Assessment Framework for Rehabilitation Sand Mining Howard Sand Plains Site of Conservation Significance

Project Name: DW100023 Howard Springs Caring for Our Country






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Executive Summary

This study is a component of an overarching project titled: "Extractives Industry Improved Response to Biodiversity for the Howard Springs Sand Plain" which has been funded over two years by the Australian Government "Caring of Our Country Program". Attainable outcomes for rehabilitating mining areas are identified as key hindrances for the extractive industry to operating sensitively within a site of conservation significance. A lack of clear endpoints and closure criteria has been identified as a key reason for poor results with rehabilitation associated with sand and gravel extraction (Talyer, 2004). This report presents an overarching approach or framework to improve rehabilitation and the associated biodiversity outcomes for sand mining associated with the Howard Springs Sandsheet habitat.

The proposed framework consists of 6 key steps which provide the foundation for developing a standardised and systematic approach to improving the biodiversity outcomes for the sand extractive industry as a whole. The approach aims to build linkages between the landscape scale objectives for conservation through to the sites scale and it brings together several components (ecological science and theory, management practices and monitoring) into a complete system. A key purpose to this framework is to strengthen practices through setting goals and learning through experience. Further experimentation is required to ensure the overarching framework and its components are refined.

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Acknowledgements

Many thanks to: the assistance of all Extractive Industry Members who provided the history and records of their tenements; in particular Sandra Johnson and June Lurssen were most supportive towards this project in providing information, contacting individual members for further detailed information as well as spreading the word within the industry. Thanks also go to Nigel Doyle for his insights into the geology of the Howard Springs Sand Plains; Dave Liddle for the vegetation mapping and comments on the initial design of this study; Steve Reynolds for conducting some initial trials of the field assessment and providing comment on the area of practice for improving conservation for the Howard River Toadlet (a Sandsheet frog).

1 Introduction

1.1 Project Scope

The majority of Darwin's fine sand supplies are extracted from a Sandsheet land type within the Greater Darwin Area and particularly within the Howard Sand Plain Site of International Conservation Significance. Within the Howard Springs Site of Conservation Significance there is a direct overlap between the values of Sandsheet as a resource and as a habitat for rare or restricted species (refer Figure 1-1).

There are several economic and hence political drivers for sand extraction to continue within the Howard Sand Plain Site of Conservation Significance, despite a direct conflict between conservation and resource utilisation values. In addition, the demand for fine sands is set to increase over time as the number of significant developments in the Darwin area continue to expand (Doyle, 2001 and Price et al, 2005).

In order to conserve the biodiversity values of the Howard Sand Plain Site of Conservation Significance there is a need to set thresholds for sustainable or "acceptable" levels of disturbance (all forms of disturbance) within the landscape as an entirety. The degree of disturbance imposed by extractive activities which may be tolerable at the landscape scale is greatly influenced by the capacity for the sand mining industry to exercise minimal impact techniques. These techniques entail avoiding disturbance of high value areas, avoiding disruption of ecological processes and ensuring that rehabilitation of mined areas can reproduce the values which existed prior to disturbance within an acceptable time frame.

Previous investigations of the outcomes for rehabilitation of sand and gravel extraction on a Territory wide scale (Tayler, 2004); and also specifically for Kakadu (Setterfield, Cook, Williams & Duff, 1993), the Greater Darwin Area (Price, Milne & Tynan, 2005), and Gove bauxite mining (Bradey & Noske, 2010); all indicate that rehabilitation outcomes are rarely identified clearly for the extractive industry. In addition, despite a considerable time passing after the initial rehabilitation (e.g. 20 years or more) the flora and fauna characteristics for extractive disturbed areas rarely match the habitat quality compared to equivalent habitat (or reference sites) which is not disturbed.

Attainable outcomes for rehabilitating mining areas are identified as key hindrances for the extractive industry to operate sensitively within a site of conservation significance. This project aims to scope and assess where rehabilitation objectives and practices, for sand extraction targeting the Sandsheet habitat within the Howard Springs Sand Plain Site of Conservation Significance, may be significantly improved for biodiversity outcomes.

This project is a component of a series of project areas managed by the Extractive Industry Association (EIA) and funded by the Caring for Our Country Program (CfoC) under the 2012- 2013 Business Plan targets for protecting critical aquatic ecosystems. The Caring for Our Country project, titled "Extractives Industry Improved Response to Biodiversity for the Howard Springs Sand Plain", targets building technical knowledge and capacity to progress improvements with biodiversity outcomes specifically for the Howard Sandsheet habitat which is targeted for sand mining.

The CfoC project works across four key outcomes areas which are associated with a range of activities and outputs, as indicated in Table 1-1. The overarching CfoC project commenced in December 2010 and has progressed through to the end of November 2012.

