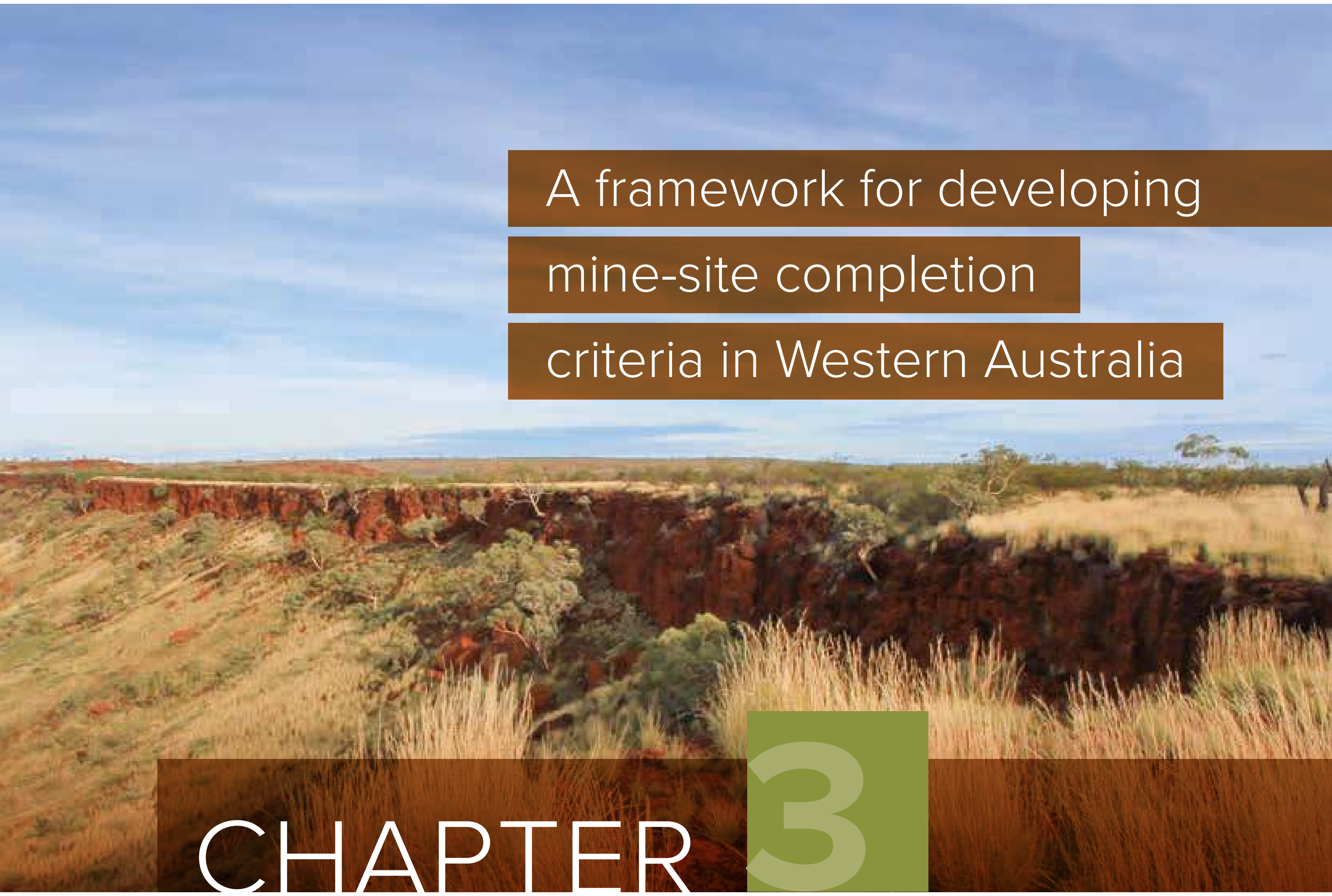

A framework for developing mine-site completion criteria in Western Australia

CHAPTER 3

Background, principles and context for risk-based completion criteria and monitoring

(1 OF 7)

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CHAPTER

3 Background, principles and context for risk-based completion criteria and monitoring

This section includes a review of current guidance, policy and scientific literature relating to completion criteria and associated monitoring. It focusses particularly on criteria and attributes relating directly, or indirectly, to biological elements in rehabilitation sites. It also considers methodologies for the selection of post-mined land uses (PMLUs), the consideration of offsets and application of risk assessment in identifying closure risk and in directing and prioritising rehabilitation effort. When discussing specific aspects and attributes, the study focusses on biophysical and environmental elements, but indicates to other elements where appropriate. This focus reflects the scope of the report, but also that most mine closure plans include environmental requirements. PMLUs that do not include environmental objectives will require consideration of other aspects and monitoring approaches (e.g. social or economic metrics). Nonetheless, the principals for completion criteria development, discussion of risk and approaches to selecting PMLUs should be relevant to all mines.

3.1 Guidelines and principles for establishing completion criteria

The importance of completion criteria in the mining life-cycle are well recognised in numerous international and national handbooks and guidelines for mine closure planning. While there is no international or national standard for the development of completion criteria (Blommerde *et al.* 2015), more than 30 documents with guidance for the establishment of completion criteria – from jurisdictions across Australia (state and federal), Canada (provincial and federal), Peru, Chile, South Africa, Finland, Asia Pacific Economic Cooperation (APEC) and states within the United States of America – were identified. The most relevant of these are reviewed below.

Documents from NSW (TIRE 2013) and Queensland (DEHP 2014) provide information specific to the mine rehabilitation and closure requirements of their jurisdictions, with the most detailed guidance on objectives and criteria for closure being provided by DEHP (2014). Rather than provide substantial detailed information on criteria development, the NSW guidance relies substantially on the Strategic Framework for Mine Closure (ANZMEC & MCA 2000) as a recommended source.

The nationally focussed Australia and New Zealand Minerals and Energy Council/ Minerals Council of Australia Strategic Framework (ANZMEC & MCA 2000) is an industry document, which promotes establishment of completion criteria that are developed and agreed with stakeholders. It states that, where possible, completion criteria should be quantitative and capable of objective verification, and identifies the importance of developing performance indicators to measure progress in meeting the completion criteria – which is distinct from, but supplementary to, monitoring to assess completion criteria.

The Leading Practice Sustainable Development Program (LPSDP) for the mining industry handbook series includes handbooks devoted to mine closure (LPSDP 2016d), mine rehabilitation (LPSDP 2016e), biodiversity management (LPSDP 2016a) and evaluating performance: monitoring and auditing (LPSDP 2016b), among others. This excellent series, which aims to encourage best practice sustainable mining both in Australia and overseas, was developed by Australian Government Department of Industry, Innovation and Science in partnership with the Department of Foreign Affairs and Trade and input from diverse contributors (DIIS 2018). The first handbook (Mine Closure; LPSDP 2006d) specifically promotes monitoring against closure objectives and criteria, with detailed guidance on objectives, principles and nature of criteria. It promotes a phased approach for criteria (development and mining; planning and earthworks; vegetation establishment; monitoring and closure). The Mine Rehabilitation handbook (LPSDP 2016e) promotes SMART (Specific Measurable Achievable Relevant and Time-bound) targets and objectives, that criteria are developed with stakeholders and recommends comparison with analogues. The handbook on monitoring (LPSDP 2016b) makes a strong link between criteria and monitoring. It provides examples of typical elements of completion criteria for landforms, water and biodiversity.

Internationally, the Canadian federal government provides a detailed overview of recommended environment management practices for all stages of the mining life cycle, including rehabilitation and closure in an ‘Environmental Code of Practice for Metal Mines’ (Environment Canada 2009). This overview publication does not address completion criteria and is limited to recommending post-closure monitoring to ensure that closure and rehabilitation measures are functioning as designed, and to demonstrate compliance with the targeted end land use. Importantly, the document does give a substantial list of sources of additional information, most from Canadian provinces but including a range of Australian publications (federal and state).

An example of a detailed consideration of criteria for closure in a Canadian jurisdiction is the guidelines for closure and reclamation in the Northwest Territories (AANDC 2013). Although the dominant environmental factors considered in those guidelines contrast strongly with those in Western Australia, a useful detailed approach is provided to establish a closure goal which must embody four closure principles: physical stability, chemical stability, no long-term active care and future use (including aesthetics and values). These closure principles guide the selection of closure objectives and criteria for mine closure (AANDC 2013).

The Canada Mining Innovation Council (CMIC) is currently undertaking a program to develop a standardised, performance-based framework for mine closure relinquishment (CMIC 2015). In order to reflect the diversity of environments, commodities and mining operations, the initiative has not been directed at defining detailed criteria with standards, but focused on standardising ‘categories’ (equating to ‘aspects’ in this review) and criteria (‘attributes’, see Table 1.1). Similar to the current project, the CMIC’s framework was to be developed in consultation with stakeholders in order to reach a broad consensus regarding the acceptable conditions for mine closure and subsequent site relinquishment (Holmes *et al.* 2015).

The remaining international examples of guidance on requirements for mine closure that were reviewed but not listed in Table 3.1 consistently identified objectives and criteria as being required, but there was little detailed guidance on establishing them.


Photo courtesy: BHP

TABLE 3.1 Published guidelines relating to mine closure and or completion criteria

Region	Document title	Reference	Details
INTERNATIONAL			
Global	Planning for Integrated Mine Closure: Toolkit	ICMM 2008	Encourages development of closure goals (equating to criteria with a measurable standard) and monitoring to demonstrate progression towards them and their achievement. Includes examples of aspects to consider and examples of related goals for some of those. Also includes intermediate (partial) goals to mark progress.
Global	International standards for the practice of ecological restoration – including principles and key concepts	McDonald *et al.* 2016	As for Society for Ecological Restoration Australasia (SERA) (SERA 2017) below, sets out framework of 'goals' and 'objectives' (criteria/standards), together with examples of specific objectives (criteria) for soils, and biological elements.
APEC	Mine Closure Checklist for Governments	APEC (2018)	A checklist for governments, not industry. Promotes consideration of the proposed post-closure land use for the landform, including closure objectives and closure criteria. Includes reference to Australian Mine Closure Handbook (LPSDP 2016d) and guidelines from Northwest Territories (AANDC 2013).
Finland	Mine Closure Handbook	Heikkinen *et al.* 2008	General guidance and examples for developing objectives and performance criteria in relation to environmental quality.
Canada	Environmental Code of Practice for Metal Mines	Environment Canada (2009)	Detailed summary of recommended environment management practices for all stage of the mining life cycle, including rehabilitation and closure. Contains extensive list of additional sources of information, including those related to mine rehabilitation and closure.
Canada – Northwest Territories	Guidelines for the Closure and Reclamation of Advanced Mineral Exploration and Mine Sites in the Northwest Territories	AANDC (2013)	Clear and detailed guidance on expectations and framework. Strongly focused on water as the key aspect/environmental factor. The closure goal is supported by closure principles which guide selection of clear and measurable closure objectives for all project components. Closure criteria can be site specific or adopted from provincial/territorial/federal standards and can be narrative statements or numerical values.
South Africa	Regulations pertaining to the financial provision for prospecting, exploration, mining or production operations	Department of Environmental Affairs (DEA) (2015)	Indicates a clear requirement for closure plans to be measurable and auditable, and to provide a vision, objectives, targets and criteria for final rehabilitation, decommissioning and closure. Does not contain guidance on criteria development.

Table 3.1 continues following page...

TABLE 3.1 Published guidelines relating to mine closure and or completion criteria

Region	Document title	Reference	Details
NATIONAL			
Australia and New Zealand	Strategic Framework for Mine Closure	ANZMEC & MCA (2000)	Promotes establishment of completion criteria that are developed and agreed with stakeholders and, where possible should be quantitative and capable of objective verification. Identifies the importance of developing performance indicators to measure progress in meeting the completion criteria, indicating appropriate trends or enabling early intervention where required.
Australia	Mine closure	LPSDP (2016d)	Promotes monitoring and reporting against agreed closure objectives and closure criteria. Relatively detailed guidance on objectives, principles and nature of criteria. Discusses a phased approach for criteria (development and mining; planning and earthworks; vegetation establishment; monitoring and closure).
Australia	Mine rehabilitation	LPSDP (2016e)	Promotes SMART targets and objectives, with success criteria that have been developed with stakeholders. Recommends comparison with analogues, not to replicate them but to inform in relation to composition, structure and function.
Australia	Biodiversity management	LPSDP (2016a)	Touches lightly on objectives and criteria with respect to biodiversity. Identifies that direct measures of abundance for fauna are lagging indicators.
Australia	Evaluating performance: monitoring and auditing	LPSDP (2016b)	Provides clear guidance on the nature and role of criteria, including the relationship of criteria to monitoring. Links strongly to related LPSDP handbooks. Gives examples of typical elements of completion criteria, for landforms, water, biodiversity, though without discussing matching of specific criteria with different stages of rehabilitation process.
Australia	National standards for the practice of ecological restoration in Australia	SERA (2017)	Set out framework of 'goals' and 'objectives' (criteria/standards), together with examples of specific objectives (criteria) for soils, and biological elements.
STATE			
Western Australia	Guidance for the Assessment of Environmental Factors	EPA (2006)	Aims to encourage best practice in setting appropriate and effective objectives for rehabilitation and assessing subsequent outcomes and promotes more effective monitoring and auditing of outcomes.
Western Australia	Guidelines for Preparing Mine Closure Plans	DMP & EPA (2015)	Specific guidance on identifying land use, closure objectives, completion criteria. Refers to ANZMEC & MCA (2000) for additional information. Includes example of tabular framework for factor, objective, criteria and measurement tools.
Western Australia	Guidelines for Mining Proposals in Western Australia	DMP (2016)	Identifies the need for performance criteria for each environmental outcome. Closure outcomes, together with related completion criteria, should be outlined in a Mine Closure Plan (MCP). Principles and purpose of monitoring for each criterion is discussed. Includes example tabular framework for factor, objective, risk, outcomes, criteria and monitoring.
NSW	Mining Operations Plan (MOP) Guidelines	TIRE (2013)	Clear expectation to provide objective criteria to establish whether rehabilitation objectives have been met; and have outcomes which are demonstrably achievable through experience in comparable situations or through site trials/research. General guidance and examples on where criteria should be directed, but not on their development or structure.
Queensland	Rehabilitation requirements for mining resource activities	DEHP (2014)	Sets out clear hierarchy for rehabilitation goals, objectives, indicators and criteria. Detailed example of objectives, indicators and criteria.

