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Designing for success: applying ecological criteria to restoration at BHP Beenup, Australia

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Abstract

The former BHP Beenup titanium minerals operation is in the biodiverse Scott River region in southwest Western Australia and was closed prematurely in 1999 after only two years of operation.

Significant modifications to the landscape (including deep dredging to 55 m, lime sand blending with the natural soils to mitigate acid generation) combined with limited previous knowledge of the recruitment biology of many of the plant species, created significant uncertainty as to the feasibility of restoring the site to near-natural communities.

This paper covers two aspects of the closure process: (1) a novel planning approach undertaken for setting the end use and target ecosystems using a designed based philosophy informed by risk assessment, and (2) the assessment of restoration success using ecological completion criteria.

In terms of planning and design, the geomorphic and biodiversity features of the regional landform types (dunes, plains, sumplands, damplands etc.) formed the basis of design of closure sites. These regional ecosystems were surveyed in detail to characterise the soils, hydrology and vegetation of each major feature, with these ecological relationships then used to develop rehabilitation design criteria. Artificial landforms (deep pools created by dredging) were modified into lakes via void infilling and the creation of extensive shallow shorelines to generate a more naturalistic final shape. The focus on ecosystem design enabled revegetation to be tailored to the specific vegetation communities that best matched the reconstructed landforms; this significantly reduced seed wastage and increased the probability of success. As far as we are aware, it is the first project of this scale in Australia that has successfully created a functional range of wetland types similar to the surrounding natural wetlands.

In terms of performance assessment, a detailed and prescriptive set of restoration and completion criteria were developed to enable a greater certainty of outcomes and enabled quantitative measurements of restoration success. The incorporation of sustainability and resilience, which are global indices of success used in ecological restoration projects outside of mining, were applied here to guide both the approach to restoration (so as to enable the site to adapt to changing climates and unpredictable events) and to the measurement of success (completion criteria). This was one of the first instances globally to embed these ecological concepts as key success categories for rehabilitation.

Fifteen years after restoration, 15 ecological communities and more than 251 plant species have been successfully restored, including many conservation-listed species. The project achieved regulatory sign off against rehabilitation completion criteria in 2018 and is one of the few 'ecologically designed' post-mining landscapes globally.

Keywords: *completion criteria, ecological restoration, end use planning, post-mined restored landscapes, wetland restoration, habitat creation, mine rehabilitation*

1 Introduction

1.1 Site context

This paper presents the ecological restoration history of the BHP Titanium Minerals Pty Ltd (BHP) Beenup mine located in the Scott Coastal Plain, 17 km northeast of Augusta in southwest Western Australia (Figure 1). BHP commenced titanium minerals mining operations in 1997 with operations ceased after only two years due to technical issues.

The Scott River region is of global significance due to its high biodiversity and high proportion of plant endemism and rare flora, reflecting a unique geology and associated hydrology (Gibson et al. 2000). It is an internationally recognised biodiversity hotspot (Conservation International 2007; Beard et al. 2000). While predominantly located on former pastureland, the mine adjoins two rivers and a national park, and was subject to enormous community scrutiny over its brief mine life. The region is characterised by complex wetland and terrestrial ecosystems influenced by varied geomorphic, hydrological and stratigraphic features intersecting at relatively small-scale, and with extensive natural underlying pyritic soils and ironstone pavements. The site sits within the Southwest Botanical Province, which is an internationally recognised biodiversity hotspot. The closure objectives were strongly influenced by the local community whose interest was in restoring the site for conservation purposes and protecting the water quality of the Scott and Blackwood rivers.

Within the mine operation area, three geological units occur within the rooting depth of vegetation (Tille & Lantzke 1990): the Warren Sands (predominantly sandy surficial deposit typically to a thickness of 5 m with a near surface ferricrete layer in central and eastern areas); Strucel Beds (predominantly dark grey and black silts, clays and silty sands occurring between 5 m and 12 m, generally pyritic and often cemented) and the Upper Beenup Beds (grey, silty and clayey sands, becoming more sandy with depth, occurring between 12 m and 25 m). The Warren Sands and Strucel Beds support extensive seasonal wetlands. Particularly rare vegetation associations occur on shallow ironstone formations associated with the Warren Sands, including the Scott River Ironstone Association, which is a threatened ecological community. The peculiar and complex ecology and physiology of plants in this region has been well documented (e.g. Poot & Lambers 2003; Poot et al. 2008; Smith & Ladd 1994; Meney & Pate 1999).

The remediation plan involved the design and construction of extensive permanent and seasonal wetlands, rehabilitation of an above-ground mine development storage area (MDSA) originally constructed as a settling dam for clay fines, and rehabilitation of surrounding upland areas (BHP Titanium Minerals [BHPTM] 1999). The total disturbance area was 335 ha, mainly located on former pastureland.