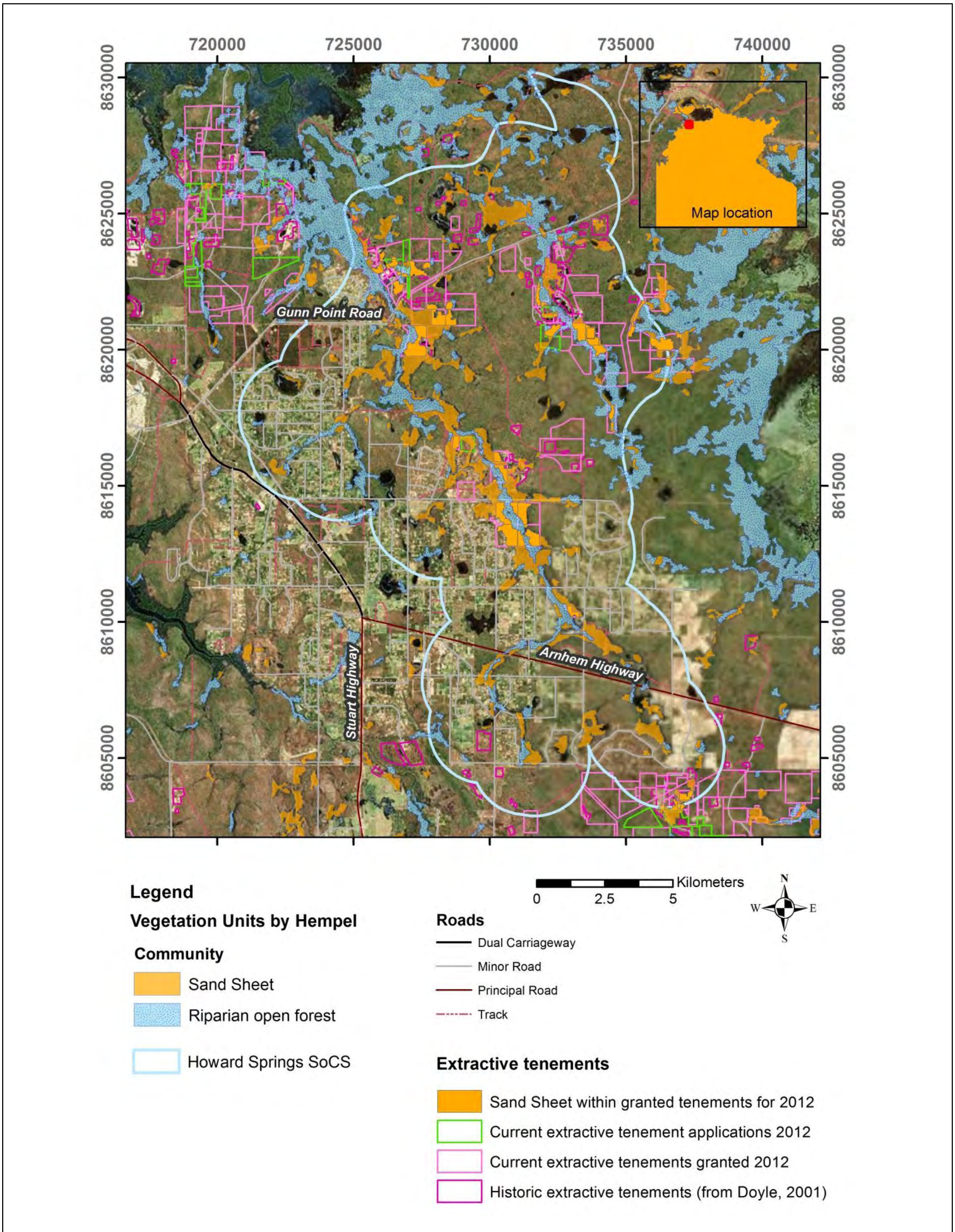


Figure 1-1 Howard Springs Sand Plain site of conservation significance, Sandsheet habitat & fine sand extractive tenements

Table 1-1 Caring of Our Country Project outcome areas and activities

Caring of Our Country Project Outcome Areas	Project Activities & Outputs
1. Improved ecological knowledge for high value species and recommendations for minimal impact techniques and conservation areas.	• Surveying and Mapping species distributions to identify high value conservation areas for: ▪ the Howard River Toadlet (a frog species better referred to as the Darwin Sandsheet Frog); and ▪ *Utricularia* species and *Thyphonium taylori* (Bladderwort species) • Proposed minimal impact techniques for the Howard River Toadlet and Bladderwort species. • Declaration of no go zones to protect these restricted species.
2. Control of outliers of Gamba & Mission Grass & Mimosa with the Scrubby Creek area as a demonstration.	• Mapping and control of Gamba & Mission Grass & Mimosa with the Scrubby Creek area over a two year period.
3. Improved biodiversity outcomes for rehabilitation of sand mining tenements	• Assessment of Rehabilitation for Sand Extraction Tenements for scope to improve biodiversity outcomes for disturbed Sandsheet habitat; *and* • Demonstration or trial of suggested rehabilitation techniques for Sandsheet habitat.
4. Capacity Building for the Extractives Industry for an improved response to working within a site of conservation significant through avoidance, minimal impact and rehabilitation techniques and standards.	• Field Day, Forum and Demonstrations highlighting the knowledge improvements gained through this project and practical applications for improved biodiversity outcomes; and • Generation of information handouts, maps, website to enhance understanding the biodiversity values and means of minimal impact for the Howard Sandsheet habitat.

