene ornata*	annual herb
25	Asteraceae	*Cephalipterum drummondii*	annual herb
25	Asteraceae	*Calocephalus multiflorus*	annual herb
25	Asteraceae	*Podolepis lessonii*	annual herb
25	Chenopodiaceae	*Maireana tomentosa* subsp. *tomentosa*	shrub
25	Dilleniaceae	*Hibbertia arcuata*	shrub
25	Fabaceae	*Acacia aulacophylla*	shrub or tree
25	Phormiaceae	*Dianella revoluta* var. *divaricata*	perennial herb
25	Poaceae	*Austrostipa elegantissima*	perennial grass
25	Proteaceae	*Hakea recurva* subsp. *recurva*	shrub or tree
25	Rutaceae	*Drummondita fulva*	shrub
17	Apiaceae	*Xanthosia kochii*	shrub
17	Asparagaceae	*Arthropodium dyeri*	perennial herb
17	Asteraceae	*Lawrencella rosea*	annual herb
17	Asteraceae	*Millotia myosotidifolia*	annual herb
17	Asteraceae	*Myriocephalus guerinae*	annual herb
17	Asteraceae	*Rhodanthe chlorocephala* subsp. *rosea*	annual herb
17	Asteraceae	*Rhodanthe manglesii*	annual herb
17	Fabaceae	*Acacia acuminata*	shrub
17	Fabaceae	*Acacia burkittii*	shrub or tree
17	Fabaceae	*Acacia effusifolia*	shrub or tree
17	Goodeniaceae	*Goodenia berardiana*	annual herb
17	Goodeniaceae	*Scaevola spinescens*	shrub
17	Lamiaceae	*Prostanthera patens*	shrub
17	Myrtaceae	*Micromyrtus racemosa*	shrub
17	Solanaceae	*Solanum nummularium*	shrub
17	Stylidiaceae	*Stylidium* sp.	

Frequency %	Family	Species	Life form
		uncommon species restore 55% of these species = 21 species	
8	Aizoaceae	*Gunniopsis glabra*	perennial herb
8	Asclepiadaceae	*Rhyncharrhena linearis*	shrub or climber
8	Asteraceae	*Schoenia cassiniana*	annual herb
8	Asteraceae	*Bellida graminea*	annual herb
8	Asteraceae	*Brachyscome ciliocarpa*	annual herb
8	Asteraceae	*Calotis hispidula*	annual herb
8	Asteraceae	*Gilruthia osbornei*	annual herb
8	Asteraceae	*Lawrencella davenportii*	annual herb
8	Asteraceae	*Myriocephalus rudallii*	annual herb
8	Asteraceae	*Olearia pimeleoides*	shrub
8	Asteraceae	*Rhodanthe battii*	annual herb
8	Brassicaceae	*Stenopetalum filifolium*	annual herb
8	Campanulaceae	*Lobelia winfridae*	annual herb
8	Chenopodiaceae	*Maireana trichoptera*	perennial herb
8	Chenopodiaceae	*Rhagodia drummondii*	shrub
8	Crassulaceae	*Crassula colorata* var. *acuminata*	succulent annual herb
8	Droseraceae	*Drosera macrantha* subsp. *macrantha*	perennial herb climber
8	Euphorbiaceae	*Calycopeplus paucifolius*	shrub
8	Fabaceae	*Acacia acanthoclada* subsp. *glaucescens*	shrub
8	Fabaceae	*Acacia caesaneura*	shrub or tree
8	Fabaceae	*Acacia sibina*	shrub or tree
8	Fabaceae	*Senna artemisioides* subsp. *petiolaris*	shrub
8	Goodeniaceae	*Goodenia occidentalis*	annual herb
8	Haloragaceae	*Gonocarpus nodulosus*	annual herb
8	Malvaceae	*Sida calyxhymenia*	shrub
8	Myrtaceae	*Aluta aspera* subsp. *hesperia*	shrub
8	Myrtaceae	*Melaleuca leiocarpa*	shrub
8	Plantaginaceae	*Plantago debilis*	annual or perennial herb
8	Poaceae	*Austrostipa scabra*	perennial grass
8	Poaceae	*Austrostipa trichophylla*	perennial grass
8	Poaceae	*Lachnagrostis filiformis*	annual grass
8	Poaceae	*Monachather paradoxus*	perennial grass
8	Poaceae	*Rytidosperma caespitosum*	grass
8	Portulacaceae	*Calandrinia eremaea*	annual herb
8	Proteaceae	*Grevillea obliquistigma* subsp. *obliquistigma*	shrub
8	Proteaceae	*Persoonia manotricha*	shrub
8	Santalaceae	*Santalum acuminatum*	shrub or tree
8	Santalaceae	*Santalum spicatum*	shrub
8	Solanaceae	*Solanum lasiophyllum*	shrub