3.2 Establishing completion criteria in Western Australia

The most relevant and detailed sources of publicly available guidance for establishing completion criteria in Western Australia are those from the Western Australian Environment Protection Authority (EPA 2006), Western Australian Department of Mining and Petroleum (DMP, now Department of Mines, Industry Regulation and Safety; DMIRS) (DMP & EPA 2015) and the Australian Government's Leading Practice Sustainable Development Program (LPSDP 2016c,d). Despite their similar aims, these vary in focus and formulations of completion criteria. EPA (2006) focusses on outcomes while DMP & EPA (2015) is process oriented. While the two guiding documents demonstrate disparity, completion criteria can be developed that conform to both sets of guiding principles (Table 3.2).

TABLE 3.2 Principles for the Development of completion criteria in Western Australia

Guidance for the Assessment of Environmental Factors: Rehabilitation of Terrestrial Ecosystems (EPA 2006)	Guidelines for Preparing Mine Closure Plans' (DMP & EPA 2015)
• Allow success to be measured within realistic timeframes, • Be sufficiently precise to allow outcomes to be effectively audited, but are also flexible when required, • Be based on sound scientific principles, • Acknowledge the consequences of permanent changes to landforms, soils and hydrology, • Be attainable in realistic timeframes, and • Ensure rehabilitation objectives have been met.	• Be developed in consultation with DMP and EPA • Be appropriate to the developmental status of the project • Follow the S.M.A.R.T principle – being: **Specific** enough to reflect a unique set of environmental, social and economic circumstances; **Measurable** to demonstrate that rehabilitation is trending towards analogue indices; **Achievable** or realistic so that the criteria being measured are attainable; **Relevant** to the objectives that are being measured and the risks being managed and flexible enough to adapt to changing circumstances without compromising objectives; and **Time-bound** so that the criteria can be monitored over an appropriate time frame to ensure the results are robust for ultimate relinquishment

These guidance publications (EPA 2006, DMP & EPA 2015) set out objectives for rehabilitation and closure (Table 3.3), which provide context for development of completion criteria. Most examples from industry of frameworks for objectives and criteria for mine rehabilitation and closure in Western Australia are based on the core structure proposed in the WA Guidelines for Preparing Mine Closure Plans (DMP & EPA 2015). Criteria are typically listed in terms of the various aspects (see Table 3.6) that together represent all elements to be considered in closure.

TABLE 3.3 Guidance for setting objectives for rehabilitation and closure in Western Australia

EPA (2006)	DMP & EPA (2015)
• Safe, stable and resilient landforms and soils; • Appropriate hydrology; • Providing visual amenity, retaining heritage values and suitable for agreed land uses; • Resilient and self-sustaining vegetation comprised of local provenance species; • Reaching agreed numeric targets for vegetation recovery; and • Comprising habitats capable of supporting all types of biodiversity.	• Physically safe to humans and animals; • Geotechnically stable; • Geochemically non-polluting/non-contaminating; and • Capable of sustaining an agreed post-mining land use.

Many Western Australia industry examples of completion criteria incorporate the additional dimension of sequential mine closure phases, with some criteria specific to each phase (Table 3 4). Typically, these phases segregate into planning/design, rehabilitation execution, and vegetation establishment and development. This reflects the reality that the physical elements of rehabilitation landforms are necessarily planned and constructed before biological components can be established. The structure of a progressive assessment sequence aims to eliminate re-work at later stages of ecosystem development. For example, the topography and soil profile of a rehabilitated site is best confirmed immediately following earthworks, when machinery is on site and access remains open. By contrast, rectification of landforms after several years of ecosystem development is inefficient, and risks disturbing the established ecosystem. An additional consideration in relation to ecosystem development is that different criteria may be appropriate at different phases. Successful rehabilitation is likely to follow a successional pattern which can be used to inform appropriate timeframes to apply to individual criteria or performance indicator targets.

TABLE 3.4 Industry examples of sequential phases used in completion criteria frameworks

Alcoa (2015)	Roy Hill Iron Ore (2018)	WA Oil Barrow Island (Stantec 2015)	Newmont Boddington Gold (Newmont 2012)	Mt Keith Nickel Mine (Stantec 2017)
Planning	Decommissioning	Earthworks and primary rehabilitation	Planning and landform construction	Pre-execution
Rehabilitation earthworks	Primary rehabilitation works		Surface preparation and vegetation establishment	Execution
Early establishment (0 to 5 years)	Early establishment	Early establishment		Post-execution
Vegetation 12 years and older	Relinquishment	Mature rehabilitation	Monitoring, remediation and relinquishment	

3.3 Risk assessments of rehabilitation and closure outcomes

3.3.1 Risk management

Risk management is an integral part of closure, decommissioning, rehabilitation and post-closure monitoring. When implemented effectively, it can enable an operation or project to identify risks and develop controls to achieve sustainable mine closure and relinquishment. Risks associated with the closure and post-closure phases in the mine life cycle cover both economic and non-economic consequences. These risks are long-term, and the expectations of the local community, government, landowners, neighbouring property owners and non-government organisations (NGOs) need to be considered (LPSDP 2016g).

The standard AS/NZS ISO 31000: 2018 Risk management – Guidelines (ISO 2018) provides a set of principles, a framework and a process for managing risk which can be used by any organisation regardless of its size, activity or sector. Organisations using it this framework can compare their risk management practices with an internationally recognised benchmark, providing sound principles for effective management and corporate governance.

Risk management frameworks encompass the identification, analysis, evaluation and treatment of risks. Historically, risk management approaches have focused on the technical aspects of risk management where contemporary risk approaches as described in ISO 31000:2018 Risk management—Guidelines now place more emphasis on communication at each stage of risk management.

Reflective of the importance of risk management during rehabilitation and closure is the level of current guidance on environmental risk assessments, which includes: the LPSDP – Risk Management (LPSDP 2016g) and Mine Closure (LPSDP 2016d) handbooks; the Guideline for Mining Proposals in Western Australia (DMP 2016) and Guidelines for Preparing Mine Closure Plans (DMP & EPA 2015), together with similar documents from Queensland (DEHP 2014) and NSW (TIRE 2013). All of these guidance documents advise on the assessment of environmental risk. DMIRS (2018) noted, however, that only a limited number of assessments incorporate the ‘consequence’ category, the environmental sensitivity of the area in which the activity is taking place.

3.3.2 Risk assessment

The AS/NZS ISO 31000: 2018 guidelines also outline the need to establish the context when conducting a risk assessment and recommends that the questions posed during the assessment are focused towards the purpose for which the assessment outcomes will be used. This includes defining how the results of the risk assessment will be used and assists in selecting the right risk assessment tool, level of effort and team for the assessment.

In South Africa, the Department of Environmental Affairs (2015) Regulations to the *Mining Act (1998)* (Appendix V) contain guidance on preparing an environmental risk assessment report, which specifically outlines the objective of the environmental risk assessment report, as follows:

- Ensure timely risk reduction through appropriate interventions;
- Identify and quantify the potential latent environmental risks related to post closure;
- Detail the approach to managing the risks;
- Quantify the potential liabilities associated with the management of the risks; and
- Outline monitoring, auditing and reporting requirements.

Leading risk management practitioners have recently shifted their focus from risk assessment to control management. This has significantly improved outcomes from the risk management process and reduced the potential for unplanned or unwanted events and outcomes (LPSDP 2016g). One method of incorporating risk planning into closure planning is to develop a risk register that incorporates the control measures to mitigate the risks (LPSDP 2016d).

Photo courtesy: BHP

3.3.3 Types of risk and considerations

Mining companies regularly conduct risk assessments that focus on health, safety, environment and financial risk. The latter includes corporate risks, such as company reputation damage from an environmental incident. From a completion criteria perspective, it is important for all stakeholders to consider the risks associated with different completion objectives, both for the construction of the completion criteria, but also for their associated monitoring approaches. The biological complexity of rehabilitation projects, the extent that these can be managed, challenges of the environment in which they occur, presence or absence of proven capability and knowledge for rehabilitation in that system, including its availability to the proponent, together with economic, political, social, timeframe or organisational factors all contribute to the risk of rehabilitation failure or success.

Technical deficiencies, such as; lack of investment in research driven improvement; lack of understanding of environmental impediments and failure to integrate rehabilitation and closure planning into the ‘life of mine’ planning can result in financial risk. Financial liability is a key driver for companies in identifying their biggest relinquishment risk, and where their closure efforts may be prioritised. This has been reflected by the Queensland Department of Environment and Heritage Protection (DEHP 2014), which presents a calculation of cost of the residual risk of a rehabilitation strategy. This cost influences a ‘residual risk payment’ at relinquishment, which reflects the nature and scale of the risk that the Government is accepting.

An important consideration during risk assessments is that potential changes to regulations may lead to unacceptable performance outcomes, due to increasing requirements at closure. Mechanisms to reduce this risk include keeping up-to-date with new and changing regulatory requirements and ensuring rehabilitation operations are consistent with scientific best practice. Consultation with regulators enables companies to mitigate the risk associated with attaining an unacceptable rehabilitation outcome, whilst internal benchmarking exercises and development of specific and measurable completion criteria that are agreed with stakeholders can be utilised to verify the rehabilitation practices that are applied.

Considering factors that limit capacity to achieve environmental rehabilitation objectives, Miller (2016) distinguishes factors that were at least theoretically within the ability of management to influence, and those that were external to control (Table 3.5). Within the last class are listed factors imposed by regulation and / or corporate strategy, such as the complexity of objectives, and those that result from the environmental attributes such as rainfall reliability, and size and tractability of the species list required for rehabilitation. To this list can be added external economic factors, and knowledge and capability gaps (Table 3.5). In relation to those that are able to be managed, factors such as the extent and timing of impacts and rehabilitation requirements; topsoil and substrate management, trained personnel retention, availability of skilled contractors and rehabilitation resource management. A recent framework of biophysical questions that may require understanding or research to ensure support for the restoration of biodiverse ecosystems includes 34 high-order questions (Miller *et al.* 2016a). While these questions may not all be necessary for rehabilitation, as opposed to restoration projects, most of them are. Newton (2016) provides a long and detailed schedule for planning and implementation of rehabilitation of Banksia woodlands after sand mining, for each step, planning, resourcing and timing can be considered to be a risk point if not implemented or considered appropriately. The absence of this kind of knowledge, or failure to find or consider this knowledge, is another risk.

TABLE 3.5 Factors influencing the capacity of rehabilitation programs to reach their goals

External to project control	Within capacity to influence
Imposed by regulation or corporate strategy	**Resulting from mine plans and activities at the site**
• Attributes of the project goals, i.e.: – Stable cover. – Stable cover using native species: – Vegetation cover goals e.g. 60% v 90% of reference. – Any representative local community. – The original or pre-existing community: – Species richness goals e.g. 50% versus 70%of reference. • Timeframes for completion and reporting	The area concerned: • Spatial extent • Diversity of communities or domains impacted • Timeframes for preparation and completion
Force majeure • Economic, political, social or regulatory change. • Buy out, bankruptcy, market collapse	Availability, storage condition and viability of biophysical resources: • Root zone subsoil. • Topsoil: – As a growing medium (volume, suitability). – As a source of seed (collection, viability, storage and respreading conditions). • Viable collected seed. • Material (seed or cuttings) for propagation. • Mulch, wood piles.
Resulting from the attributes of the site or environment	
Attributes of the site, pre-mining: • Richness of the community – how many species. • The mix of species: – Number that can be returned from topsoil seed. – Number to be returned from: seed; greenstock; cuttings; tissue culture. • Number with known germination and/or propagation techniques: Complexity and reliability of techniques.	Ability to mobilise/ manage resources: • Scheduling in relation to season: • Topsoil collection. • Collection and storage of seed. • Landforming and soil profile reconstruction. • Site treatments (ripping, fertiliser, irrigation, mulch, etc.). • Topsoil respreading. • Propagation of greenstock. • Seed treatments. • Application of seed. • Planting greenstock. Equipment and capacity: • Landforming, ripping, irrigation. • Propagation, nursery, seed store. • Seed treatments. • Seeding (direct seeding, broadcast seeding). Personnel, culture and knowledge: • Trained and experienced staff or contractors • Existence of, and ability to learn from, similar attempts in region • Willingness to invest in and extend best practice • Understanding of limitations, with willingness to invest in R&D or adaptive management
Attributes of the site, post-mining: • Appropriateness for the target community: Landform – exposure to radiation, wind, erosion, slope stability. • Site hydrology: landform, soil texture and profiles to enhance infiltration and water retention. • Substrate physical and chemical properties. • Onsite threats (weeds, grazing, etc.). • Type and severity of impact (exploration track vs waste rock dump). • Site hostility: e.g. tailings vs drill pad. • Presence of toxic wastes, radioactive materials, acid drainage, etc.	
Events: • Reliance on episodic rainfall. • Fire, severe drought, storms-erosion. • Change in management or policy, downsizing.	Attributes of the site, post-mining: • Capacity to modify or amend post-mining conditions to suit the target community. • Capacity to modify the target community to suit the post-mining conditions (or to compromise). • Connectivity and edges. • Ability to manage threats. • Site security.