Under the auspice of the CfoC project, a technical team, which represents the organisations undertaking the individual projects, has collaborated with the Extractive Industry Association to assemble an improved best practice approach to operating within a site of conservation significance. Some of the key roles of the technical group have included: to bring together a range of ecological information and make suggestions for minimal impact techniques.

This study constitutes one of several CfoC reports contributing to furthering the technical knowledge base for the extractive industry. Further information for each of the key outcome areas for the Caring for Our Country project may be found in separate reports and literature. This study draws upon the improved ecological knowledge for high value species and recommendations for minimal impact techniques and in particular the following reports:

- Reynolds, S & Grattidge, A 2013, Distribution, Status and Habitat Requirements of the Howard River Toadlet (a Sandsheet Frog) Uperoleia daviesae (Anura: Myobatrachidae).

and

- Liddle, DT, Harkness, P., Westaway, J. & Lewis, DL 2012, Vegetation communities and biodiversity values of the seasonally saturated lands of the Howard Sand Plains Site of Conservation Significance in the Northern Territory of Australia.

1.2 Project Objectives

The aim of this study is to:

- Examine the application of a generic framework for developing a suite of closure criteria for the rehabilitation of mined Sandsheet Habitat which is based on sound ecological theory;
- Suggest a simple assessment and scorecard methodology which may detect whether rehabilitating Sandsheet sites are progressing either towards or away from the desired closure criteria; and
- Inform as much as possible where there is scope to improve practices for reinstating both ecological processes and biodiversity outcomes, with consideration of both site specific and landscape scale goals, for either conserving or reinstating the key values of the Howard Sandsheet habitats.

The specific steps towards achieving these objectives has included:

- Reviewing the ecology and management context for Sandsheet Habitat within the Howard Sand Plain Site of Conservation Significance.
- Reviewing the current status of sand mining practices and rehabilitation guidelines.
- Reviewing the ecological theories behind defining and gauging rehabilitation success.
- Establishing some broadly defined categories of acceptable or desired rehabilitation outcomes for disturbed Sandsheet habitat across the spectrum of potential rehabilitation outcomes
- Proposing a hierarchy of closure criteria (end points of tenement responsibility) aligned with the broad categories of desired or acceptable rehabilitation outcomes.
- Identifying a range of indicators which may suggest the management context (e.g. the pre-existing environment: *vegetation type and ecological processes such as surface drainage and likely fire regime*), restoration efforts (e.g. *depth and drainage of the remnant burrow as well as the management and use of top soil*) and progress or achievement against the selected closure criteria.
- Developing a simple assessment and scorecard method (encompassing: the management context, restoration effort and progress towards success criteria) which may apply to the broad categories of anticipated rehabilitation outcomes (and hence have similar closure criteria).

and

- From the results of this study suggest where each of the broad categories of rehabilitation outcomes may be improved to refine the reinstatement of pre-existing ecological functionality and likely biodiversity values.

This report presents:

- an outline of the management context and conservation values of the Howard Sand Plain Site of Conservation Significance;
- the background to the landscape restoration inclusive of the current status of sand mining practices and rehabilitation guidelines; and
- a suggested framework to improved rehabilitation outcomes and means of assessing success.

The study concludes with a discussion of future directions for further investigations and a summary of key points for rehabilitation practices which required further investigation for improved biodiversity outcomes.

2 Management Context

2.1 Focus Area

The area of focus for sand extraction is the Sand Plain land type (alternatively known as Sandsheet Heath Vegetation type) within the greater Darwin region, which occurs within an approximate 30km radius from the centre of Darwin (Figure 1-1).

2.2 Climate

The climate is typically monsoonal with a pronounced wet and dry season. The majority (90%) of the annual rainfall (1729 mm according to the Darwin Airport records) occurs during the wet season between the months of December and April (BOM, 2012).

During the wet season (December – March) the rainfall in Northern Australia can be highly erosive with a rainfall of considerable intensity (100 mm/hour) (Boggs, et al, 2000). The remainder of the year features very little rainfall (with an average monthly rainfall of 0-100mm) and is either dry (with a monthly average of 37-52% humidity) or in the later part of the year experiences increasing levels of humidity (with a monthly average of 52% - 65%) and occasional storms during the build-up (October to December) (BOM, 2012).

2.3 Topography, Geology & Hydrology

The topography of the greater Darwin region consists of relatively flat to gently undulating surface situated on a slightly elevated plain, approximately 30-40m above sea level (Nott, 2003). The majority of the region is flood plain with minor elevated ridges in the south (Figure 2-1).

The surface waters generally flow from the higher ridges in the south, northwards towards the ocean. The Howard Sand Plain Site of Conservation Significance is located largely within the Howard Springs Catchment in which the surface waters flow in a Northerly direction (Figure 2-2). However the southern part of the Howard Sand Plain Site of Conservation Significance is located within the Adelaide River Catchment and the surface waters for this catchment flow eastwards.