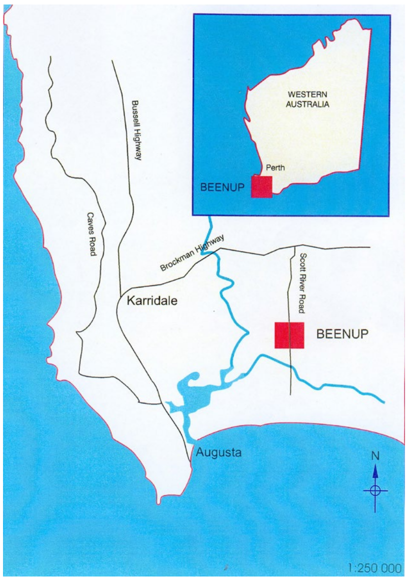


Figure 1 Location of the BHP Beenup titanium minerals site

The entire remediation process at this site was complex due to the presence of pyritic materials and groundwater contamination arising from acid drainage, the depth of dredging (60 m), and the position of the mine immediately upstream of the Scott and Blackwood rivers and adjacent to the Scott River National Park. In terms of rehabilitation, the key technical challenges were as follows:

- Extensive physical modification of much of the site.
- Soil remediation (lime sand blending with native soils) to manage pyrite oxidation risks; this practice resulted in high pH, carbonate rich soils in a region characterised predominantly by iron rich acidic soils.
- The connection of the site with the regional drainage system. Three creeks enter the site from adjacent pasture areas, carrying nutrient-enriched waters and weed propagules. Discharge from the site enters both the Scott and Blackwood rivers, both conservation protected features.
- Stakeholder expectations that the site would be successfully rehabilitated predominantly to native vegetation and pasture so as to reintegrate with the surrounds and protect water quality.
- A high level of uncertainty as to the outcomes possible for the site.

1.2 Purpose and definitions

The objectives of this aspect of the closure planning were to:

1. Develop a planning approach for target end use and ecosystems using a designed based philosophy informed by risk assessment.
2. Develop a method for assessing restoration success using ecological completion criteria.

The following completion terms were developed to frame the approach:

- End use: agreed land uses post-closure.
- Goal: final desired outcomes for the site.
- Objectives: the critical steps needed to achieve goals.
- Attribute: the broad category within which completion criteria are defined (e.g. land use, plant density).
- Criteria: the measurable parameters for each objective.
- Value indicators: additional criteria used to support the completion criteria, but not included in regulatory assessment.
- Performance measures: the metrics used to assess each criterion.

1.3 Current mine rehabilitation approaches

Current best practice approaches to mining rehabilitation where the focus is on native ecosystems tend to involve a process of landform readjustment after mining to create stable landforms, (integrated with the surrounding landscapes, where practical), with topsoil placed and profiled prior to seeding with a general suite of native species selected from the broad regional wetland or terrestrial vegetation communities.

Although this is often supplemented by targeted research where there are complexities (e.g. restoring recalcitrant species, or insufficient topsoil, or poor-quality topsoil), the application of ecological restoration as an approach for designing and restoring post-mined environments) is still uncommon in Australia.

Although rehabilitation plans are now generally agreed before mine closure, end-use plans and completion criteria are generally not finalised before rehabilitation commences at many mine sites (although the process of stakeholder engagement around possible scenarios may have begun). This means that opportunities to commence rehabilitation early in a mine life, and to work towards a common trajectory, are constrained.

The current approach, while still common, is predicated on some key assumptions that do not always, and perhaps rarely do, hold true in many mining environments. These assumptions and the more probable reality are outlined in Table 1.

In the particular case of the BHP Beenup mine, the standard rehabilitation trajectory was challenged by two key factors: (1) an active and informed stakeholder community, many who deeply opposed the mine since it was first proposed (which is dealt with in a related paper in this issue by Norrish et al.), and (2) the premature closure of the mine after only two years of operation. Upon closure, BHP needed to determine a methodology for delivering on the final agreed end use and rehabilitation goals. A five-year remediation and rehabilitation process was commenced (BHPTM 2001), within an environment of risk and uncertainty in terms of what could be realistically achieved, what it would cost, and whether the outcome would be acceptable to community and government.

BHP engaged Syrinx Environmental PL (Syrinx) to assist in developing a restoration approach and undertaking studies to support success of the site from an ecological restoration perspective.