Appendix 4. Rare and threatened flora – *Acacia woodmaniorum*

This appendix outlines key resources and timing for maximising *A. woodmaniorum* restoration opportunities. Although the Kings Park – SMC research program did not address *A. woodmaniorum* restoration per se, the following can be used as a comprehensive approach to be considered prior to ground disturbance offering the leading practice approaches to restoration.

Given the size of the *A. woodmaniorum* restoration program is small (1600 plants to be restored) this offers a great opportunity to utilise many approaches that are not efficient when dealing with large scale restoration activities.

Step 1: **Habitat study** (3 months prior to ground disturbance)

In December 2016 BGPA submitted a proposal to undertake an "Acacia woodmaniorum habitat study" to SMC. This proposal had a detailed approach, schedule and budget to achieve the following three objectives:

1. To review previous species distribution or habitat modelling undertaken by Maia for A. woodmaniorum.
2. To further characterise the habitat in which *A. woodmaniorum* currently occurs; and
3. Develop a "first-pass" model for the purpose of predicting where *A. woodmaniorum* could potentially occur across the Mungada (Blue Hills) range.

The habitat study is anticipated to take 70 days and should be completed prior to translocation or restoration activities of *A. woodmaniorum*. Please consult the proposal for further information.

Step 2: **Seed** (October- December of each year of operation)

SMC currently have a collection of seed of the target species. Although 900 seed are currently in collections, this amount is considered small for restoration activities where survival rates of seedlings may be as low as 1-10%. A more efficient use of the current valuable seed collection is likely to occur from the generation of nursery raised seedlings. This is particularly relevant given the defined target number of individuals required to be restored (1600), allowing for more intensive propagation approaches to be explored.

If future seed collections are made direct or supplementary seeding programs may occur alongside nursery production of seedlings. Seeds will need to be treated for dormancy release prior to sowing. Although BGPA have not undertaken this research – Acacia seeds have simple dormancy mechanisms that are easily overcome and generally result in high germination percentages. Treating seeds with hot water (95°C for 1-2mins) should be a useful starting point to break dormancy. Kings Park has examined 24 species of Acacia as part of the research program to date with an average germination success rate of 85%.

If propagating seedlings, Kings Park usually sows 2-3 seeds per pot to ensure an emergent Acacia seedling. Although specific work on the species has not been conducted, a minimum success level for Acacia propagation is 60-70%.

For seed that is collected and requires storage before use, it is suggested that seeds be dried at low RH (15%) and then frozen. Viability of these seeds will remain unaffected if stored appropriately. This will help to ensure longevity and protection from subsequent predation.

Step 3: **Plants** (immediately prior to ground disturbance)

The salvage of mature plants is useful although not the primary resource for restoration activities. Plants would be salvaged prior to any impacts and plant selection should be based on genetic information for the species and distribution. Consultation with DPaW staff that generated the genetic information for *A. woodmaniorum* would be valuable.

Salvaged plants could be used in three ways: direct translocation, for seed production and for cutting production.