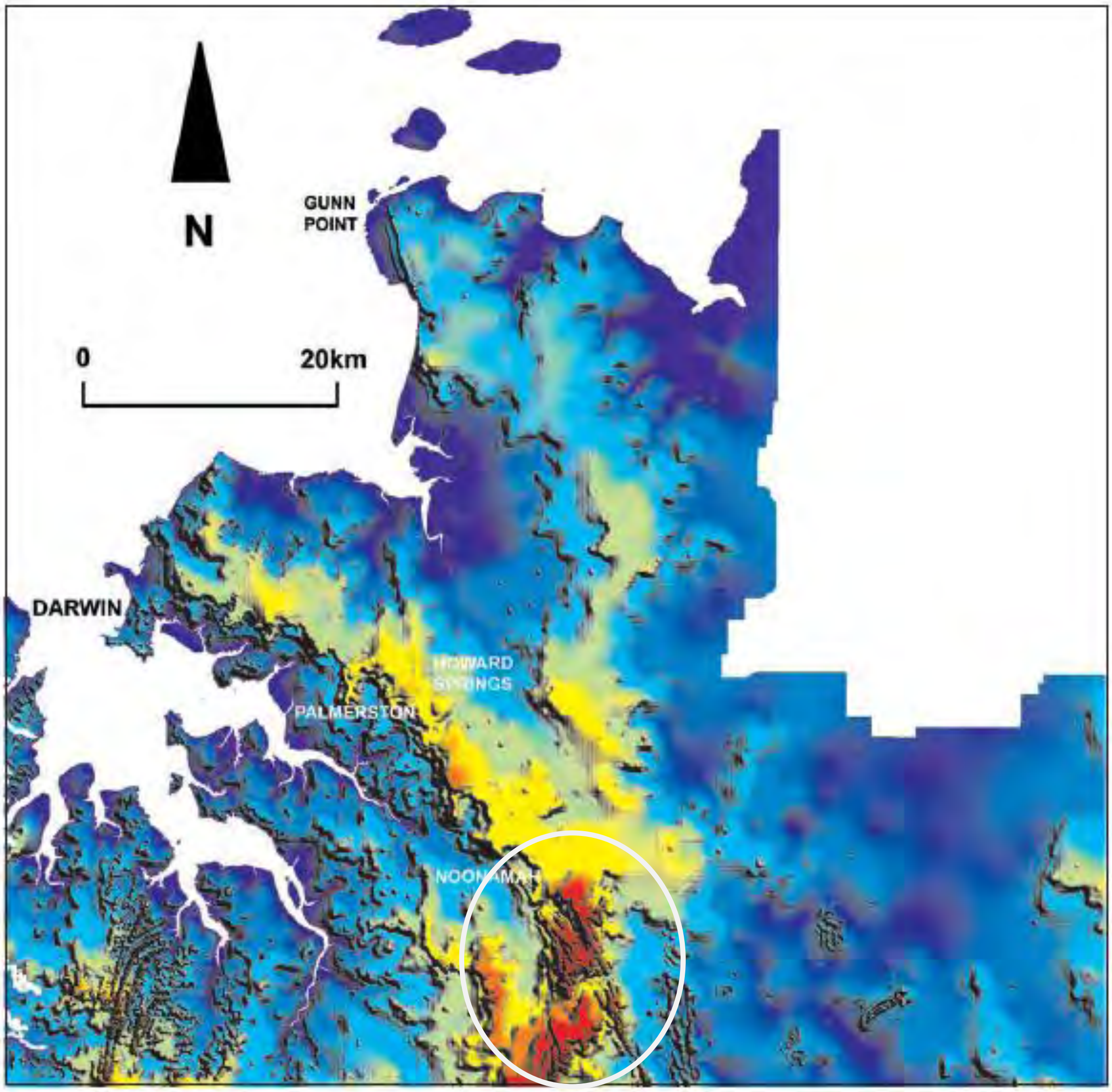


Figure 11. Digital Elevation Model of the Darwin area. Blue areas represent floodplains and mangrove swamps. Green and yellow areas are lateritic plains and red areas are elevated ridges

The circled area indicates the quartzite ridges which is one of the sources of fine sands for the Howard Springs area.

Figure 2-1 Digital elevation model for the greater Darwin area (taken from Doyle, 2001)