Table 1 Discrepancy between common assumptions and reality in mining rehabilitation

Aspect	Assumptions	Reality
Time	The mining process is often long so that restoration/rehabilitation has time on its side to ensure expectations around closure can be agreed with ample consultation and assessment of progressive success.	Further, 'future' research needs to be applied to optimise success. Communities and regulators want certainty as to what is intended and assurance that it can be delivered.
Quality	Rehabilitation methods are relatively well known and standard approaches can deliver adequate outcomes. Learning by trial approaches are acceptable to improve on outcomes.	Not all sites are standard, and early interrogation of likely risks and knowledge gaps is needed to adapt standards and develop methods appropriate to each site. Simple revegetation outcomes with low biodiversity values and poor resilience is unlikely to be acceptable in the future.
Cost	Costs of investing in rehabilitation today may translate to a wasted investment tomorrow, if the end use scenarios change and/or if expectations of standards change.	Progressive rehabilitation leads to continuous improvement, more cost-efficient methods, shows corporate commitment, and builds stakeholder confidence.
Risk	Regulators determine acceptable end use and completion criteria.	Communities and the constraints of site are the ultimate determinants of future land uses and completion criteria in many mining areas, particular those in ecologically sensitive or less remote areas with competing land uses.
	The probability of restoration success is strongly determined by chance (climate, predation etc.). This is too uncertain to anticipate.	Rehabilitation success is strongly determined by the level of knowledge and application of this to rehabilitation practices.

2 Risk-based planning framework

The strategy undertaken for rehabilitation of Beenup followed a prescriptive, risk-based approach to the design and reconstruction of ecosystems and associated vegetation communities (Syrinx Environmental PL 2001). A series of process steps were followed that essentially were focused on improving the understanding of the site, modifying the site to best match the regional landforms so as to support a diversity of ecosystem types, and undertaking a series of 'rapid research' projects in order to reduce the cost of the revegetation in particular, and ultimately the risk of failure. The initial steps in the process focused on characterising the pre- and post-mining landscapes and guiding the landform design. This involved:

1. Agreeing on the end use and proportions of pasture and native vegetation areas.
2. Undertaking baseline studies (four events within 10 years to capture climatic variability) to characterise:
    a. Ecosystem types (e.g. seasonal and permanent wetlands, dunes, ironstone plains).
    b. Vegetation communities (structure, species richness, plant density and cover).
    c. Soil type, stratigraphy, hydrology within each ecosystem type to determine relationships with groundwater, and soil physical and chemical parameters.
    d. Weed types and extent in relation to extent of disturbance.
3. Plot and reconnaissance surveys were conducted for vegetation assessments within each of the regional ecosystem types. Stratigraphic bores and some piezometers were installed within these sites, with regional bores also used as part of the analysis of ecosystem—vegetation community—soil-hydrology relationships.
4. Design of final landforms and soils to best match reconstructed landforms with the regional natural ecosystem types.
5. Characterising (by field investigations) the post-mining landscape to assess conformance with regional ecosystems in terms of topography, soils (stratigraphy, chemistry, granulometry) and hydrology (depth to groundwater, likely hydroperiods of constructed wetlands).
6. Undertaking revegetation research and feasibility.