Direct translocation: Plants should be removed at a time when earth moving machinery is on-site. Collection of as much of the root mass as possible will assist with establishment. Plants should then be moved to large pots (to accommodate the root mass) and placed under irrigation in a nursery in natural field soils. Communication with Karara about *A. woodmaniorum* or Cliffs with other rare species would also be useful. Plants could be planted out in restoration sites the following winter when the soil substrate is moist.

Seed production: An alternate strategy could be to use the above plants collected for direct translocation and instead of planting out into restoration sites they may be used to produce seeds. This will reduce impacts on remaining extant populations and produce more regular quantities of seed for restoration. A detailed plan for establishing the seed production area should be considered to ensure genetic integrity of plant population is retained. Irrigation and fertiliser application should occur seasonally to ensure resources are maximised to assist with flowering and seed fill. Having plants in close proximity to pollinator networks will also assist in seed production.

Cuttings production: This approach is more expensive than seed propagation approaches and will usually generate limited genetically diverse materials. With 1600 plants to be impacted, there is an ability to source multiple (10-20) cuttings prior to impact from every individual ensuring conservation of genetic material. Although cuttings of *A. woodmaniorum* have not previously been undertaken by Kings Park, advice from KML via SMC highlights that cuttings success rates are very high (60-80% survival after 1 year). Cuttings should be attempted in periods of new growth and can be outsourced to nurseries in Perth with demonstrated cuttings expertise. Cuttings would need to be propagated for 6 months-1 year prior to restoration.

For all plants it would be advantageous to irrigate (at least to the median rainfall scenario) in the field at least for the first year to ensure root development for on-going resilience.

Step 4: **Topsoil** (at time of ground disturbance)

The topsoil seedbank is considered the most valuable source of propagules for restoration purposes and in addition to providing seed, topsoil also contains the appropriate fungal and bacterial symbionts required for promoting the successful establishment of many plant species.

Previous research indicates that maximum biodiversity return from topsoil comes from direct return, a process where topsoil is harvested from a donor site and immediately transferred to a recipient site. Stripping topsoil ideally is undertaken in the summer immediately preceding restoration activities. This requires two aspects to be simultaneously managed – the clearing of the donor (reference) and the recreation of the recipient (rehabilitation) site. Topsoil should be replaced dry during the summer/autumn period prior to restoration.

For *A. woodmaniorum*, where possible, the collection of topsoil in the immediate and more general vicinity of the plants will be invaluable prior to rehabilitation. If topsoil can't be directly returned storage may be an option however soil seed banks should be dry prior to putting into storage and then kept dry (tarpaulin) prior to use. Storage will result in the loss of some viability of the soil seedbank however this has not been quantified for *A. woodmaniorum*. It has been noted that plants of *A. woodmaniorum* are growing in disturbed drill pads where topsoil is limited, possibly indicating that topsoil is not a pre-requisite for establishment. However utilising soils associated with A. woodmaniorum niches will provide greater confidence that all biotic associations are preserved increasing the confidence around restoration success.

See Interim recovery plan: https://www.dpaw.wa.gov.au/images/documents/plants-animals/threatened-species/recovery_plans/Approved_interim_recovery_plans_/acacia_woodmaniorum.pdf