Source: adapted from Miller 2016

The extent of these challenges may guide decisions about the types of completion criteria used, their numerical targets and the rigor of monitoring and reporting appropriate for their assessment. These decisions are clearly relevant to regulators and other stakeholders when acceptable completion criteria for a project are considered. Many of the risks are amenable to management within a project but this ability, together with other risks, are attributes of the proponents: these proponent-risks should be considered realistically by all parties.

3.3.4 Effectiveness of risk controls

The evaluation of closure success is most commonly assessed in the context of rehabilitation failure. The Queensland closure guidance (DEHP 2014) is an example where rehabilitation failure is identified for consideration, as follows:

> *"Even if all criteria are met for several years, there is no guarantee that the rehabilitation will not fail in the future. The risk of failure is called the residual risk. A closure strategy, which is presented as a proposed control to reduce the residual risk is likely to be viewed as 'more robust' if it includes the propensity for failure. A risk assessment that considers the following should be used to determine how to calculate residual risk:*
>
> - *What components of the rehabilitation are most likely to fail (hazards);*
> - *The likelihood of failure; and*
> - *The consequences of failure."*

The uncertainty associated with the evaluation of closure success is also considered within Yukon Energy Mines & Resources (2013), which states that:

> *"While the Rehabilitation and Closure Plan (RCP) must describe robust measures and demonstrate how those are expected to achieve the reclamation and closure objectives and design criteria, there are often uncertainties and risks that may lead to unacceptable performance outcomes. The RCP should identify and characterize key risks and uncertainties, and provide measures for addressing them where possible."*

The development of risk ratings that could be utilised as a guide for evaluating closure success against key environmental risks would partially reduce the subjectivity associated with their assessment.

3.4 Selection of post-mining land uses

Two components of completion criteria development principles in Western Australia are that the completion criteria be agreed to by regulators, and be based on agreed PMLUs. The selection of PMLUs is a critical component required before closure objectives and completion criteria can be set. A two-stage process, PMLU selection should result from discussion between industry, regulators and key stakeholders (including likely or representative PMLU managers) to agree on the PMLU, but this discussion could benefit from application of a preliminary decision-making methodology. Cumulative impact assessment processes are also providing regional contexts for site-based PMLU decisions (Commonwealth of Australia 2018).

3.4.1 Decision-making tools

There are a number of well-established formal methodologies to facilitate decision making. Multi-attribute decision-making (MADM) can be used as a methodology to evaluate, compare and rank project alternatives against a set of criteria (Hajkowicz & Collins 2007). The decision maker assigns scores or weights to each criterion. Various methods exist for criteria-weighting and options-evaluation, such as multiple criteria utility functions, goals achievement matrix, goal programming, or Analytical Hierarchy Process (AHP) (Janssen 1992). In mine site rehabilitation, commonly applied MADM methods are Mined Land Suitability Analysis (MLSA), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and AHP (Narrei & Osanloo 2011; Soltanmohammadi *et al.* 2008, 2009, 2010). Within the MLSA framework, Soltanmohammadi et al. (2010) propose a list of eight broad end land uses (subdivided into 23 specific uses) and 50 evaluation criteria grouped into economic, social, technical and mine site factors. Following a series of comparisons and calculations, the AHP-TOPSIS approach results in preference ranking list for possible post-mining land uses. Variations of this framework have been proposed, for example, using 'fuzzy' AHP to deal with vague data (Masoumi *et al.* 2014) or incorporating spatial analysis (Palogos *et al.* 2017). Multi-attribute decision-making processes have been criticised for the subjective nature of the weightings that are chosen to represent the analyst's assessment of the relative importance of each criteria (Dobes & Bennett 2009; Ergas 2009), and for the use of overly complicated mathematical functions that obscure the decision-making process. This methodological complexity may also hinder the widespread application of MADM to guide post-mine land use decisions.

Land suitability assessments (LSA) or land capability assessment (LCA) are an important tool in Western Australia's rural planning system (van Gool *et al.* 2005). The assessments are based on the capacity of land to sustain specific land uses such as cropping, irrigated agriculture and forestry which could be used post-mining as well. Assessment of land capability considers the specific requirements of the land use and the risks of degradation associated with the land use (Rowe et al. 1981). LSA/LCA produces five land capability classes that define the suitability of land for a certain use.

Benefit-Cost Analysis (BCA) is the primary tool that economists use to determine whether a particular course of action (e.g. policy project or rehabilitation proposal) promotes economic efficiency (Kotchen 2010). In a BCA, all the impacts of an action, to all affected parties, at all points in time, are measured and expressed in a common monetary unit. If the present value of the benefits is larger than the present value of the costs, the project improves overall social welfare. It should be noted that BCA does not only incorporate the financial effects of a policy but should account for all the social cost and benefit impact, both financial and non-financial (non-marketed) values (Pearce *et al.* 2006).

3.4.2 Environmental offsets and approval conditions

Environmental offsets are an offsite action(s) to address the significant residual environmental impacts of a development or an activity (Government of Western Australia 2011, 2014). In Western Australia, offsets can form a key component of an approvals process and, together with direct requirements of the approval conditions, may dictate that the PMLUs for a specific area within a site is for conservation or a natural environment.

Offsets are a mechanism to provide environmental benefits to counterbalance the significant residual environmental impacts or risks of a project (Government of Western Australia 2011, 2014). The offsets are applied when there are residual impacts to rare and/or endangered species; areas within a formal conservation reserve system; important environmental systems and species that are protected under international agreements; and areas that are already defined as being critically impacted in a cumulative context. They may also be required when the impact causes flora or fauna to become endangered or it affects an ecosystem with an important ecological function (Government of Western Australia 2014).

Offsets may be direct or indirect through the forms of land acquisition, on-ground management or research projects. The type of offset depends on the impact predicted, the options for offsets in the vicinity of the project and the state of knowledge of the environment being impacted (Government of Western Australia 2014). In some cases, an environmental offset may be in the form of the ecological restoration of the impacted site or a nearby site, which will dictate the end land use.

May *et al.* (2016) reviewed the effectiveness of offsets approved between 2004 and 2015 in Western Australia, concluding that less than 40% of the 208 offsets studied were effective, according to simple measures. Relevant to completion criteria formulation and assessment, it was found that 18% of offsets were inadequately reported, and concluded that improvement is required to ensure approval conditions actually measure ecological outcomes.

3.5 Identifying an appropriate reference

The application of completion criteria for biological attributes typically relies on comparison with a reference state, concept, model or ecosystem. The SER International Primer on Ecological Restoration (SER 2004) identifies three strategies used to evaluate rehabilitated landscapes in relation to reference ecosystems:

- **Direct comparisons** result in completion criteria that can be directly measured and are based on data from reference sites. For example, reference site data may be based on detailed plant surveys and vegetation mapping.
- **Attribute analysis** seeks to confirm that essential criteria required for ecosystems to function have been reinstated. These criteria equate to the overall objectives of a rehabilitation project which ensure an ecosystem will continue to recover without further management inputs.
- **Trajectory analysis** looks at trends in ecosystem properties and functions that gradually recover towards a reference condition.

Each of these strategies requires a comprehensive understanding of the reference ecosystem (SER 2004). The SER Primer addresses ecosystem restoration, which, depending on project objectives, usually has different objectives to rehabilitation, and is defined as being on a pathway to a restored state, where the restored state matches the reference state in relation to the nine attributes listed in Table 3.6 (SER 2004). Use of a reference benchmark in rehabilitation does not mean that targets are necessarily equal to the reference state, but rather they are informed by it. That is, the criteria may be 90% of vegetation cover or 70% of species richness (for example), irrespective of the form of the reference, if agreed with stakeholders. Using a reference system is a critical aspect of achieving appropriate rehabilitation outcomes, as it provides a clear depiction of the long-term goals of the restoration project and a development state to evaluate against. However, there are a range of constraints, ranging from the abiotic to the biotic, that influence efforts to replicate natural ecosystems in mining landforms (EPA 2006). Abiotic factors include potentially-unfavourable properties of mine waste materials, while biotic factors include those associated with biodiversity and environmental threats such as weeds and disease.

When considering possible outcomes from mine rehabilitation, it needs to be recognised that landforms, substrates and hydrology are often altered such that return to pre-existing conditions may not always be practical (Gould 2011). A principle for development of completion criteria is that they should ‘acknowledge the consequences of permanent changes to landforms, soils and hydrology’. This fact is a key reason why rehabilitation after mining activity often results in the appearance of an altered ecosystem (Doley & Audet 2013, 2016). Soil physical structure, and probably also soil biological and chemical properties, will be different to those of the site prior to mining. Other factors, such as slope and hydrological characteristics, will add further to the differences (Suding & Cross 2006, Stuble *et al.* 2017). These altered properties may make site conditions no longer well suited to support the pre-existing ecosystem, and vegetation attributes and rehabilitation development trajectories will differ from those in an undisturbed reference ecosystem. There are four approaches to this problem:

1 While the post-mining system, with its altered landform, hydrology and soils, is altered from its pre-mining state, it may be more like other natural system analogues. If, for example, the site is now more arid, rocky or saline, and if there are natural regional analogues, it may be possible to identify a natural ecosystem from the region that is a more achievable objective. This may result in a more natural, although still different, outcome (Garrah & Campbell 2011);

2 Consider the site attributes that most differ and implement elements to mitigate the difference – by blending growth media, adjusting rehabilitation site substrate profiles, adding amendments and so on (Rokich *et al*. 2000; Erickson *et al.* 2016) – in order to maximise the chances of succeeding with a pre-mining reference;

3 A mixture of the above approaches, whereby a regional ecosystem different to the pre-existing state is employed as a reference, and the site is adapted to make it better able to support that community; and

4 Agree on a different or novel ecosystem or land use – if appropriate.

Identifying key ecosystem attributes relies on adequate understanding of the reference ecosystem, particularly the composition (species), structure (complexity and configuration) and function (processes and dynamics) (SERA 2017). There are few Western Australian ecosystems that have this level of understanding. The most notable exception is the jarrah (Eucalyptus marginata) forest which has been the subject of substantial rehabilitation-related research over several decades driven primarily by bauxite mining operations (e.g. Gardner & Bell 2007) – see Section 5.6.3 for details. While there are still advances to be made in the level of understanding of the jarrah forest ecosystem, the vast majority of Western Australian mining operations do not have the same level of ecological understanding, but with appropriate resourcing in research could rapidly progress at least the basics of this knowledge.

Given that vegetation composition is a typical attribute measured in rehabilitated areas, it is critical that aspects such as successional patterns are well understood. In Pilbara ecosystems, for example, it is typical for early vegetation to be dominated by short-lived colonising species at relatively high densities which, after time, give way to a different vegetation profile dominated by long-lived perennials at low density. There is often a lack of natural recruitment into rehabilitated areas (e.g. Norman 2006; Bellairs 2000) and for this reason, the early establishment of plant species richness is essential. With best practice, this may be achieved early in mine site rehabilitation in Western Australia, with those sites subsequently exhibiting trends of decreasing species richness and increasing vegetation cover with time. These predictable successional processes are not always reflected in the structure of completion criteria, particularly if vegetation parameters are treated together and expected to exhibit similar trends with time. Using the post-disturbance trajectories of the reference system – such as after fire in many natural systems – may be a mechanism to benchmark against this dynamism.

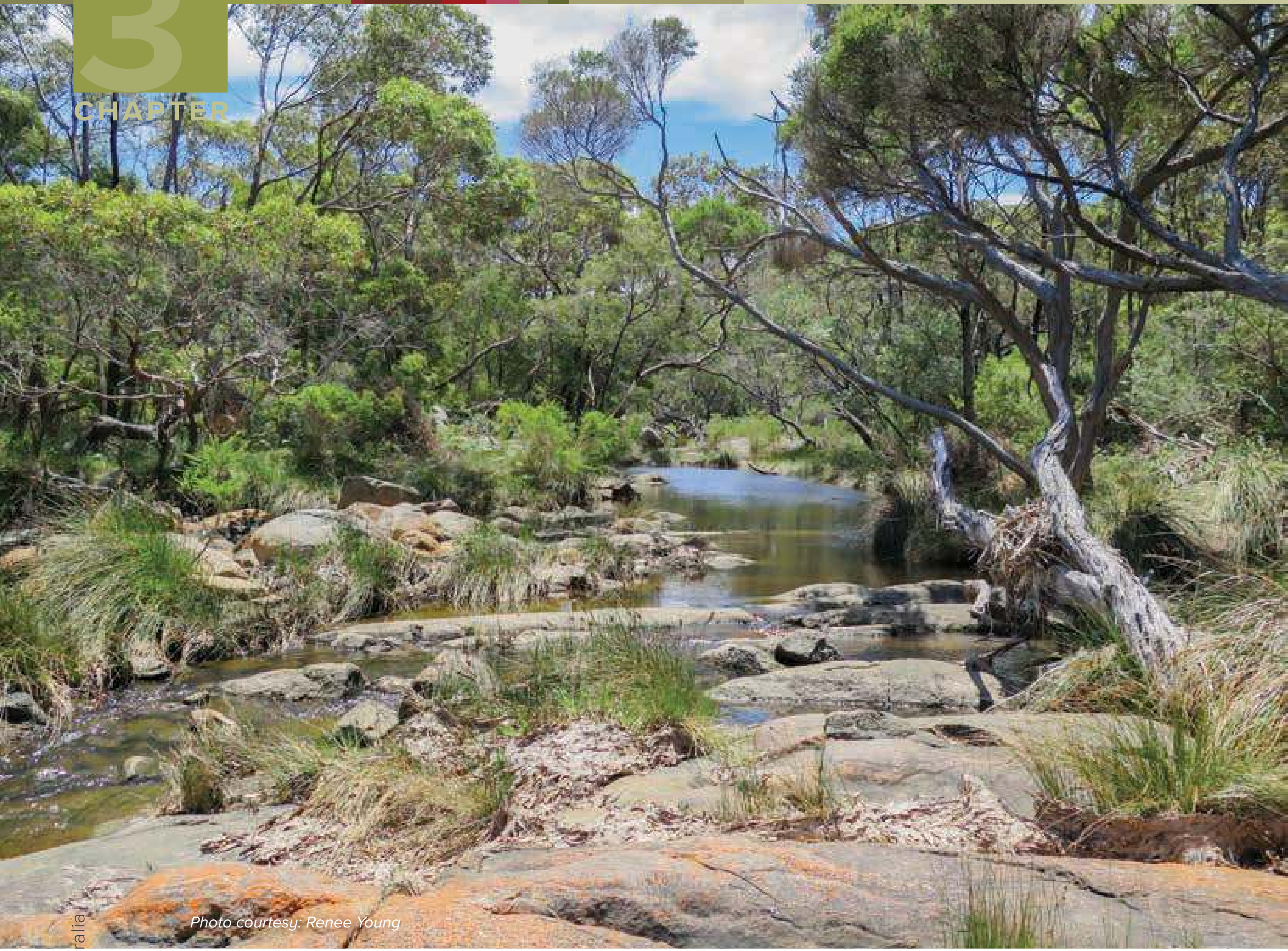


Photo courtesy: Renee Young

This is not yet a well-used approach, and it is possible that there are pragmatic or ecological reasons why the numeric value of the criterion should vary with time (e.g. 90% of the benchmark during establishment and 70% subsequently). However, this has not been explored.