2.1 Delineation of completion zones

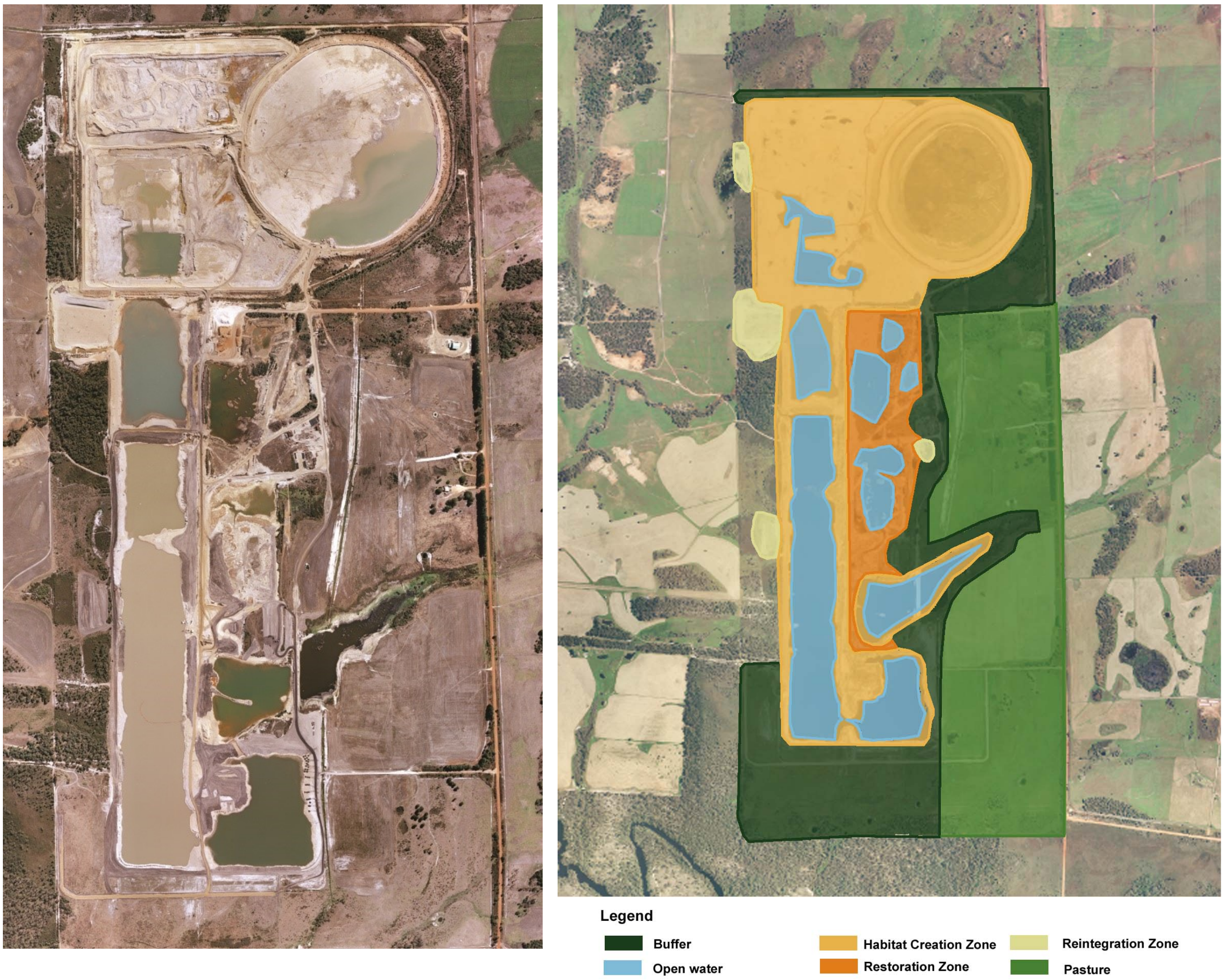
A site analysis was undertaken and areas ranked based on the magnitude and type of disturbance, in order to derive the potential for restoration success.

Five completion zones were delineated based on analysis of the type and extent of land disturbance (Figure 2):

1. Restoration zones: highest-level restoration capability based on reconstruction of regionally similar ecosystem units and vegetation types.
2. Reintegration zones: next level capability based on enhancement of disturbed or cleared remnants and linkage to adjacent vegetation types.
3. Habitat creation zones: applies to areas that are artificial within the region including landforms (such as permanent lakes, beaches, MDSA), and soil profiles (lime sand blended areas).
4. Buffers: lowest level restoration effort designed to protect the site from adjacent land uses (such as pasture, offsite agricultural runoff), and equally to protect natural vegetation areas, such as the adjacent Scott River National Park.
5. Pasture: not covered here since was assessed by separate criteria.

For each zone, specific completion objectives were set to reflect their restoration potential:

1. Species richness and tree, shrub and herb density in each ecosystem unit within restoration zones to be similar to that of regionally similar communities.
2. Tree, shrub and herb density within reintegration zones to be similar to that of adjacent communities, and species similar to adjacent communities.
3. Tree, shrub and herb density within habitat creation zones to be similar to that of adjacent communities; species and composition to be appropriate to the modified profiles, while remaining visually compatible with adjacent communities.
4. Tree, shrub and herb density within buffer zones to be appropriate to protect restored native vegetation zones on the site and adjacent National Park boundary, and be visually compatible with adjacent communities.



(a) (b)

Figure 2 (a) Site in 2002 at commencement of rehabilitation; (b) completion zones defined for the site