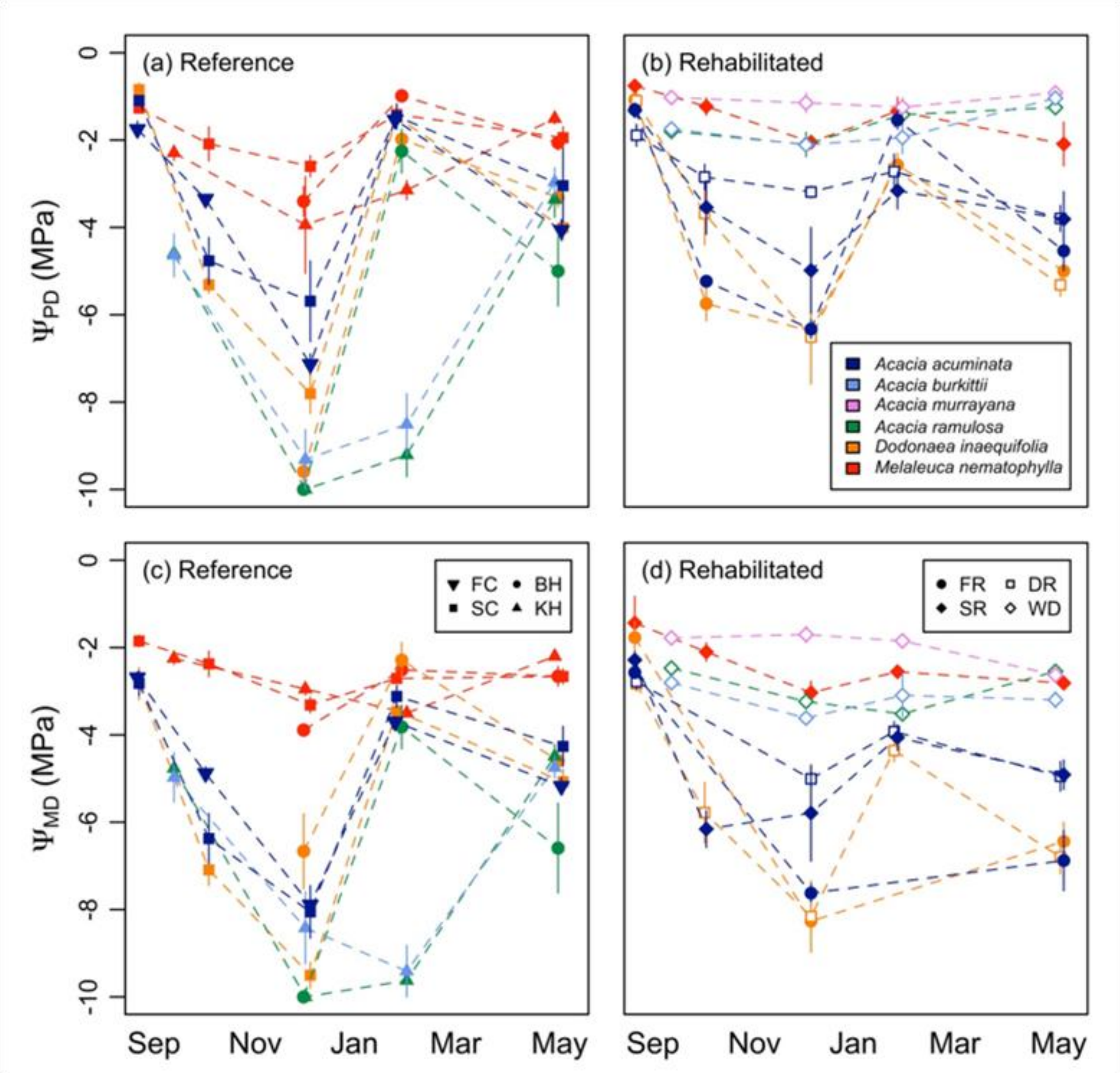
Appendix 5. Example seed mix for an 18 ha area at Koolanooka (possibly the Detritals Waste Dump) indicating the total weight of seeds in the seed mix (kg), number of seeds per 100 grams, the total number of seeds in the seed batch, the number of seeds per ha and per m^2, and the abundance in the reference site (DEC 3).