Pit lakes are an alternative land use (rather than a novel ecosystem – they are just new lakes) where there are no obvious reference or analogue sites (Blanchette & Lund 2016). Blanchette and Lund (2016) speculated that the natural evolution of pit lakes is limited by low levels of carbon. However, our understanding of the ecology of pit lakes and their catchments across Western Australia or Australia is limited. River diversions and river alterations at closure also pose challenges for traditional use of reference sites as each site is directly influenced by all sites upstream and small alterations in hydrology can have profound effects on geomorphology and biota. Blanchette and Lund (2017) and Blanchette et al. (2016) use a 'systems variability' approach to define whether rehabilitation is successful without the need for reference sites and using standard ecological monitoring approaches.

An alternative approach to using undisturbed reference sites is to use an actual rehabilitation outcome, if acceptable, at the mine site as the benchmark for completion criteria for future rehabilitation (Mine Earth 2013). Essentially, it recognises that there may not be sufficient knowledge to define adequate performance in terms of specific attributes in a reference ecosystem. This approach has been accepted at very few sites and presents a risk of low standards of restoration becoming accepted and replicated across multiple sites. It would be critical for this approach to demonstrate a clear understanding and documentation of the methods used to achieve the reference rehabilitation and a clear plan to replicate or improve on it. As part of that, a related program of research-focused monitoring should be instigated to ensure continuous improvement.

3.6 Attributes relevant to mine closure

International, national and state guidelines for mine closure identify many different attributes that can be used in the definition of completion criteria. Although most guiding documents list similar attributes, the terminology is often inconsistent, with no document providing a single, comprehensive attribute list. To bridge this gap, a thorough literature review for the environmental attributes was carried out including guidelines, scientific papers and expert consultation. This table was then expanded upon to also include non-environmental attributes to provide a single consolidated list for the definition of completion criteria. The non-environmental attributes provided have not been through the same scientific review process as the environmental attributes, rather populated via input from DMIRS, DWER and industry consultation. A formal review of non-environmental aspects, attributes and monitoring is identified as a gap and a recommended as future project to support revised versions of this report. References that provide further information on listed attributes are also included.

It is worth noting that while in this review attributes have been presented in the specific context of aspects of mine closure, SERA (2017) proposed an alternative grouping framed from a broader ecological perspective, which is appropriate for all restoration projects (Table 3.6). While focussed on restoration, both SER and SERA attributes are also broadly applicable to mine closure and the more detailed level of specific attributes considered in this review would also fall within these broader ecological descriptors.

TABLE 3.6 Broad alignment of aspects from local and international guidelines for rehabilitated and restored ecosystems

	SER (2004) Restoration Attribute	EPA (2006) Rehabilitation criteria	SERA (2017) Restoration attribute
Physical	4. Physical environment	1. Safe, stable, suitable for agreed use without inputs 2. Heritage and visual amenity 3. Appropriate hydrology 4. Acceptable off-site impacts 5. No major pollution, acid soils *6. Soil structure and function	Physical conditions
Biodiversity	1. Structure 3. Functional groups	9. Abundance or density 12. Canopy and keystone species 16. Habitat diversity	Community structure
	1. Structure 2. Indigenous species 3. Functional groups	8. Species diversity 10. Genetic diversity 11. Ecosystem diversity *13. Effective weed control 15. Animal diversity	Species composition
	8. Resilient 9. Self-sustaining 5. Function	*6. Soil structure and function 7. Self-sustaining and resilient	Ecosystem function
	6. Landscape integration 7. External threats	*13. Effective weed control 14. Pest and disease control	External exchanges Absence of threats

* Criteria repeat in two attributes.
Note: aspects are defined as criteria and attributes in source documents.

Attributes relating to physical and chemical aspects of waste materials and soils in rehabilitated mine sites are well established, whereas attributes and their measurement relating to biological elements are more dynamic, reflecting the advances in technology, for example in DNA sequencing (Muñoz-Rojas 2018). In addition, it should be recognised that processes and interactions in ecosystems are complex, often relatively poorly understood for Western Australia ecosystems, and the subject of substantial current research.

As an example of the large number and diversity of environmental attributes that could be considered for use in completion criteria, Wortley *et al.* (2013) reviewed 301 articles related to assessing restoration and found that the biological attributes used could be classified broadly into: 'vegetation structure'; 'ecological processes'; and 'diversity and abundance'. Vegetation structure was included in 118 papers (39%), most commonly in combination with diversity and abundance measures. Ecological processes were measured in 127 papers (42%) in total, with the most common topics being: nutrient cycling, soil structure or stability; dispersal success/ mechanisms, faunal activity and carbon storage. Attributes in the final category, diversity and abundance, were the most frequently measured with 213 papers (67%), in which about two thirds used flora and 40% used fauna. The diversity and abundance of invertebrate fauna (48 papers) were measured more frequently than vertebrates (34 papers). More specifically, Muñoz-Rojas (2018) listed 20 key soil indicators with application to restoration, and highlighted developing molecular technologies and spectroscopic techniques with potential application. Similarly, Jasper (2002) reviewed more than 40 research papers dealing with soil quality in agriculture or mine rehabilitation and identified 58 individual measures of soil properties or processes, including 22 physical, 15 chemical and 21 biological measures. Selection of attributes that best suit the practical purpose and timeframe of mine closure and relinquishment is a key challenge faced by mining companies.

Attributes to be considered for completion criteria range from those that can be directly verified or measured on the site itself, through to sensitive receptors that may be offsite, but with potential to be affected by a factor associated with the closed mine through an exposure pathway. This section aims to present a comprehensive list of attributes that could be used in completion criteria for Western Australia mine sites (Table 3.7). In the following section, considerations for selecting attributes are discussed, and a recommended list of appropriate attributes presented.

Photo courtesy: Mike Young

TABLE 3.7 Attributes applicable for the definition of completion criteria identified from the reviewed references

Few attributes are appropriate for all settings, while others not listed may also be valuable: the list focusses on environmental attributes, but also provides some as indicators for other aspects. The most recommended attributes (based on considerations of Section 3.6.1 *Attribute selection*) are indicated in grey shading).

Aspect	Biotic	Possible attributes	Type*	References
Water and drainage	Abiotic	Design and construction of landforms and drainage features	P	Barritt *et al.* (2016)
	Abiotic	Quality, quantity and fate of surface water flow	Q	ANZECC & ARMCANZ (2000a); ANZECC & ARMCANZ (2000b); Smith *et al.* (2004b)
	Abiotic	Integrity of drainage structures	Q	
	Abiotic	Connectivity with regional drainage (lakes and rivers)	Q	
	Abiotic	Pit lake bathymetry	P/Q	Blanchette & Lund (2016, 2017); Blanchette *et al.* (2016); McCullough & Lund (2006)
	Abiotic	Pit lake sediment quality	Q	
	Abiotic	Pit lake water quality	Q	
	Abiotic	Surface water quality, quantity and timing	Q	
	Abiotic	Surface water chemistry and turbidity	Q	
	Biotic	Aquatic biota (algae, macrophytes; invertebrate and vertebrate fauna)	Q	
	Biotic	Riparian vegetation	Q	
	Abiotic	Surface water chemistry and turbidity	Q	ANZECC & ARMCANZ (2000a); ANZECC & ARMCANZ (2000b); Smith *et al.* (2004b)
	Abiotic	Groundwater chemistry	Q	
	Abiotic	Direction and quantity of groundwater flows	Q	LPSDP (2016h); LPSDP (2016e)
	Abiotic	Level of groundwater table	Q	LPSDP (2016h); LPSDP (2016e)
	Abiotic	Treatment, discharge and disposal of poor-quality water and sewage	Q	
Mine waste and hazardous materials	Abiotic	Landform design & construction	P	Barritt *et al.* (2016); LPSDP (2016b, 2016e, 2016g)
	Abiotic	Residual alkalinity	Q	LPSDP (2016g, 2016f, 2016c)
	Abiotic	Particle size and erodibility	Q	Moore (2004); LPSDP (2016e, 2016c)
	Abiotic	Strength	Q	
	Abiotic	Acid, alkali or salt production potential	Q	INAP (2009); LPSDP (2016e, 2016g, 2016f, 2016c, 2016h)
	Abiotic	Total and soluble metals and metalloids	Q	
	Abiotic	Spontaneous combustion potential	Q	INAP (2009); LPSDP (2016e, 2016c)
	Abiotic	pH and electrical conductivity	Q	INAP (2009); LPSDP (2016e, 2016g, 2016f, 2016c, 2016h)
	Abiotic	Radiation	Q	INAP (2009); (LPSDP 2016e, 2016c)
	Abiotic	Asbestiform minerals	Q/P	
	Abiotic	Design and construction of containment structures for hostile wastes	P	INAP (2009); (LPSDP 2016g, 2016f, 2016c)
	Abiotic	Physical integrity of containment structures for hostile wastes	Q	
	Abiotic	Dust	Q	LPSDP (2009)
	Abiotic	Sediment quality	Q	ANZECC & ARMCANZ (2000a); ANZECC & ARMCANZ (2000b); Smith *et al.* (2004b)
	Biotic	Plant metal uptake	Q	
	Abiotic	Other types of waste: fuels, lubricants, detergents, explosives, solvents and paints	Q/P	LPSDP (2016e)

* **Type:**

P = installed/built as planned – a process for emplacing these attributes is approved initially and then certified as and when constructed;

C = categorical – the feature is required to be present or absent;

Q = quantitative – the attribute can be measured and compared against a numerical target.

Table 3.7 continues following page...

TABLE 3.7 Attributes applicable for the definition of completion criteria identified from the reviewed references

Aspect	Biotic	Possible attributes	Type*	References
Physical and surface stability	Abiotic	Soil coarse fraction content	Q/P	
	Abiotic	Soil fraction particle size analysis (texture)	Q	LPSDP (2016e)
	Abiotic	Hydraulic conductivity	Q	Moore (2004)
	Abiotic	Sodicity, slaking and dispersion	Q	
	Abiotic	Clay mineralogy	Q	
	Abiotic	Soil strength	Q	
	Abiotic	Surface resistance to disturbance	Q	
	Abiotic	Erosion rills, gullies, piping	Q	
	Abiotic	Sediment loss	Q	
	Abiotic	Placement of appropriate surface materials	P/Q	
	Abiotic	Tailings storage facilities (TSFs): Structural stability	Q	LPSDP (2016d, 2016e)
	Abiotic	Tailings storage facilities (TSFs): Compatibility with surrounding landscape and PMLUs	P	
	Abiotic	Earthworks as designed	P	LPSDP (2016c, 2016c)
	Abiotic	Subsidence	Q	
Soil fertility and surface profile	Abiotic	Soil texture (particle size distribution)	Q	Moore (2004); INAP (2009); DEC (2010)
	Abiotic	Slaking, dispersion and sodicity	Q	
	Abiotic	Compaction	Q	
	Abiotic	Stability of surface drainage lines	Q	
	Abiotic	Bulk density, depth of ripping and soil strength	Q/P	
	Abiotic	Aggregate stability	Q	
	Abiotic	Water infiltration	Q	
	Abiotic	Plant-available water	Q	
	Abiotic	Soil profile as designed	P/Q	
	Abiotic	Electrical conductivity	Q	
	Abiotic	Nutrient pools (N, P, K, S)	Q	
	Abiotic	Plant-available nutrients; cation exchange capacity	Q	
	Abiotic	Heavy metal bioavailability	Q	
	Biotic	Organic carbon (total, labile, microbial)	Q	
	Biotic	Microbial activity (respiration, enzyme activity)	Q	
	Biotic	Microbial taxonomic and functional diversity (genetic, physiological)	Q	
	Biotic	Soil invertebrate abundance and composition	Q/C	
	Biotic	Presence of specific functional soil microbial populations (e.g. mycorrhizal fungal abundance, N-fixing bacteria)	Q/C	
	Biotic	Root pathogens	Q	
	Biotic	Biological surface crust formation (cryptogram cover)	Q	
	Biotic	Proportion of area receiving topsoil	P	

Table 3.7 continues following page...