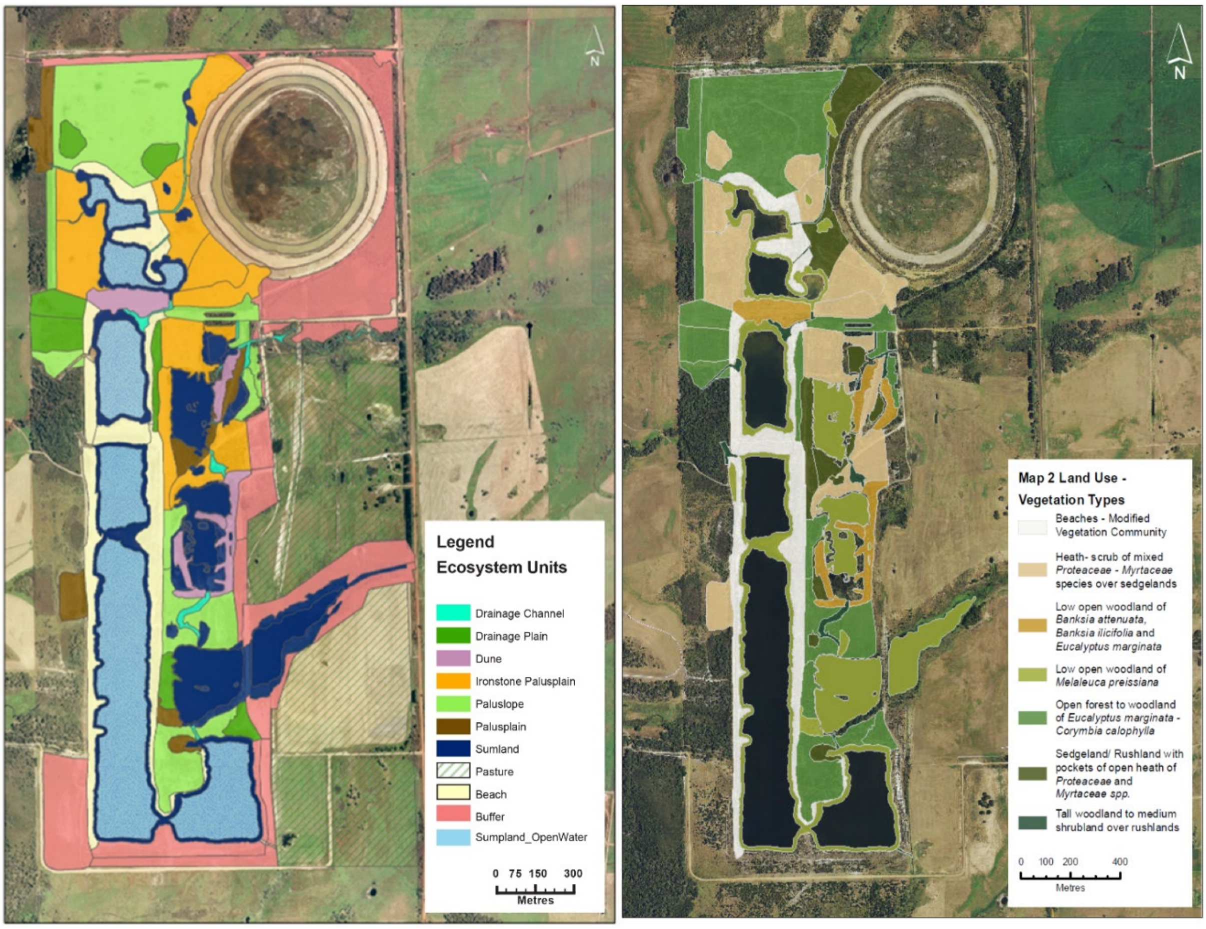
2.2 Delineation of target ecosystems and vegetation communities

Target ecosystems were delineated based on their geomorphic, hydrological and broad vegetation characteristics (using regional baseline data). Target vegetation communities were selected from the regional baseline surveys and matched to each reconstructed landform.

Based on the regional surveys (Syrinx Environmental PL 2002), the following key ecosystem units were identified, using the terminology of the global classification system established for wetlands (Semeniuk 1987), and for dunes and dryland plains (Tille & Lantzke 1990) in the Scott River region:

- Lakes (permanent pools): all permanent water bodies.
- Sumplands: seasonally inundated basin type wetlands and beaches fringing permanent pools.
- Palusplains: seasonally saturated plains, <1 m from the winter water table. These were separated into sand and ironstone palusplains.
- Paluslopes: seasonally moist slopes, <1 m from the winter water table surrounding sumplands and lakes.
- Channels: drains and existing streams, permanent or seasonally flowing.
- Dunes and beaches: sandy soils, >1 m above winter water table.
- Dryland plains: flat upland areas, >1 m above winter water table.

While the reconstructed landforms are not an exact replication of baseline conditions, they represent best fit. The target ecosystems for the site are shown in Figure 3(a).