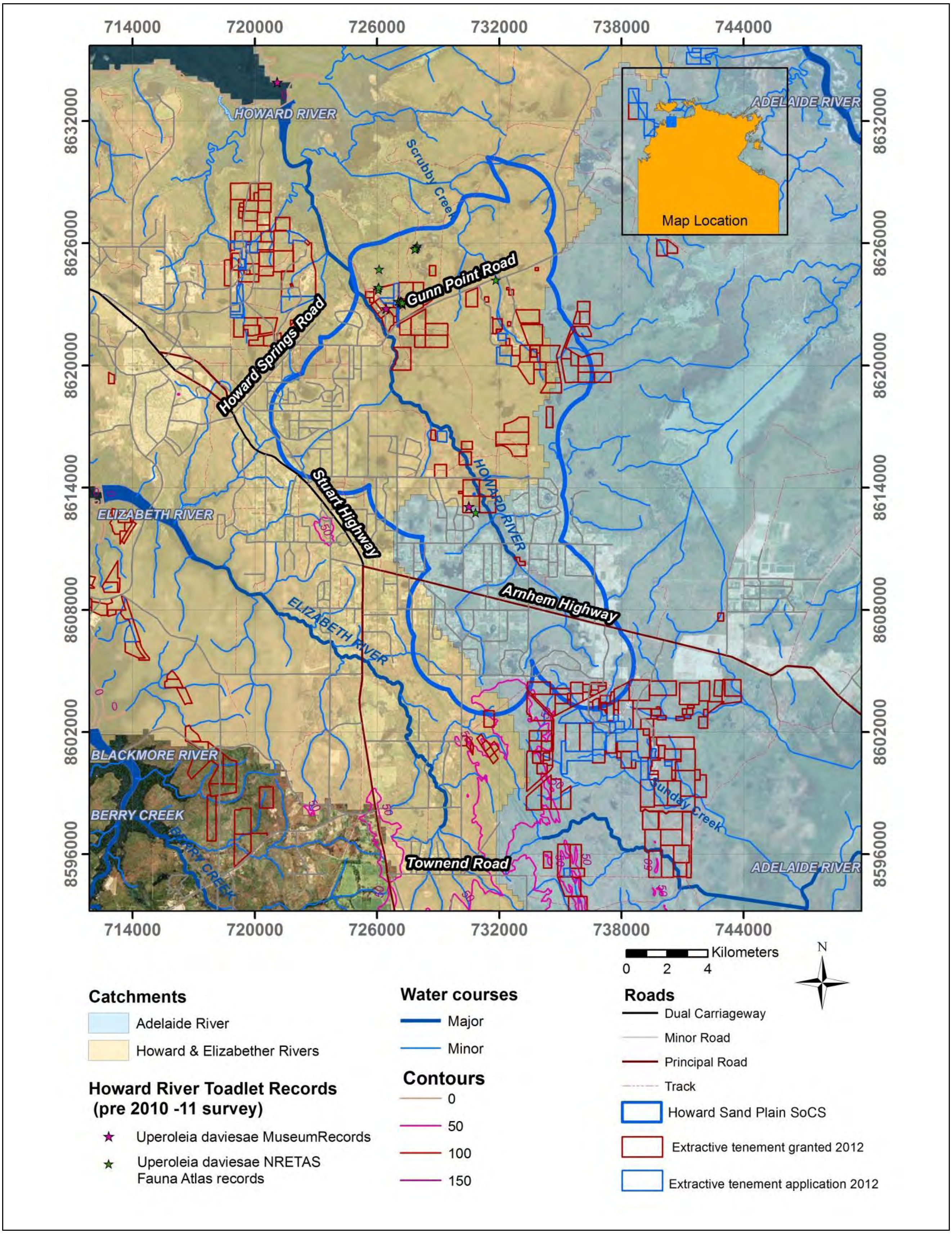


Figure 2-2 Catchments and drainage within the Howard Sand Plain site of conservation significance

The geology of the Greater Darwin Region is dominated by deeply weathered lateritic regolith which largely formed 20 Million years ago but is still actively forming on labile cretaceous marine sediments (Nott, 2003 and Doyle, 2001). The cretaceous sediments, deposited approximately 90 million years ago form a near horizontal strata overlaying a Proterozoic basement strata (the Pine Creek Orogen basement rock formed over 1.9 Billion years ago) which is extensively folded and can feature near vertical quartz seams (Nott, 2003 and Doyle, 2001). The Proterozoic basement varies in formation from west to east according to metamorphic grade (Nott, 2003). A simplified cross section, presented in Figure 2-3, illustrates the main geological strata within the Darwin region.

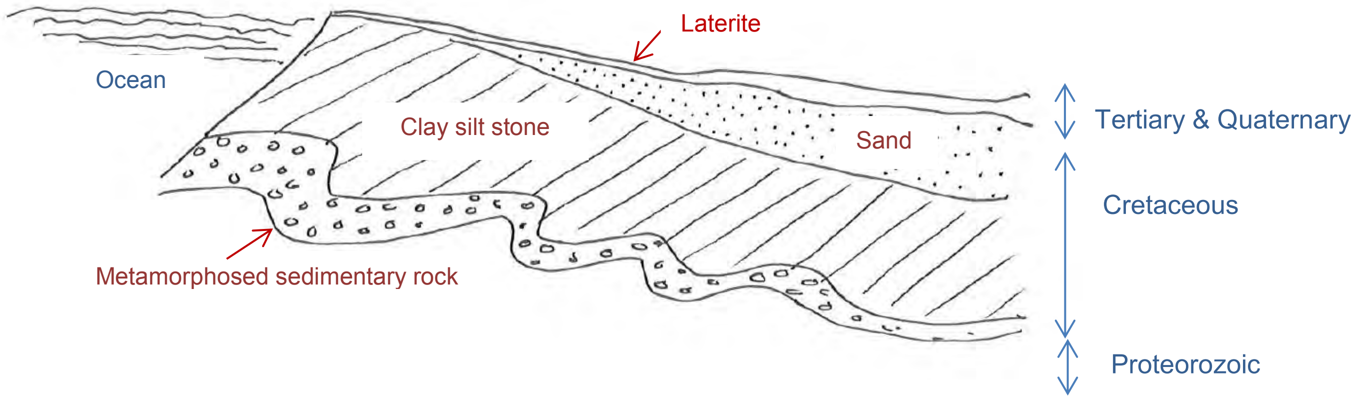


Figure 2-3 A simplified cross section demonstrating the major geological strata for the greater Darwin region (Adapted from Doyle, 2001)