TABLE 3.7 Attributes applicable for the definition of completion criteria identified from the reviewed references

Aspect	Biotic	Possible attributes	Type*	References
Flora and vegetation	Biotic	Numbers of species and quantities of viable seed in seed mix	P	LPSDP (2016d, 2016a, 2016b, 2016f)
	Biotic	Number of seedlings planted	P	
	Biotic	Plant stem density	Q/P	
	Biotic	Vegetation cover	Q	
	Biotic	Vegetation productivity (biomass, foliar cover, height)	Q	
	Biotic	Species richness	Q	
	Biotic	Species diversity (richness, evenness)	Q	
	Biotic	Vegetation composition	Q	
	Biotic	Litter cover	Q	
	Biotic	Presence/abundance of keystone, priority or recalcitrant species	Q/C	
	Biotic	Presence of key functional groups	Q/C	
	Biotic	Community structure – presence of all strata	Q/C	
	Biotic	Community structure – patchiness, gaps, banding	Q/C	
	Biotic	Palatable & and non-palatable species	Q	
	Biotic	Disease-resistant species	Q/C	
	Biotic	Weed species presence and abundance	Q/C	
	Biotic	Condition of sensitive communities	Q/C	
	Biotic	Aquatic biota (algae, macrophytes; invertebrate and vertebrate fauna)	Q	
	Biotic	Riparian vegetation establishing	Q	
Flora / habitat	Abiotic	Constructed habitat features (breeding and refuge)	P	
	Biotic	Vegetation and litter habitat (foraging, breeding and refuge, in general or for conservation significant species)	Q	
	Biotic	Habitat complexity	Q	
	Biotic	Species presence, abundance and composition (terrestrial and aquatic, invertebrate and vertebrate)	Q/C	
	Biotic	Presence of vertebrate pests	Q/C	
	Biotic	Subterranean fauna (stygofauna and troglofauna)	Q	
	Biotic	Species and quantities of viable seed in broadcast seed – for fauna requirements	P	
	Biotic	Seedlings planted – for fauna requirements	P	
	Biotic	Indicator species abundance	Q	
	Biotic	Indicator species group richness and composition	Q	
	Biotic	Presence of keystone or significant species	Q/C	

Table 3.7 continues following page...

TABLE 3.7 Attributes applicable for the definition of completion criteria identified from the reviewed references

Aspect	Biotic	Possible attributes	Type*	References
Ecosystem function and sustainability	Abiotic	Rainfall capture & infiltration	Q	
	Abiotic	Soil surface stability	Q	
	Abiotic	Bare ground area, largest gap size	Q	
	Biotic	Biological surface crust formation (cryptogram cover)	Q	
	Biotic	Nutrient cycling (nutrient retention/loss pathways, trophic food webs)	Q	
	Biotic	Soil microbial function – solvita, respiration	Q	
	Biotic	Presence of different successional groups	Q/C	
	Biotic	Indicator species group richness and composition	Q	
	Biotic	On site nesting / breeding of fauna	Q/C	
	Biotic	Plant growth, survival, rooting depth, physiological function	Q	
	Biotic	Plant species reproduction and recruitment: Flower, seed production, seedbanks	Q	
	Biotic	Capability for self-replacement: seedbanks, seedlings mature 2nd generation	Q	
	Biotic	Connections with nearby systems in place, functioning: corridors; pollinator, gene movement	Q/P	
	Either	Offsite impacts absent or managed: dust, groundwater, disturbance	Q/P	
	Either	Key threats absent or managed: feral grazers, predators, pathogens, weeds, etc	Q/C/P	
	Biotic	Resilience to long-term climate trends	Q	
	Biotic	Resilience to disturbance (such as fire, drought, extreme weather events)	Q	
	Biotic	Feed on offer, livestock, timber, grain productivity (production PMLUs)	Q	
Social / economic	Aspect out of scope for this report: range of indicative attributes only	Recreation opportunities provided, maintained	P	ICMM (2003, 2008, 2012)
		Heritage values protected	P	
		Aesthetics (Visual Amenity)	P	
		Other ecosystem service provision	Q	
		Access and safety	P	
		Infrastructure removed	P	
		Sustainability of utilities	P	
		Land tenure (e.g. site is incorporated into conservation reserve)	P	
		Social progress: Health, education, employment, livelihoods and incomes	P/Q	

* **Type:**

P = installed/built as planned – a process for emplacing these attributes is approved initially and then certified as and when constructed;

C = categorical – the feature is required to be present or absent;

Q = quantitative – the attribute can be measured and compared against a numerical target.

3.6.1 Attribute selection

Considerations

While the number of possible indicators is very large (c.f. Table 3.7), selected attributes should be appropriate to the location, and relevant to the defined closure objectives and identified risks. Attributes that measure key components of early development in ecosystems are particularly important. The challenge is to identify biological indicators that are both meaningful and practical to measure. In Queensland, proponents are obliged to justify the selection of attributes used in criteria, including how the relationship between the criteria and rehabilitation objective has been established, supported by references to authoritative sources or relevant monitoring data (DEHP 2014).

The selected attributes used in criteria should be relevant to PMLUs, and meaningful and measurable. In addition to the principles for completion criteria described in Table 3.2 (e.g. SMART), some important requirements of attributes included in completion criteria, (e.g. EPA (2006); DMP & EPA (2015); Jasper (2002), are as follows:

- Address priority aspects;
- Be significant for rehabilitation outcomes;
- Measure an element that can be directly managed or remediated;
- Have manageable sampling intensity;
- Have low error associated with measurement, including reliable data capture from different observers;
- Have available interpretation criteria: no ambiguity in interpretation;
- Hove local reference data available or able to be sourced;
- Be responsive in appropriate timeframes, and
- Be reproducible and auditable by a third party.

A list of attributes, with recommendations based on these factors, is given on the previous pages in Table 3.7.

A number of issues should be considered when selecting attributes that are most useful for completion criteria for mine rehabilitation and closure in Western Australia for PMLUs that include ecological objectives. Leading versus lagging indicators; successional change and dynamism; fauna return; temporary water bodies and; climate and climate change are discussed below.

Leading versus lagging indicators

Completion criteria aim to determine whether a domain has reached its desired state or is on a desired trajectory. It is useful to establish criteria that may be able to provide information on performance sufficiently early to allow a timely management response, if required, on the rehabilitated area. If completion criteria are not able to be expressed in this manner, it may still be valuable for managers to develop interim targets and / or appropriate monitoring for early detection. Two important reasons to move the focus of criteria to early, or ‘leading’, indicators are:

- An early assessment of adequacy of revegetation makes it more practical and cost-effective for mining operations to be able to mobilise machinery and other resources required for remedial works; and
- In most Western Australian ecosystems, there is likely to be relatively little passive recruitment into revegetated areas after initial establishment (e.g. Norman *et al.* 2006; Stantec 2015), making it critical to focus on the early establishment stage to ensure revegetation success.

In the context of mine closure, it is a challenge to rely on criteria which may take many years to be evaluated (Figure 3.1). In these circumstances, lagging indicators may be not practical because of the time required to assess success of the measured attribute. In general, a focus on improving understanding of the most appropriate starting conditions (e.g. soils, initial plant populations, nutrient levels) is likely to be required to consistently give the best rehabilitation outcome.

The value of focussing on initial establishment is demonstrated in current completion criteria for Alcoa’s bauxite operations. As explained in the case study Section 5.6.3, the stocking rate of Eucalyptus species and density of legumes at nine months, and species richness and density of re-sprouter species at 15 months, are the four key measures of rehabilitation adequacy (Alcoa 2015). Importantly, these parameters are measured early enough so that it is relatively practical to remediate, if required. Reliance on these four criteria, measured at early stages of vegetation, is made possible because of the substantial research base that has been established, and stakeholder confidence in Alcoa's consistent application of a well-defined rehabilitation procedure. The model of relatively simple completion criteria that are based on a detailed understanding of ecosystem development processes and outcomes, and on consistent rehabilitation practices, is directly applicable for all mining operations.

In contrast to the high level of understanding of re-establishment of ecosystem structure and function after bauxite mining in the northern jarrah forest, there is a relatively limited understanding of the most appropriate rehabilitation strategy for local ecosystems (and particularly pit lakes) at most Western Australian mine sites. Inevitably, this leads to a lack of certainty in the outcome, which in turn makes measures of long-term ecosystem development unworkable as completion criteria. Improved understanding of the most important elements required to be in place at the outset will then provide a basis for defining appropriate criteria as leading indicators, and place the focus on critical early phases of landform design, soil reconstruction and vegetation establishment.

Indicators need to be a measure of, or directly linked to, an attribute that most strongly correlates with trajectory towards, or likelihood of achieving, desired final states, as well as being something that can actually be managed and remediated during closure execution, as required. For example, in relation to vertebrate fauna return to a rehabilitated ecosystem, a leading criterion may be the number of constructed fauna habitats, and or re-establishment of key plant species that provide physical or foraging habitat. If these habitat elements are inadequate, there is an opportunity to correct them during closure. By contrast, the actual timing and extent of return of the fauna species of interest to rehabilitated areas is inherently uncertain, making it less suitable as completion criteria. Even if fauna return was a direct reflection of the adequacy of rehabilitation efforts, it remains a lagging indicator because it may not be fully measurable until after development of suitable habitat. It has also been found that early return of bio-indicator species, such as ants, may be a poor predictor of longer-term outcomes (Majer *et al.* 2013). Additionally, in pit lakes, our understanding of faunal establishment and development is very poor (see McCullough and Lund 2011). However, monitoring fauna to understand their response to the re-established ecosystem is valuable, including their use of constructed habitats, because it informs continual improvement in the rehabilitation approach.

Photo courtesy: Alcoa

Dynamic references and rehabilitation trajectory

Selected references are often a mature phase of vegetation or community, whereas rehabilitation is usually still on a trajectory, hopefully, towards the mature phase state. Dynamic targets can be developed based on the behaviour of a dynamic reference if there is an appropriate reference process for this purpose (Figure 3.1). Fire is a common natural disturbance in many Western Australian ecosystems and may provide this opportunity. Even if the sequence of dynamic references is not available, comparing rehabilitation and references at one time when they are the same age since disturbance/establishment may be useful.

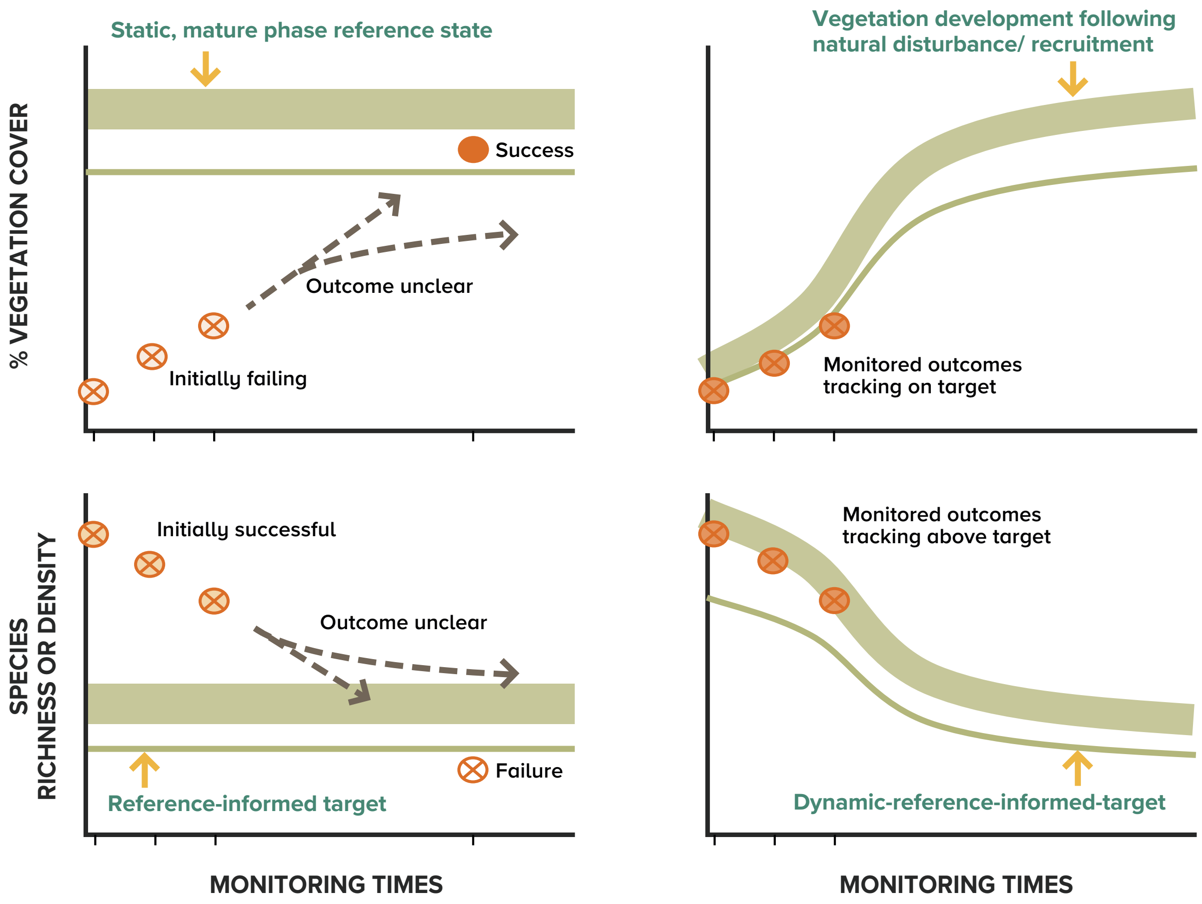


FIGURE 3.1 Monitoring models of restoration
Restoration with a mature phase **(left)** versus a developing-vegetation dynamic reference **(right)** for indices which increase over time **(top**; e.g. Vegetation Cover) and for indices which decline over time **(bottom**; e.g. Species Richness).