(a) (b)

Figure 3 (a) Layout of the site showing final ecosystem units; (b) distribution of target vegetation communities

Vegetation surveys identified the following main vegetation groups (present within regional baseline ecosystems) as suited to the reconstructed landforms (Figure 3(b)):

1. Open forest to woodland of *Eucalyptus marginata—Corymbia calophylla*.
2. Low open woodland of *Banksia attenuata, B. ilicifolia* and *E. marginata*.
3. Low open woodland of *Melaleuca preissiana*.
4. Heath-scrub of mixed Proteaceae—Myrtaceae species over sedgelands.
5. Sedgeland/rushland with pockets of open heath of Proteaceae and Myrtaceae spp.
6. Tall woodland to medium shrubland over rushlands.

Floristic analysis showed that the structural composition, species richness and densities differed between these vegetation communities; these variances were used to define completion criteria and target ranges for each ecosystem unit.

Revegetation efforts were targeted at establishing the dominant species from within each of the strata for each community, and ensuring the ratio of trees to shrubs to herbs was similar to surrounding sites (i.e. the structure of final communities reflected baseline sites).

2.3 Assessing the probability of revegetation success

This component of the restoration process focused on undertaking a revegetation risk assessment to determine the constraints to success. This was derived from analysis of the following:

- Germination and recruitment potential of the native species for each ecosystem type.
- Availability of seed and/or tubestock in commercial nurseries.
- Relative cost of various revegetation approaches.

A literature review was undertaken to establish known recruitment responses for the 293 species present within the regional baseline surveys. In parallel, germination experiments were undertaken for known recalcitrant species (predominantly from the Restionaceae family) that formed a significant component of the regional vegetation communities, but which had not previously been researched in terms of overcoming dormancy. This data was combined and used to generate the likely cost of revegetation, calculating the cost of a successfully establishing seedlings, using seed purchase and/or collection costs, seed cleaning costs, and discounting for viability, germinability and seedling survival losses.

Assessment of the commercial availability of seeds and/or tubestock indicated that more than 80% of species were not commercially available. As such, a comprehensive seed collection program was undertaken with more than 100 million seeds collected from more than 110 perennial species in surrounding areas.

Species were ranked against recruitment strategies, difficulty of propagation and probability of establishment success (high, medium and low risk). This data was used to derive seeding rates (for those with at least some potential to establish via direct seeding), or tubestock planting numbers (for those species with low probability of success from seed).

Two approaches to revegetation of the site were analysed to determine the lowest risk method in terms of probability of success and cost:

1. Simple selection of species mixes based on wetland, dryland and transitional.
2. More complex matching of species selections to individual landform units (i.e. seasonal wet, permanent wet, flowing, static, slopes, dunes).

The analysis showed that the first approach carries substantially greater inherent risks as follows:

- Poor germination and establishment of seeds and survival of propagules (due to mismatch of species with site conditions).
- Greater risk of failure due to inappropriate selection of species and propagule types (seeds versus tubestock).
- Higher requirement for supplementary revegetation and maintenance.
- Requirement for very high seeding densities and planting densities to compensate for losses.
- Low final species richness and density outcomes.

The quantification of these risks (dollar value) was estimated for the site by breaking down the species suited to each specific ecosystem type and comparing the overlap between these sites. The assumption is that species not suited to specific ecosystem conditions would fail to germinate and/or survive. Using this approach just for wetland areas, and assuming a 100 ha area for illustration purposes, where 50 ha are shallow sumplands, 30 ha are deep sumplands, and 20 ha are palusplain, the number of wetland species in common for deep sumplands and all other areas is approximately five of a possible 150 generic wetland species (i.e. 3%). Therefore, the loss is 97%. Based on a nominal cost of AUD 6,000 per ha, this would equate to around an AUD 580,000 loss. Based on this risk analysis, BHP chose to proceed with the second approach, i.e. more specific matching of species to landforms. Final revegetation costs per hectare were at the lower end of typical mine site rehabilitation costs, which affirmed that more focus at the ecological planning and design stages and the more prescriptive restoration approach was cost-effective.

3 Progressing towards completion

3.1 Measuring success

A simple framework was developed for establishing completion criteria (BHPTM 2011). The planning structure was a five-staged process as follows:

- Define completion goals for the site.
- Define the completion objectives relevant to the established goals.
- Define the completion criteria for each objective.
- Define additional value indicators for each objective, where applicable.
- Define the performance measures.

The completion goals agreed upon for Beenup were as follows:

1. Rehabilitation: reintegration of the site with the surrounding natural ecosystems.
2. End use: development of the site into a conservation/recreation reserve with some surrounding pasture (linking to adjacent land uses).

Two objectives were adopted:

1. Biodiversity: restoration and maintenance of biodiversity to a level that has conservation value to flora, fauna and people.
2. Sustainability: creation of a sustainable site that requires minimum maintenance intervention.

Completion criteria were then developed to reflect the above objectives.