Quaternary sediments which represent extensive marine and alluvial deposits from the Holocene sea-level rise, are largely absent in the Darwin region, which is due to extensive weathering. In contrast quaternary sediments dominate the surface geology within the major catchments which surround Darwin; the Alligator and Daly River Catchments (Figure 2-4) (Nott, 2003)

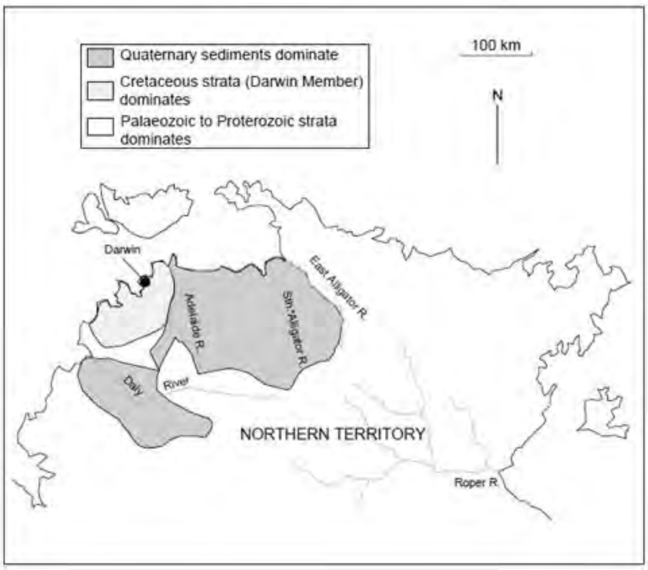


Figure 2-4. A simple geological map illustrating the surface dominance of cretaceous marine sediments in contrast to the dominance of quaternary sediments for the surrounding Alligator and Daly catchments (Nott, 2003)

A cross section from Darwin City to the Mary River in the south-east (Figure 2-5) indicates that within the vicinity of the Howard River, the coarse Howard Sand Member is relatively close to the surface (within 2-30m) and may be either covered by a Darwin Claystone (a unit of the Bathurst Island formation) or exposed at the surface where the laterite layer is eroded away (Doyle, 2001).

The Howard Sand member is the more extensive sand source within the greater Darwin area. These sands provide the main supply of Darwin's rounded course sands (grain size of less than 2mm). There are only a few extractive operations focusing on this source as accessing this sand requires removal of the clay layer and also dredging for its extraction, due to the shallow water table.

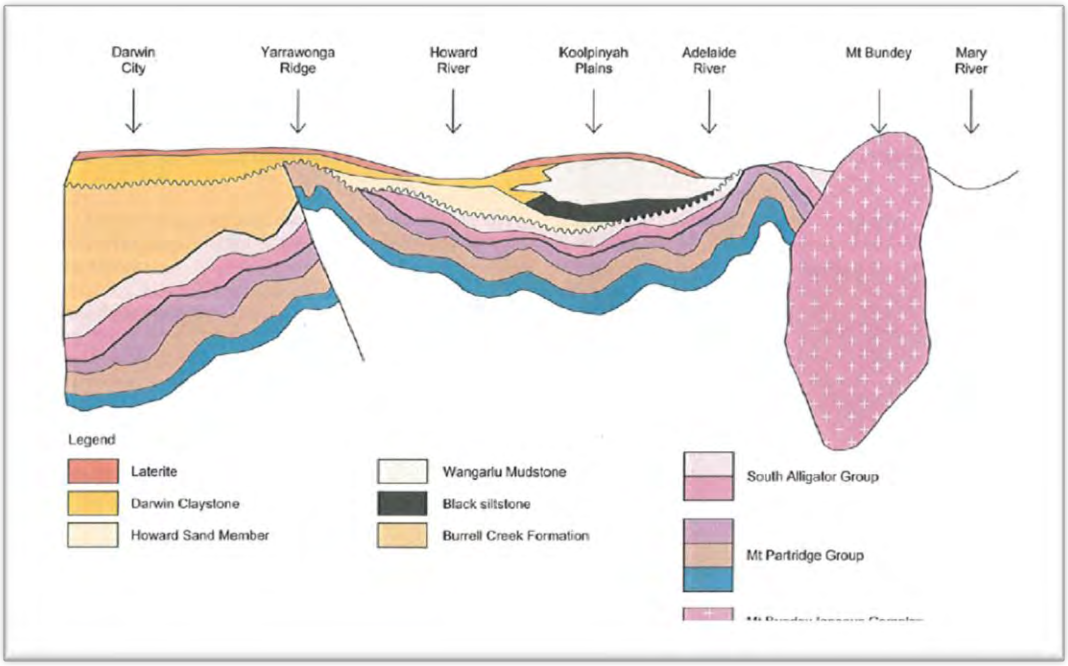


Figure 2-5 Geological cross section for the greater Darwin area (from Doyle, 2001)

The Darwin flood plains are well drained due to the laterite and deep sand substrates. The laterite duricrust features a network of solution tubes facilitating surface to ground water movements (Doyle, 2001). Movement of the surface water flows through the laterite, sand and clay substrates to the ground water aquifers is rapid (Doyle, 2001). The main aquifers within the Darwin Region occur in the lateritic profile, the cretaceous sandstone and the Koolpinyah Dolomite basement (Doyle, 2001). The aquifer within the Koolpinyah Dolomite basement has a very high water holding capacity.