Species	Weight (kg)	seeds per kg	total seeds	seeds per ha	seeds per m^2	Abundance (%) in DEC 3
Acacia ramulosa	50	10710	535,479	29,749	3	68
Acacia acuminata	18	142548	2,565,857	142,548	14	53
Acacia tetragonophylla	6	66875	401,252	22,292	2	68
Allocasuarina acutivalvis	2.2	477490	1,050,478	58,360	6	63
Daviesia hakeoides	0.075					53
Dodonaea inaequifolia	0.2	326797	65,359	3,631	0.4	58
Hakea recurva	0.4	56200	22,480	1,249	0.1	42
Monachather paradoxa	0.02	291545	5,831	324	0.03	74
Podolepis canescens	0.1	6215813	621,581	34,532	3	47
Ptilotus polystachyus	10.25	436681	4,475,983	248,666	25	42
Ptilotus obovatus	10	294638	2,946,376	163,688	16	63
Solanum lasiophyllum	1.8	1190476	2,142,857	119,048	12	63
Waitzia acuminata	0.15	3846154	576,923	32,051	3	47
total	**99.195**		**15410456**	**856136**	**86**	
per ha	**5.510**					

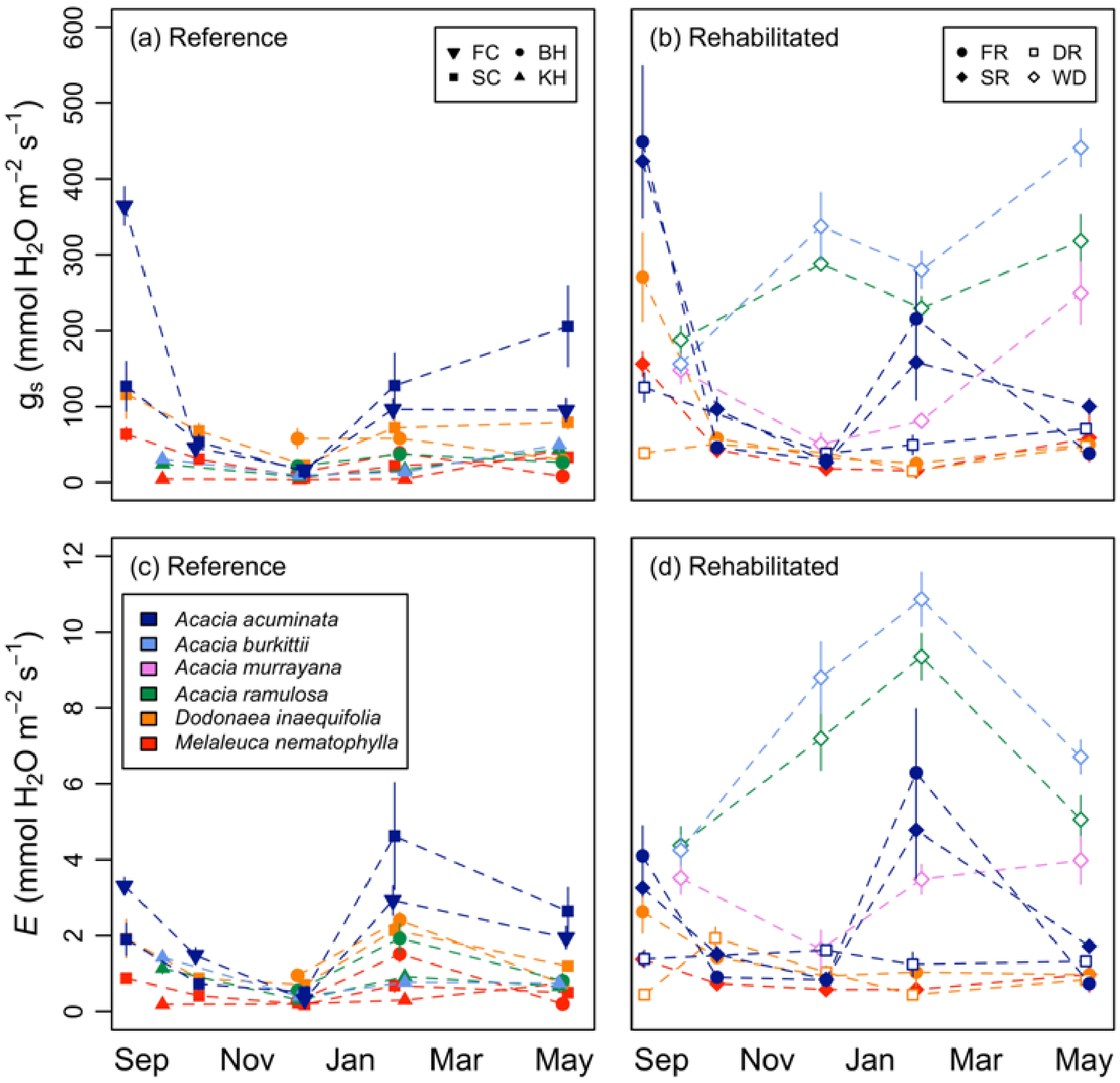
Appendix 6. Example seed mix for the Southfold Waste Dump (domain 2a) indicating the total weight of seeds in the seed mix (kg), number of seeds per 100 grams, the total number of seeds in the seed batch, the number of seeds per ha and per m^2, and the abundance in the reference site (DEC 4).