A total of 21 completion criteria were developed, of which 10 are ecological criteria (C1, C2, etc.) and two are value indicators (denoted V1, V2, not assessed by regulators) (Table 2). Progress images of the site are shown in Figure 5.

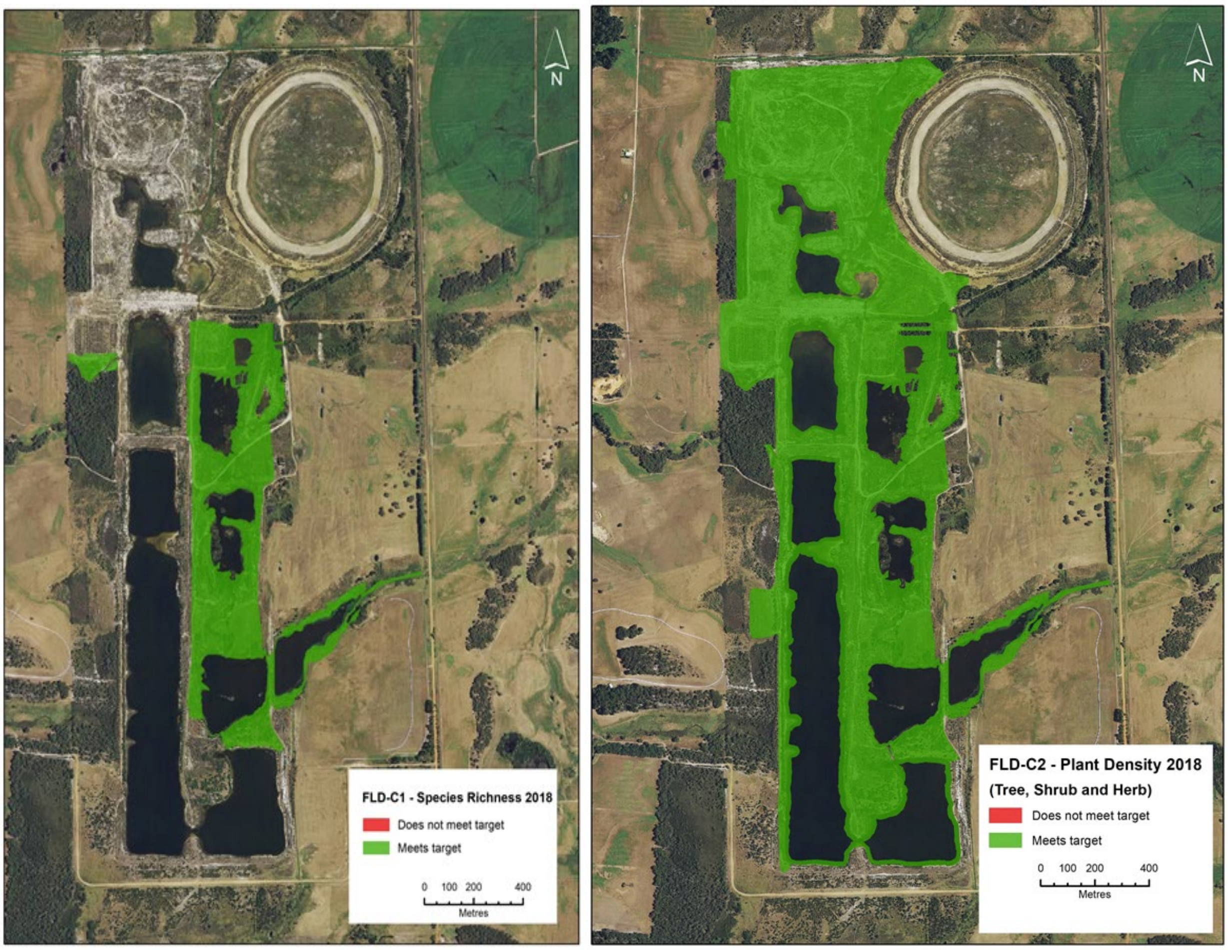
The site was progressively monitored against these criteria over a 12-year period (2003–2015), with a final assessment of sites made in 2018. Most of the site (>85%) was compliant with ecosystem resilience and floristic completion criteria in 2015, approximately 10 years after rehabilitation works ceased in a given area. All completion criteria were met in 2018.