The water table in the greater Darwin area is quite shallow and can rise to 2m below the surface during the wet season and then drop to 8-10m below the surface during the dry season (Doyle, 2001). The cretaceous substrates are generally moist within the first 1-2 metres below the laterite layer which suggests a perched water table and that the laterite layer plays a role in minimising evaporation and transpiration losses (Doyle, 2001).

Further east toward Gunn point the depth to base rock increases and the overlying claystone also increases in thickness above the Howard Sand Member. In addition the Howard sands dip below a black siltstone. The geology along a north-east transect from the Daly through to the Adelaide Catchments suggests that the

Howard River area features a much more reliable and accessible hydrogeological regime than the surrounds.

Darwin's main source of fine sands (the base for concrete) constitutes alluvial deposits of sand which have accumulated within the shallow to deep impressions in the surface layer of laterite. These deposits of fine sands are geologically recent, that is within the last 10 thousand to 20 Million years. Quartzite ridges to the south of the Howard River are the primary source of these fine sands within the Sunday Creek area and the deposits are formed through historic surface flows as suggested by the absence of gravel; which if present would indicate more turbulent river flows involved in their deposition (Nigel Doyle, Personal communication, Sept, 2012). Another major source of fine sand is eroded or reworked sandy clay and claystone from the Darwin claystone a basal unit of the Bathurst Island formation which is concentrated along the Howard River drainage channels and Scrubby Creek (Doyle, 2001). The rate of fine sand formation is very slow and likely to take at least hundreds of years (Nigel Doyle, Personal communication, Sept, 2012).

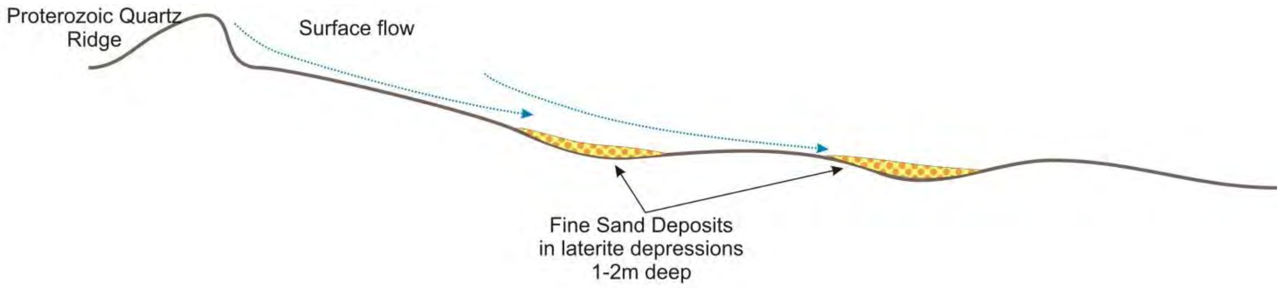


Figure 2-6 A conceptual diagram illustrating how the fine sand deposits within the Darwin region are formed

The alluvial deposits of fine sand form the Sandsheet land type consists of relatively small patches within the greater landscape (e.g. ranging from 0.03km^2 to 3km^2, based on mapping by Hempel, 2003) scattered largely within 2km of the main tributaries and particularly the Howard River. These patches of fine sand consist of shallow deposits on laterite (or in channels where the laterite has been etched away) which are on average 1m deep (Doyle, 2001). Deposits of fine sand also occur beyond the Howard River catchment (e.g. along Gunn Point Road) but may be sparse amongst a predominantly claystone geology. The greater concentration of fine sand which is also close to Darwin is situated within the Howard Springs area.

2.4 Howard Sand Plain Site of Conservation Significance

The Howard Sand Plain Site of International Conservation Significance was identified in a study undertaken by NRETAS in 2009. It is one of 56 sites of conservation significance for the Northern Territory. The boundary of the Howard Sand Plain SoCS includes a number of sub-catchments inclusive of the Howard River and part of the Adelaide River. This defined area, in particular, features a significant proportion of the Sandsheet land type, alternatively identified as a Sandsheet Heath Vegetation type (Harrison, et al, 2009). Sandsheet is considered a rare vegetation type covering approximately 56km^2 within the Greater Darwin area (NRETAS, 2012).

The Sandsheet Heath vegetation associated with the Sandsheet land type is characterised by having acidic infertile sandy soils overlaying an impermeable deposit of clay of laterite. This seasonally saturated land type typically features a specific suite of common plant species which are adapted to the rapid drainage pattern. The upper canopy species of the Sandsheet heath includes: *Grevillea pteridifolia*, *Banksia dentata*, *Melaleuca nervosa*, *Lophostemon lactifluus,* and *Verticordia cunninghamii* while the ground species can typically include: *Dapsylanthes spathaceus*, *Xyris complanata* and a variety of sedges. The actual suite of species occurring within the Sandsheet vegetation type can vary enough to warrant classification into a number of subtypes (Liddle, et al, 2012).