Monitoring based on a static reference state cannot allow strong inference of final outcomes unless the rehabilitation reaches or passes the target. Over the long-term success, but not failure can be confirmed for metrics that increase through time, and failure but success can be confirmed for those that increase through time. Comparing rehabilitation to a reference trajectory based on a dynamic developmental sequence apparent in the reference system that occurs following a natural disturbance or episodic recruitment event such as fire allows continual assessment against a dynamic reference and more informed prediction of the likelihood of success at any time.

Ecological parameters often have a predictable trajectory in natural systems after disturbance, some increasing others decreasing. Table 3.8 indicates common trajectories in attribute values that vary over time in rehabilitation. Some, such as weed cover, may vary in trajectory across sites depending on the identity of the weed species.

TABLE 3.8 Common directions of change in environmental metrics after rehabilitation

Direction	Metrics
Increasing	Plant cover Weed cover Structure and structural complexity Litter and nutrient cycling Soil carbon Fungi and soil biotic function Similarity of soil microbial community to reference Compositional similarity to reference Flowering and seed production Habitat elements for many fauna (hollows, logs) Resilience
Little change	Compositional similarity to reference Weed cover
Decreasing	Tree or plant density Species richness Bare ground Weed cover Erosion

Fauna return in the context of completion criteria

Vegetation parameters are established as the most common completion criteria and are often assumed to be effective surrogate for all other types of organisms. However, this is not always the case (Cristescu *et al.* 2012; Cross *et al.* 2019) and, thus, further work is required to validate recovery trends for fauna in a wide range of habitats (EPA 2006). Soil micro-fauna are typically brought to rehabilitated areas with respread topsoil, if collected and stored appropriately (Jasper 2007). Invertebrate fauna may also be introduced through topsoil or may recolonise from adjacent areas. Vertebrates are usually the last to recolonise, once complex vegetation assemblages and invertebrate prey are established (Thompson & Thompson 2006). Clearly, faunal successional sequence is complex and will not always be completed within required timeframes (Brennan *et al.* 2005). In addition, the presence of fauna within rehabilitation areas does not always indicate permanent, successful recolonisation (Gould 2011). The lagging nature of fauna monitoring outcomes may mean that it is best suited as a research tool rather than a completion criterion, assessing the effectiveness of current rehabilitation works for the purpose of informing further improvement, if appropriate leading indicators are available (LPSDP 2016b).

Challenges posed by water bodies

There are a range of attributes related to surface waterbodies including abiotic (water and sediment quality), hydrological characteristics (volume, flow and frequency) and biotic components (algae, macrophytes, invertebrate and vertebrate fauna). Principles that underlie guidelines such as ANZECC & ARMCANZ (2000a) have limited application to intermittent and permanent lakes and rivers, particularly in relation to mining impacts (Smith *et al.* 2004b). Smith *et al.* (2004b) review methods for water quality assessment of temporary streams and lakes, assessing the suitability of chemical and biological methods available, and providing broad recommendations.

While any number of chemical and biological indicators may be suitable for monitoring purposes, the key to effective monitoring is to first establish an understanding of the natural variability of the system. This includes seasonal fluctuations, which can vary substantially particularly in intermittent waters. Once this natural variation in baseline conditions is understood, completion criteria can be developed based on robust statistical analyses. These criteria can be utilised for comparison over time.

For waterbodies, relevant completion criteria can be established for water and sediment quality, and aquatic biota. For the former, this may involve deriving trigger values according to the upper limits of baseline data ranges, and for the latter this may comprise developing indices related to species richness (diversity), abundance and or composition.

Aquatic biota groups typically employed for completion criteria include algae, such as diatoms, and/or aquatic invertebrates (Lund & McCullough 2011; McCullough & Lund 2011) both of which are ubiquitous and are often numerically abundant. These groups are also associated with taxa that have mostly well-documented tolerance limits in the scientific literature or in specialist consultant databases. Well-defined tolerance limits of these organisms allow for comparison of monitoring data over time, and against ambient environmental conditions. The success in the use of these organisms is also linked to the experience of the taxonomists involved. Although the impact of water quality on macroinvertebrate diversity is reasonably well understood, factors such as habitat and food resources that might limit macroinvertebrate diversity in pit lakes is poorly understood (McCullough & Lund 2011). Using DNA analysis to investigate microbial assemblages (Blanchette & Lund 2018) and increasingly other aquatic fauna offers challenges and opportunities to the development of completion criteria. In addition, a more holistic approach should be undertaken for the assessment of waterbodies, where several environmental attributes such as aquatic invertebrates and algae may be measured in relation to factors such as salinity, to ensure that the desired outcome for completion criteria has been achieved. Usually these criteria may include an objective that the abiotic and biotic attributes of an aquatic ecosystem are comparable to natural or reference waterbodies in the region (although see Blanchette & Lund 2017 and Blanchette *et al.* 2016 for a counter argument).

Recognising the constraints of climate

Successful establishment of vegetation in rehabilitated areas depends on adequate rainfall at the time when viable seeds are present. The timing and amount of rainfall is unpredictable over much of Western Australia, meaning that rehabilitation outcomes may vary strongly from year to year. In a recent study of rehabilitation after iron ore mining, Shackelford *et al.* (2018) found that rainfall timing and quantity in the first two years of establishment was critical to revegetation outcomes. Higher rainfall in the first year was generally associated with greater plant density and cover in rehabilitated areas. Ensuring that rehabilitation activities are timed to coincide with most favourable climatic conditions is an important step in successful rehabilitation outcomes. Establishing timeframes for assessment that take into account this factor is critical in these systems. At the same time, developing techniques that may be able to ‘wait’ for good conditions may be an additional response.

There is debate in the field of restoration ecology as to how feasible it is to consider a changing climate in restoration practices in order to maximise long-term sustainability outcomes. One approach is to maximise genetic diversity in the system, potentially increasing diversity compared to the pre disturbance ecosystem. This may involve greater flexibility in considerations of appropriate provenance for plant species used in seed collection programs for site rehabilitation (Broadhurst *et al.* 2008). This will require greater understanding of the physiological tolerance zones of key perennial species to a changing climate, for example the drying trend exhibited in south-west Western Australia or the increased frequency of extreme weather events (Hancock *et al.* 2018). Embedding networked and standardised experimental trials into restoration activity has been identified as an approach that will support improved decision making for climate resilient restoration planning (Prober *et al.* 2018).

3.7 Monitoring environmental attributes

Within the mining context, monitoring can be defined as the gathering, analysis and interpretation of information for the assessment of performance (LPSDP 2016a). A separate process is auditing, which is the systematic review of monitoring procedures and results, to check that all commitments have been fulfilled by comparing the findings against agreed criteria. Although monitoring and auditing are separate processes entailing different methods and outcomes, they often come together under ‘monitoring and maintenance frameworks’ outlined by mine closure planning guidelines (ANZMEC & MCA 2000; ICMM 2008; DMP & EPA 2015). For example, according to the ICMM Planning for Integrated Closure Toolkit (ICMM 2008), closure monitoring programs need to establish: baseline conditions; quantification of changes that might occur; how progression towards goals can be measured; and how the achievement of goals can be demonstrated.

Following cessation of mining, monitoring should continue until it can be demonstrated that closure outcomes and completion criteria have been met (ANZMEC & MCA 2000; DMP & EPA 2015). It is often unlikely that many ecological conditions can be met within less than five years, while minimum monitoring periods after closure are usually in the order of 10 years. In Western Australia (DMP & EPA 2015), mine closure plans must provide appropriate detail on their monitoring procedures for each of their closure criteria. Closure monitoring frameworks shall include a number of items, such as methodologies (sampling, analysis and reporting), receiving environments, exposure pathways, reference trends and quality control systems.

In line with international standards (ANZMEC & MCA 2000), monitoring plans in Western Australia must also provide contingency and remedial strategies to be applied when indicators show a risk that completion criteria may not be met. This is understood as a risk-based approach, when monitoring and auditing results are used to review and refine completion criteria towards acceptable and realistic targets. Risk-based monitoring and auditing also has the advantage of reducing uncertainty in closure costs and contributing to orderly and timely closure outcomes.

3.7.1 Key monitoring methodologies

Given that completion criteria should be quantifiable, repeatable and auditable, it is good practice to create criteria that are amenable to statistical assessment. Arguably, a higher standard of evidence may be required to ensure that completion criteria have been met for attributes with higher levels of risk.

Monitoring programs should be designed to unambiguously and effectively answer the question posed by each completion criteria, and this requires appropriate sampling design. The way that completion criteria are formulated may also influence monitoring design and, indeed, completion criteria formulation should take into consideration the consequences for monitoring. For example, if completion criteria are expressed relative to a threshold (e.g. weed cover not more than a nominal percentage), then sampling needs to demonstrate that all sites are on the correct side of the target value. On the other hand, if completion criteria are expressed as being 'similar to' a target, then statistical tests of difference are required which take into account the average values of weed cover in both the rehabilitated and reference site samples and their variation.

This section discusses monitoring approaches for assessing completion criteria and identifies a range of techniques available for several key attributes and issues surrounding their use. It primarily focusses on ecological parameters relevant for completion criteria that are employed in various guidelines for rehabilitation and restoration (SER 2004; Wortley *et al.* 2013; SERA 2017) and in related literature (Ruiz-Jaén & Aide 2005a, 2005b; Lechner *et al.* 2012; Miller *et al.* 2016b).

The scientific literature that reviews monitoring methods in rehabilitation focuses on rehabilitation monitoring methods that are published in scientific studies. These may not represent a complete sample of appropriate monitoring approaches, project types and post-mining land uses, and would over-represent those with associated research projects. For example, Ruiz-Jaen and Aide (2005a), Matthews and Endress (2008) and Wortley *et al.* (2013), review the types of measures employed in published scientific literature to assess 'ecological restoration'. These reviews find that most studies focus on one, or two, of three types of attributes: measures of diversity and abundance are most frequently reported, followed by measures of vegetation structure, and of ecological functioning. Wortley *et al.* (2013) suggest that diversity and abundance measures are employed in the majority (76% in their analysis) of studies, as they represent a primary objective of restoration, but also as they indicate habitat suitability and/or can be a proxy for other outcomes. Ruiz-Jaen and Aide (2005a) note that no restoration research published at that time measured all the attributes identified in the SER Primer (SER 2004) and encourage the use of at least two variables within each of the three SER ecosystem attributes that relate to ecosystem functioning.

Ecological monitoring procedures relevant for assessing ecological completion criteria are detailed in a number of recent books devoted to the subject (e.g. Likens & Lindenmayer 2018), as well as text books on restoration such as (Galatowitsch 2012). Many guidelines discuss monitoring approaches and issues in relation to mining rehabilitation, and the locally relevant documents are summarised in Table 3.9. The points that relate to sampling design constraints and specific to monitoring of rehabilitation and comparison with reference site data for completion criteria are addressed in the following sections.

TABLE 3.9 Key guidance documents for monitoring methods in relation to mining impacts and rehabilitation

Title	Reference	Comments
Evaluating performance: monitoring and auditing	LPSDP 2016b	Provides “Typical elements of a monitoring and performance program” including, what to monitor and how often, and example performance criteria. Does not include specifics of how to monitor but does provide guidance on criteria, and their relationship to monitoring. Gives examples of typical element of completion criteria, for landforms, water, biodiversity
Biodiversity management	LPSDP 2016a	Outlines key principles and procedures for assessing, managing, and monitoring biodiversity values, including monitoring and reporting on biodiversity management performance
Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 1	ANZECC & ARMCANZ (2000a)	Volume 1: provides a management framework for applying the guidelines to natural and semi-natural marine and freshwater resources. It also provides a summary of the water and sediment quality guidelines to protect and manage environmental values supported by the water resources, as well as advice on designing and implementing monitoring and assessment programs Sections 1–7 contain the body of the guidelines and specifies trigger values for the protection of aquatic ecosystems and the numerical criteria for protection of other environmental values
Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 2	ANZECC & ARMCANZ (2000b)	Volume 2 (Section 8) provides further guidance on protecting aquatic ecosystems, and describes water quality issues, modifying factors, decision trees, toxicant profiles and biological assessment
Review of methods for water quality assessment of temporary stream and lake systems	Smith *et al.* (2004b)	Provides a practical review and guidance for assessing the quality of temporary waters (using chemical and biological indicators). Of particular relevance for evaluating the impacts of mining in arid and semi-arid regions of Australia
Guidelines for Mining Proposals in Western Australia	DMP (2016)	Principles and purpose of monitoring are discussed for each criterion. Includes example tabular framework of: factor, objective, risk, outcomes, criteria and monitoring
Guidelines for Preparing Mine Closure Plans	DMP & EPA (2015)	Provides a planning process is in place so that the mine can be closed, decommissioned and rehabilitated to meet DMP and EPA’s objectives for rehabilitation and closure in Western Australia
Technical Guidance – Flora and vegetation surveys for environmental impact assessment	EPA (2016b)	Directed at planning and undertaking flora and vegetation surveys for environmental impact assessment (EIA)
Technical Guidance – Terrestrial fauna surveys	EPA (2016f)	Provides direction and information on general standards and protocols for terrestrial fauna surveys for EIA
Technical Guidance – Sampling methods for terrestrial vertebrate fauna	EPA (2016d)	Addresses survey design and sampling methods for terrestrial vertebrate fauna in the context of proposals where fauna is a relevant environmental factor
Technical Guidance – Subterranean fauna survey	EPA (2016e)	Addresses how subterranean fauna are considered in EIA in WA and provides advice to proponents on the level of information and survey required and how to analyse the results
Technical Guidance – Sampling methods for subterranean fauna	EPA (2016c)	Addresses survey design and sampling methods for subterranean fauna in the context of proposals where subterranean fauna is a relevant environmental factor
Soil Guide: a handbook for understanding and managing agricultural soils	Moore (2004)	Integrates assessment of soil properties, their influence on soil fertility and land degradation, and options for management or remediation
Global Acid Rock Drainage Guide	INAP (2009)	A summary of the best practices and technologies for prediction, prevention and management of acid rock drainage
Managing waste rock storage design – can we build a waste rock dump that works?	Barritt *et al.* (2016)	Overview of principle of appropriate design of waste rock landforms, with associated case study
Hazardous materials management	LPSDP 2016c	Addresses environmental issues associated with hazardous materials, such as minerals, process chemicals, dangerous goods, radioactive materials and wastes