Species	**Weight (kg)**	**seeds per 100 gram**	**total seeds**	**seeds per ha**	**seeds per m^2**	**Abundance (%) in DEC 4**
Acacia acuminata	5.76	142548	821,074	45,615	5	14
Acacia assimilis	10.65	382555	4,074,216	226,345	23	86
Acacia coolgardiensis	4	260988	1,043,950	57,997	6	29
Acacia exocarpoides	0.09	31174	2,806	156	0.02	14
Acacia stereophylla	0.2	319489	63,898	3,550	0.4	86
Allocasuarina campestris	0.25	581531	145,383	8,077	1	29
Austrostipa trichophylla	0.25	196000	49,000	2,722	0.3	14
Brunonia australis	0.02	792896	15,858	881	0.09	29
Dioscorea hastifolia	0.00078		200	11	0.001	14
Melaleuca cordata	0.1	3571429	357,143	19,841	2	57
Monachather paradoxus	0.01	291545	2,915	162	0.02	86
Solanum ellipticum	0.1					57
Thysanotus manglesianus	0.007	1234568	8,642	480	0.05	86
total	**21.43778**		**6585085**	**365838**	**37**	
per ha	**5.359445**					

Appendix 7. Examples of physiological measurements undertaken at SMC sites. Included is the level of replication and variation experienced in measuring some of the traits.



Mean ± SE predawn (ΨPD; (a) and (b)) and midday (ΨMD; (c) and (d)) water potential of *Acacia acuminata*, *A. burkittii*, *A. murrayana*, *A. ramulosa*, *Dodonaea inaequifolia*, and *Melaleuca nematophylla* on each of the study sites over the course of one summer. One leaf from up to five mature and well-established plants per species was measured on each of the four reference sites. On rehabilitated mine sites, plants were less than four years old. One leaf from up to five seedlings per species was measured across four rehabilitated mine sites. Reference sites include Flat Control (FC), Slope Control (SC), Blue Hills (BH) and Karara Hill (KH). Rehabilitated sites include Flat Rehab (FR), Slope Rehab (SR), Detritals (DR) and Waste Rock Dump (WD).



Stomatal conductance (gs; (a) and (b); mean ± SE) and transpiration (E; (c) and (d); mean ± SE) of *Acacia acuminata*, *A. burkittii*, *A. murrayana*, *A. ramulosa*, *Dodonaea inaequifolia*, and *Melaleuca nematophylla* on reference ((a) and (c)) and rehabilitated ((b) and (d)) sites over the course of one summer. One leaf from up to five mature and well-established plants per species was measured on each of the four reference sites. On rehabilitated mine sites, plants were less than four years old. One leaf from up to five seedlings per species was measured across four rehabilitated mine sites. Reference sites include Flat Control (FC), Slope Control (SC), Blue Hills (BH) and Karara Hill (KH). Rehabilitated sites include Flat Rehab (FR), Slope Rehab (SR), Detritals (DR) and Waste Rock Dump (WD).