Table 2 Completion criteria targets

Attribute	Criteria (guideline for acceptance)
Land use	LU-C1 No less than 20% native vegetation, including woodland and heath vegetation.
	LU-C2 No less than 10% native vegetation along watercourses.
	LU-C3 Remaining areas to comprise no more than 70% of pasture, buffer zones and open water areas.
Ecosystem/ community	ED-C1 Creation of more than five ecosystem units across site.
	ED-C2 Initial establishment of a minimum of five vegetation groups, which must include open forest, woodland, heath-scrub and sedgeland/rushland structural categories.
Floristic species diversity	FLD-C1 Species richness—for restoration zones a minimum 60% of regional baseline species richness for each ecosystem unit present.
	FLD-C2 Plant density (all zones, except buffers)—for each stratum and ecosystem unit, a density trending towards the range recorded for the equivalent regional baseline ecosystem unit.
	FLD-C3 Plant density (buffers)—a minimum native plant density within each plot equivalent to 60% projected cover.
Ecosystem resilience	ER-C1 Weed abundance to be no greater than that recorded in similar adjacent natural vegetation areas.
	ER-C2 Priority 1 weed species as detailed in Weed Management Plan to be eradicated, or if not able to be eradicated, to be contained with an acceptable ongoing maintenance level control program in place.
	ER-VI1 Demonstrated capacity of flora and fauna to reproduce as evidenced by seedling recruitment and vegetative reproduction.
	ER-VI2 Demonstrated capacity of the site to recover from fire drought and other disturbances.

At rehabilitation completion, the following outcomes were achieved:

- Land use criteria (LU C1-C3) were exceeded, given a greater proportion of the site was rehabilitated to native vegetation rather than pasture. Overall, around 389 ha were successfully restored to native vegetation and wetlands, which included the mine disturbance area plus additional revegetation of buffer areas.
- Ecosystem diversity criteria (ED C1-C2) were exceeded—nine ecosystem units and six vegetation groups were successfully restored (criteria require more than five units and five groups).
- Floristic diversity criteria (FLD C1-C3) were met:
  - Species richness targets were met in all restoration zones to which they apply (Figure 4(a)). A total of 251 species were recorded onsite (compared to a baseline of 293). Fourteen rare and priority species were successfully restored onsite.
  - Plant density targets were met for all areas and strata (Figure 4(b)).



(a) (b)

Figure 4 Areas showing compliance (green) with (a) species richness criteria; (b) plant density criteria for all strata

Figure 5 Site progress—(a) 2002 view from MDSA dam; (b) same view in 2008; (c) wetland one in 2018; (d) wetland four in 2018; (e) aerial view 2015

- Ecosystem resilience criteria (ER C1-C2) and value indicators (ER V1-V2) were met:
  - Weed abundance—the site has achieved targets.
  - Priority (Target 1) weed species—weed species that have the capacity to compromise restoration success or are declared weeds within the shire or of national significance) are adequately contained onsite and are not considered a threat provided standard maintenance of the site continues.
  - Seedling recruitment—seedling recruitment recorded over an eight-year period showed an increase in species richness and density over time. A total of 107 species were recorded during recruitment monitoring events, including 36 herb species, 63 shrub species and eight tree species.
  - Aggregated data for all ecosystems shows a density range of 2–5.8 seedlings/m^2. This is sufficient evidence that plants have matured to a point where flowering, seed set and recruitment can sustain the vegetation of the site and will be resilient to major disturbances, such as fire, prolonged drought and eventual senescence of adult plants.

Taking into account the extended period of below average annual rainfall at Beenup over most of its post-mining life, and in particular the very dry summer periods, the success of the project validates the ecological restoration approach applied to the site.

4 Conclusion

This project achieved the successful reintroduction of nine ecosystem types and 15 vegetation communities over 380 ha and over 250 species (including rare and priority species) in a heavily disturbed and modified post-mining environment.

The approach, which was based on developing a detailed and prescriptive set of restoration and completion criteria, allowed a greater certainty of outcomes and enabled quantitative measurements of restoration success. The incorporation of sustainability and resilience, which are global indices of success used in ecological restoration projects outside of mining, were applied here to guide both the approach to restoration (so as to enable the site to adapt to changing climates and unpredictable events) and to the measurement of success (completion criteria). This was one of the first instances globally to embed these ecological concepts as key success categories for rehabilitation. As far as we are aware, it is the first project of this scale in Australia that has successfully created a functional range of wetland types similar to the surrounding natural wetlands. In support of this, aquatic fauna surveys undertaken by Wetland Research & Management (2009) concluded that these wetlands 'exceed the values and condition of many natural wetlands and provide a level of ecological function comparable to natural wetlands of the southwest of Western Australia'.

The combined wetland and dryland revegetation works were completed using more than 100 million seeds collected from the local region. New data was generated on the propagation and recruitment probability of around 40 rush and sedge species not used in restoration or commercial applications previously. A significant number of rare and priority species have been returned to the site, and as such the site plays an important role in supporting the existing conservation reserves in the Scott River region.

Acknowledgement

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