3.7.2 Sampling independence

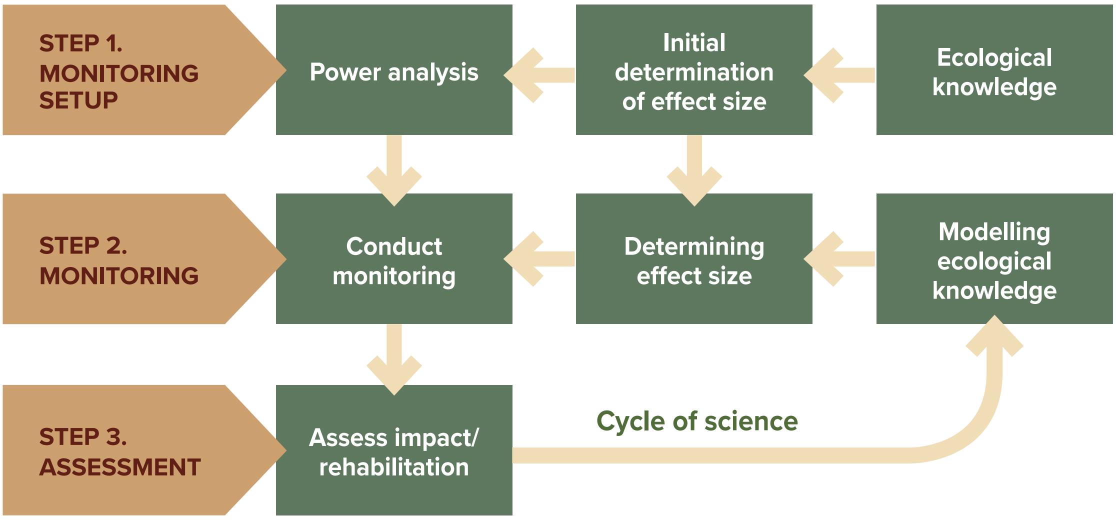
A fundamental principle of sampling design for statistical testing, but equally for other testing approaches, is that samples are representative and independent (Likens & Lindenmayer 2018). Representative means that samples (e.g. plots) are distributed in an unbiased way across the variation present in measured parameter in the sample area and capture a fair representation of that variance. Independent means both that plots are not all selected where outcomes are particularly good (e.g. places were weed cover is zero) or are not chosen to include sites with the highest and lowest values, but that the selection is neutral or independent in relation to the value being tested. Typically, this means randomly. If some factor is known to influence the parameter in question, such as year of rehabilitation, then these factors should be sampled and tested as separate groups. Sampling designs, such as random-sited systematic approaches, can make the logistics of a random design simpler, but still deliver an independent design, although sometimes at the expense of spatial representation.

Sampling independence is a particular issue for aquatic systems where, for example, in rivers all sites are interconnected and are essentially not-independent. It is advised that specialist advice is sought prior to development of monitoring for aquatic ecosystems.

Spatial autocorrelation and pseudo-replication are other issues of concern to ecological monitoring and in research. They relate to sample independence and inference. Spatial autocorrelation occurs when a feature of concern has a specific spatial pattern (such as seedling emergence in riplines but not intervening crests), and sampling is spaced at the same scale as the pattern. It is easily avoided with some consideration. Pseudo-replication is a problem for many ecological studies, and in a rehabilitation setting it may be particularly difficult to avoid. It occurs where all sampling replicates are placed in a single treatment or polygon for a given age and domain, rather than many. Multiple samples in just one treatment block allow assessment of that treatment block and it is wrong to assume it can be generalised to other blocks of the same treatment and capture representative variance of the year and domain. Ideal design would include multiple instances of the thing being tested, rather than multiple replicates within just one. This can be an issue in rehabilitation monitoring, but more often reporting only relates to the area monitored.

3.7.3 Statistical power

The critical importance of understanding and employing statistical power in mine rehabilitation monitoring for completion is emphasised by Lechner *et al.* (2012). Power is a measure of the confidence that a statistical sampling design is able to detect a difference of a given size if where such a difference exists. Low power arises when designs include few data points, or there is very high variance in the data and the effect size being tested is small. Effect size describes the minimum size of a difference that is being tested and it should be based on a consideration of what a meaningful difference would be. For instance, very intensive sampling would be required to be confident that a 1% difference in mature forest cover between a sample of reference plots and monitored rehabilitation sites could be statistically significant under normal standards (e.g. in an ANOVA with $p<0.05$). Most designs would not have adequate power to detect a difference at this effect size, but a trade-off exists between sampling intensity, power and minimum effect size. Instead, for this example, it might be important to know if a survey design could detect a 15% difference in vegetation cover, because that is a more ecologically relevant and meaningful difference. If a test finds a significant difference, then power is adequate, but if it does not, it may be that either there was no difference, or that the design was not powerful enough to find one that did exist. Power can be assessed prior to survey design, with some input knowledge of likely variation in data and a determination of the minimum effect size (see figure), or it can be assessed after the case. Assessing after the case does not help with design but does indicate whether the test is robust or not. Considering power draws attention to number of samples in a survey, the area (or accuracy) of samples (e.g. plots), the variance of the parameters and the effect size. Technical statistical advice is recommended for power analysis or consideration.



Source: Lechner et al. 2012

FIGURE 3.2 A model for incorporating effect size in monitoring design

3.7.4 Monitoring for diverse purposes

Monitoring is critical for completion criteria assessment but is also valuable for other purposes. For instance, both adaptive management and strategic research require monitoring to test specific treatments and support changes in approach to improve processes. Likewise, monitoring is useful to maintain ongoing awareness of areas that may require remediation or follow up action, or to track progress towards achieving completion criteria, prior to any point where regulatory assessment or reporting is required. Monitoring for these purposes could be designed on a different schedule, with different intensities and methods, and even to address metrics other than those required for completion criteria.

An important complement to monitoring for a mining operation is a commitment to retain detailed meta-data relating to each rehabilitated area including dates, site treatments, seed mixes, and climatic conditions.

3.7.5 Monitoring ecological attributes

Major categories of ecological attributes relate to flora and vegetation; fauna and fauna habitat; and ecosystem function and sustainability. Each of these have their challenges for monitoring and assessment.

Flora and vegetation

Flora and vegetation attributes address the structure and composition of vegetation. The composition of a community is the list of species, their identity and their relative abundance.

The most basic composition attribute is species richness which is a simple count of species present. Richness is often conflated with ‘species diversity’ which, in a technical sense, is a different measure. Diversity takes into account both richness, and the relative evenness of abundance of the species present (Hill 1973). It is rare that species evenness, and hence species diversity, would be used in completion criteria, simply because most of the importance associated with the concept of diversity is captured by richness alone, and evenness is rarely a key concern on its own in rehabilitation (Martin *et al.* 2005). Calculation of evenness and diversity requires a count of abundance for each species, whereas richness simply requires a count of species. When evenness is not of concern, use of the term ‘richness’, instead of ‘diversity’, will avoid causing confusion among ecologists.

Species richness, while a simple count, is not necessarily simple to compare between samples. This is due to a problem with scale, resulting from the species-area curve, or the species-accumulation curve. Essentially, as more individuals are counted (or accumulated) in a sample, more species may be found. This would be the case if all species occurred at the same abundance, but is exacerbated by the fact that many species are infrequent, and that most have patchy occurrences (Miller *et al.* 2016b). As a result, comparisons of reference site richness data with rehabilitation monitoring data require the measurements to be on the same basis. At a minimum, this means surveying the same number of samples each of the same area, but a further complication arises from changing density through time. Young rehabilitation sites may have many seedlings per m^2 and hence potentially many species. Through time, seedling numbers thin out and ultimately there may be few or no plants in a single m^2, which may also be the case in mature reference woodland vegetation, for instance (Figure 3.1). Thus, richness samples need to take into account both area and density, or number of plants surveyed. Rarefaction enables comparisons of richness among samples of different sizes (Gotelli & Colwell 2001). Approaches also exist which enable estimation of total richness for a given area from a set of samples within it, although these should be employed with some caution (Chiarucci *et al.* 2003). At a minimum, species richness should be reported as both mean number of species per plot and total number of species found in a sample of plots, given that the same species will not be found in each plot, for this reason richness should not be surveyed in unbounded relevés (Table 3.12).

In much of Western Australia, fire is a regular event in natural ecosystems and post-fire recovery results in many new individuals recruiting, often including new species which were not observed in the mature vegetation. These short-lived, or ephemeral plants, are part of the ecosystem and ideally should be assessed in reference state survey. Furthermore, these ephemeral species are useful in rehabilitation, helping to quickly establish cover after disturbance, and may assist with ameliorating the local environment for seedlings of longer lived species, including by adding soil carbon as they senesce and decompose (Miller *et al.* 2016a). The presence of these short-lived fire-responding species after fire, or in rehabilitation if transferred topsoils, add another element to boost richness and lead to longer-term changes following disturbance or rehabilitation (Gosper *et al.* 2012). Solutions to the complexity of incorporating successional changes in richness and density in completion criteria development and monitoring may require some local ecological understanding and careful thinking to move beyond comparison of young rehabilitation with mature phase reference vegetation (Matthews *et al.* 2009). The process of developing performance targets that reflect regeneration process following natural disturbance provides data and insights on timeframes for rehabilitation development (Kirkman *et al.* 2013).

Beyond a base measure of richness, community composition is infrequently quantified as a restoration target in itself – in spite of techniques for assessing ecological similarity or difference being well developed in community ecology and project goals often including expressions such as returning a similar vegetation community (Ruiz-Jaén & Aide 2005a; Koch & Hobbs 2007; Wortley *et al.* 2013; Miller *et al.* 2016a). If it is important that the same, or indeed a different, specific vegetation community is to be returned (such as if mining in a threatened ecological community or nature reserve), then it is reasonable that a completion criterion should require confirmation that the community returned is in fact the same as the target. Variation in community composition is measured through similarity (or dissimilarity) metrics (Ruiz-Jaén & Aide 2005a), which consider the relative similarity of the list of species that occur in pairs or groups of sites (with or without their varying abundance depending on the measure). Composition varies spatially in natural communities as a result of species patchiness and turnover, and between communities. In practice, not all communities are defined in this way, and no global standard for difference in similarity is accepted as definition of a change in community, but statistical tools such as ANOSIM, adonis, PERMANOVA and MANOVA can help to identify if two sets of vegetation samples differ in composition, while SIMPER (similarity percentages) and Indicator Species Analysis assist with identifying which species contribute to differences (Dufrene & Legendre 1997; McCune & Grace 2002)

A number of techniques for measuring vegetation cover are well known, and several new technologies are becoming increasingly important in this field.

TABLE 3.10 Comparison of methods for estimation of vegetation cover

Method	Variations	Strengths	Weakness	Outputs
Photopoint monitoring		• Simple to employ • Provides visual record useful for communication	• Site based and field intensive • Does not provide numeric data	• An image
Visual estimation	• Several estimation scales (Braun-Blanquet, Domin scale) and tools exist	• Simple to learn and employ • Appropriate for assessing gross changes • Can easily include vegetation structure, weed assessment and vegetation composition in the same survey • Technically simple	• Site based and field intensive • Prone to high error and low repeatability even among experienced users	• Estimated total cover for plot • Cover per species • Live and dead cover
Point or line intercepts	• Line or pole intercept approaches	• Simple to learn and employ • Repeatable and objective • Appropriate for assessing smaller differences in cover • Technically simple	• Site based and field intensive • Less well known and used • Time consuming	• Measured cover for plot • Cover per species • Live and dead cover • Structure
Remote sensing	• Image analysis • LiDAR • Aerial photogrammetry • Drone, plane or satellite platforms	• Able to assess broad areas rather than sampled points • Can often largely be implemented remotely • LiDAR able to provide vegetation structure data • With training can distinguish some distinct species in some settings (e.g. weeds) • Enables some assessment of change in condition or growth if repeated • Rapidly improving in capability	• Technologically intensive • Still experimental in some areas • Produces sometimes unwieldy volumes of data	• Total site cover • Can extract point cover • Size and shape of gaps and bare ground • Spatial patterns • Cover per species (for select species)

Remote sensing techniques are increasingly being employed to assess rehabilitation vegetation cover, and are considered effective at this task (Homolova *et al.* 2013; Atkinson 2018). Analysis of images from satellite, fixed-wing plane or drone-mounted sensors can detect the presence of vegetation or bare ground with remarkable spatial resolution. Issues with shadows, movement, image angle, time of year, varying atmospheric conditions and sensor status make comparison of repeated surveys challenging for specific points, but these issues can often be more manageable over larger areas. With sufficient returns per m^2, LiDAR (light detection and ranging) is effective for assessing vegetation structure and is increasingly able to traverse very large areas — the massive data associated with such efforts can be a challenge for management and analysis, but capability is increasing in this area also. Structure from motion or photogrammetric methods, requiring overlap of images from different angles, can be used to interpret surface (ground and canopy) heights and to classify vegetation and ground. Analysis in variation of values from multispectral sensors are frequently used to assess change in vegetation greenness or condition, with greenness measures such as Normalised Difference Vegetation Index (NDVI) being well known. Comparison of images from different seasons can pick up annual versus perennial (and hence sometimes weed cover) and total plant cover change through time. The application of techniques such as object-based image analysis to differentiate species has the potential to further extend the value of aerial imagery (Homolova *et al.* 2013; Whiteside *et al.* 2011). With appropriate ground truthing and validation, these data can be expected to be more accurate and robust than that gathered from on-ground monitoring alone. Extensive training, calibration and validation of multispectral, and especially of hyperspectral imagery, is increasingly being able to detect objects of different types in remotely sensed images. This artificial intelligence/machine learning training must be undertaken for specific regions, soil types and vegetation types, and for each species, if species detection is required. While species detection is a feasible future capability, it is unlikely to ever be able to replace on-ground botanical survey, but it would be valuable for broad structural change.

Fauna and fauna habitat

Unless a specific priority, such as where threatened species, habitat or ecological communities are impacted, fauna are not often included in completion criteria for a number of reasons, including those discussed in the previous section. Where fauna or habitat- focussed completion criteria are required, monitoring can be indirect focusing on resources and habitat availability for fauna, or direct, measuring fauna populations. Fauna monitoring protocols vary widely by species and groups, with some groups being particularly challenging to study, and low detection rates and mobility mean that specialised statistical approaches are often required.

Fauna also deliver key ecosystem functions, such as bioturbation, nutrient cycling, population regulation through predation and herbivory, pollination, dispersal and provide food resources for higher tropic orders. Monitoring for function is discussed below. Monitoring fauna as indicator groups for rehabilitation development and function has been examined by Majer and colleagues in a series of studies. Bisevac and Majer (1999a, b) compare monitoring effort for vascular plant species, amphibian species, reptile species, bird species, mammal species, arthropod orders and ant species in Kwongan shrublands. It was found that while field and processing times varied, information yield (number of taxa) was highest for plants and arthropods, and effort required (time) was of the same order for these groups but higher for vertebrates. Majer (1983) and Majer and Nichols (1998) demonstrated that ants are particularly amenable for monitoring, recording relatively high species per hour of effort. This result is broadly confirmed in an analysis of monitoring in Jarrah forest rehabilitation (Majer *et al.* 2007) where spiders, true bugs (Hemiptera) and beetles were also shown to be useful indicators.

Ecosystem function; resilience and self-sustaining capacity

Ecosystem function and functionality are diffuse concepts that address the effectiveness of sustaining processes in ecosystems. These high-order processes are made up of many interacting and contributing sub-processes (Table 3.11). While it is important that these functions are active and effective, their complexity makes them challenging as criteria for measuring success: the attributes often take longer to develop in rehabilitation than other criteria and are difficult to measure (Ruiz-Jaén & Aide 2005b). With the exception of those relating to regeneration capacity and resilience — the ability of systems to respond to perturbation (Standish *et al.* 2014) — many functions are best demonstrated by their outcomes (Table 3.11), if they can be summarised in a simple way. The key outcome is the support for the ecosystem, which can be measured by the cover and richness of vegetation and the richness and abundance of the fauna community. Resilience and regeneration capacity are sometimes only demonstrated when they are required, such as in response to events such as fire: if they are not present, then the system fails. As such, it is useful to measure by experimentally manipulating or testing in sample areas (Herath *et al.* 2009; Miller *et al.* 2016a).

TABLE 3.11 Outcomes, processes and elements comprising the concept of ecosystem function

Functional outcome	High-order ecosystem process	Component elements
Production of viable and genetically fit offspring in necessary quantities for population replacement	• Connectivity and gene flow	• Mating systems • Viable population size • Pollen viability • Pollinator presence and activity • Seed dispersal agents present and active • Landscape connectivity for fauna movement
Regulation and support for plants and macro fauna	• Plant – animal interactions; • Trophic interactions; • Inter and intra-specific interactions; • Substrate resource availability	• Herbivory • Food sources for higher trophic orders • Competition and facilitation • Plant physiological function
Soil development, health and function	• Nutrient cycling; • Plant nutrient acquisition; • Nitrogen fixing	• Mycorrhizal fungi • Decomposer community • Soil microbial community • Biological soil crusts • Scratching and digging animals • Soil compaction and physical strength
Dynamic responses to abiotic processes	• Responsiveness to environmental disturbance and variation; • Resilience; • Successional change; • Self-organisation of spatial pattern	• Seedbank development and persistence • Development of lignotubers • Disturbance events (e.g. fire, inundation, tree fall) within natural regimes • Immigration, colonisation
Stable and functional landscapes	• Natural erosion and deposition regimes; • Retention of soil moisture; • Hydrological flows	• Vegetation cover establishment • Soil carbon development • Rainfall infiltration and retention • Absence or natural seasonal cycling of hydrophobicity • Soil turnover by digging animals

Developing and established molecular techniques are increasingly being recognised and shown to be powerful tools for understanding cryptic biological patterns in diverse environments (Williams *et al.* 2014; Fernandes *et al.* 2018). Metabarcoding or eDNA analysis (analysis of DNA present in environmental samples) is capable of detecting patterns of abundance and change in biotic communities (Fernandes *et al.* 2018). In a rehabilitation context, this can be particularly useful for understanding the development and state of soil microbial or groundwater stygofauna communities or detecting the presence or population composition of cryptic fauna species in a landscape (e.g. Bilbies, Macrotis lagotis) (Fernandes *et al.* 2018). The molecular information derived from these analyses enables identification of taxa or individuals – if the identity of either is already recorded in a library of samples matched with vouchered confirmed reference collections of the species – or of operational taxonomic units (OTUs). Analysis of OTUs can provide useful indication of the richness and composition of samples, and their relation to reference samples, even though the identity of the species represented is unknown (Banning *et al.* 2011). Soil functional attributes are increasingly being measured in battery techniques which assess many functions simultaneously (Muñoz-Rojas *et al.* 2016b). Microbial assemblages determined from '16S DNA analysis' is challenging much of our understanding of the underlying microbial processes in aquatic ecosystems (such as in sulphate reduction) that may be important for rehabilitation or remediation (e.g. Green *et al.* 2017). Landscape Function Analysis (LFA) is a tool specifically designed to simplify assessment of soil function and facilitate monitoring of restoration state or trajectory in relation to a reference condition. LFA involves transect-based soil surface assessment, designed to provide indicators of soil stability, infiltration and nutrient cycling. Combined with vegetation, erosion and habitat complexity assessments (as Ecosystem Function Analysis; EFA) these tools have been widely applied within the Western Australian mining industry (Tongway & Hindley 2003). While simple to apply and retaining many adherents (Maestre & Puche 2009; Munro *et al.* 2012), LFA and EFA are increasingly being replaced by either direct functional measures such as soil carbon respiration, or measures of rehabilitation biotic outcomes alone as they become simpler and better known.

3.8 Designing ecological monitoring of rehabilitation in relation to risk

As noted in Section 3.3.3 above, rehabilitation risk can be derived from a combination of the importance of the values that are impacted or required to be replaced, and the challenges in achieving them (arising from lack of precedent or knowledge, lack of demonstrated capability or commitment, environmental constraints, exceptionally short or long time frames or other complexities; Table 3.5).

Completion criteria prioritisation and formulation should be based on risk assessment (Section 2.7.2). The subsequent design of monitoring programs to assess criteria should be tailored to reflect the specific formulation and expression of criteria. This can be an iterative process: it is advisable to consider potential monitoring approaches to some extent when formulating criteria. Completion criteria may not all represent attributes considered to be high risk, and sometimes risk may be recognised as varying across rehabilitation domains. Even though attributes may be considered lower risk, sometimes there may be a need for monitoring, whether as part of completion criteria or for other purposes. Monitoring lower risk attributes or locations may not require the same evidence, design, monitoring intensity or standard of testing as high-risk attributes or sites. The table on the following pages lists the most common ecological attributes monitored, together with standard approaches appropriate for varying levels of risk (Table 3.12).

Photo courtesy: Alcoa

TABLE 3.12 Ecological parameters useful or used in completion criteria development with monitoring approaches

Monitoring approaches are suggested as appropriate for varying levels of failure risk. A plus sign (+) indicates that requirements are additive from the previous column. Basic statistical tests and other useful tools appropriate for demonstrating success are shown with shading to indicate the minimum level of risk to which they should be applied. Higher risk approaches can be applied at lower levels if feasible and efficient.

	Low risk	Moderate risk	High risk	Statistical test	Other tools	Relationships with other measures
FLORA AND VEGETATION						
Plant community species richness	Mean species richness within plots	+ total richness in survey (area corrected in some form)	+ rarefied species counts adjusted for number of individuals and or plots; adjust for successional trajectory	t – test ANOVA	Species-area or accumulation curves for visualisation	Stand-alone top-level measure
Diversity						A specific reason required to do this and not just Richness
Vegetation composition	Confirm all species in seeding and topsoil source are from local community	Confirm all species in rehabilitation are from the target community; ensure framework taxa are present	+ assess similarity and differences relative to reference; ensure indicator species are present	Adonis, ANOSIM	Classification; Ordination (NMDS, PCA)	Stand-alone, top-level measure
Functional types	Ensure mix of life forms are used in seed mix or present in rehabilitation	+ ensure mix of successional stages / life span are used in seed mix or present in rehabilitation	+ asses presence and relative abundance of agreed functional types (consider pollination syndromes, flowering times, seed types, storage modes)	Adonis, ANOSIM	Classification; Ordination (NMDS, PCA)	Supplements composition, as an additional measure for high standard projects, or could replace it if a lower standard acceptable
Provenance	Propagules should be regionally sourced	Apply agreed collection zone – e.g. distance and/or bioregion	Assess provenance zones or collect only from local (on site/ adjacent) sources			Stand-alone, but rarely a criterion, more often a required part of process
Vegetation cover	Photopoint comparison	Visual estimation (eg Braun-Blanquet or Domin scale)	Quantify intercepts on points or transects, or; use remote sensing	t – test ANOVA	Analyse gap or patch size distributions, variance in cover	Often a stand-alone measure, but could be replaced by density or structure
Vegetation structure	Photopoint comparison	Apply physiognomic classification rules	Assess/estimate cover in strata			Supplements Cover, as an additional measure for high standard projects, or could replace it if a lower standard acceptable

Table 3.12 continues following page...

TABLE 3.12 Published guidelines relating to mine closure and or completion criteria

	Low risk	Moderate risk	High risk	Statistical test	Other tools	Relationships with other measures
Stem density	Counts in plots, transects or PCQ		+ compare with reference successional (e.g. post-fire) trajectory	t – test ANOVA		Rarely more effective than Cover unless a specific tree species density is required
Weed abundance	Presence of non-native species	Estimated or measured cover in plots, or survey of density; remote sensing if effective	+ map weed distribution	t – test ANOVA		Stand-alone as required
FAUNA AND FAUNA HABITAT						
Non-specific fauna	List resident, breeding, visitor observations	Survey key groups for occurrence	Assess presence or abundance of indicator species/ guilds	ANOVA Ordination	PERMANOVA ANOSIM	Assessed for highest standard projects
Specific fauna (if required)	Appropriate habitat or resources	Record of presence	Appropriate quantitative approach; camera traps; pitfall survey; radio tracking	ANOVA		Stand-alone as required
Fauna habitat	As per vegetation cover (low or medium)	+ as per vegetation structure (high), + presence of food sources	+ survey density and quality of specific elements – nest hollows, roost trees, food sources	ANOVA		Assessed for high standard projects; complemented by vegetation cover and/or structure
Other biota		Presence of major fungal guilds	+eDNA analysis for soil biota	PERMANOVA ANOSIM	Classification; Ordination (NMDS, PCA)	Assessed for highest standard projects, can be used with, or instead of, ecological function

Table 3.12 continues following page...

TABLE 3.12 Published guidelines relating to mine closure and or completion criteria

	Low risk	Moderate risk	High risk	Statistical test Other tools	Relationships with other measures
ECOSYSTEM FUNCTION AND SUSTAINABILITY					
Resilience	Evidence of flowering and seed production	Evidence of seedbank viability (seedbank audit) and/or recruitment	Test by experimentally imposing disturbance – assessing a set of other measures (cover, composition, weeds etc.	ANOVA Ordination	Important but difficult to assess properly; best associated with on-site research. Overlap with 'self-sustaining', and may employ others for assessment
Ecological function	Subjective 'condition' assessment	Compare plant growth and survival rates with reference at same stage	Soil microbial Function tests; compare plant ecophysiological performance	ANOVA	Similar to 'self-sustaining'
Landscape function	Assess largest bare ground gap area	Compare quantified bare ground with reference	Measure infiltration; soil transpiration; survey erosion	ANOVA	Can be complemented by ecophysiological performance (Ecological function). May be redundant if vegetation cover and structure developing as required
Connectivity or landscape integration	Physical connectivity as planned	+ assess hydrological connectivity	+ radio tracking for fauna; paternity assessment for pollen flow	ANOVA Relevant tests	Stand-alone
'Self-sustaining'	Evidence of, growth, survival, flowering and seed production	Recruitment or seedbanks demonstrated in field; Ecophysiological performance at least equal to reference for similar stage	Several generations observed at stand replacement level; demographic modelling	PVA	Similar to resilience and also difficult to demonstrate, may be addressed through mix of resilience and ecological function measures
Specific ecosystem service	Presence of features supporting service delivery	Quantify abundance of feature providing the service delivery	Social or economic analysis of value of services provided	As appropriate	This form of completion criteria is more appropriately considered among social or economic attributes, but its monitoring may include biological elements, such as in bioremediation by wetlands, honey production or carbon storage

(END OF CHAPTER 3)