The main reasons the Sandsheet habitat with the Howard Springs Area are of international conservation value is because collectively these areas feature an extremely high diversity of bladderworts (ephemeral carnivorous plant species of the *Utricularia genus and the rare herb Typhonium taylori)* Taylor (an international specialist in *Utricularia* species based in Kew Gardens) upon a survey of the Darwin area in 1989, commented, that the Darwin region exhibited an extremely high diversity of this genus compared to other locations on world-wide scale (Liddle, 2012).

The Howard Springs Sandsheet feature at least 26 Bladderwort species (NRETAS, 2009) of which several are rare or restricted to this land type within the Greater Darwin area alone. In addition the Howard River Toadlet (a small native frog of the *Uperoleia* genus) is only found within Sandsheet habitat within the Greater Darwin area. The Howard River Toadlet is the only frog species in the Territory listed as vulnerable and it is considered threatened due to its restricted occurrence and the impacts of clearing of the Sandsheet habitat. A number of the *Utricularia* species and herb *Typhonium taylori (EBPC listed as endangered)* are also listed as threatened or near threatened under the NT legislation (NRETAS, 2012).

Although fine sand deposits exist beyond the Greater Darwin area, the Howard Springs area exhibits some particularly unusual diversity in flora and fauna compared to other regions in the near surrounds and also compared to sandy habitats in other parts of the Northern Territory such as Kakadu. A plausible explanation for the biological significance of the Howard Springs Area may be due to a particular combination of habitat qualities inclusive of rapid drainage and reliable ground water (both on a macro and micro scale), a long history of geological weathering compared to surrounding catchments (the Alligator and Daly Rivers are less weathered) and possibly geological isolation due to different soil types and major Rivers restricting species movements (Renee Catullo, Personal Communication, 2012).

Although the Howard Springs area is recognised a site of international significance; the Sandsheet habitat in this area is considered rare and at risk, and a number of threatened species (under the Northern Territory Parks and Conservation Wildlife Act an one under the EPBC Act) feature within this habitat type, the Howard Sandsheet is not listed as a threatened community nor afforded any official or legislated level of protection (NRETAS, 2009 and NRETAS, 2012).

Currently, there are no thresholds for disturbance to the Sandsheet habitat in the Howard Springs Area, nor is there a means of tracking accumulative impacts to conservation values through readily traceable disturbance, such as clearing or the habitat quality resulting where rehabilitation is a requirement.

2.5 Sand Extraction within the Greater Darwin Area

Extractive materials include sand, gravel and other materials used in construction. These materials are generally high volume; low cost commodities which need to be sourced close to their centre of use as the haulage costs effects the market prices considerably.

Sand extraction provides the basic raw materials for Darwin’s construction industry. The Howard Sand Plains Site of Conservation Significance is the prime source for fine sands (rounded sands less than 0.6 mm in diameter) and the coarse sands, which are less than 2mm and generally more angular than the fine sands (Doyle, 2001 and Talyer, 2004).

Fine sand extraction accounts for the bulk of sand extraction (by land area and volume) occurring within the Howard Sand Plains Site of Conservation significance (Price et al, 2005). There are only a few coarse sand extractive operations due the need to remove the overlaying substrate and the dredging required as the sand source coincides with the shallow ground water table (Doyle, 2001).

In the Northern Territory the Mineral Titles Act and the Mining Management Act govern the exploration for and production of minerals.

The Mineral Titles Act provides for the authorisation of mining activities and sets out the administrative processes for authorising these activities through the granting of a title. Sand extraction is generally licenced under either:

- an Extractive Permit (EMP) which allows a holder to extract, remove, store and process extractive minerals for a maximum area of 100 hectares with a maximum term of 2 years, renewable for further periods of 2 years. or
- an Extractive Mineral Lease (EML) which authorises a holder to mine, quarry or extract minerals and construct infrastructure for a maximum area of 100 hectares with a maximum term of 10 years, renewable.

All extraction operations are subject to the provisions of the Mining Management Act and the Regulations under other laws of the Northern Territory. The Mining Management Act largely focuses on non-regulatory agreements. All mines must abide by the Mining Management Act by submitting a Mining Management Plan. The objectives of the Mining Management Plan are to ensure that the development of mineral resources is in accordance with the best practice health, safety and environmental standards and to protect the environment and health and safety of all persons on mining sites. Once a Mining Management Plan is accepted, the operator is held accountable to their approved plan.

The industry groups involved in fine sand extraction consists of small family owned operations and medium sized corporations with approximately 15 staff (refer to Tayler, 2004). Due to the scale of their operations, the extractors of fine sand generally seek authorisation of an EMP.

Extractive operators are licenced to remove substrate at no deeper than 2m and within one hectare burrow pits. Specific site practices stipulate that each burrow pit should be separated by a 25m buffer of native vegetation (DOR, 2010).

Over the past and currently, there has been very little awareness of the conservation values of the Howard Sandsheet. There are no specific guidelines for operating sensitively, including goals for rehabilitation, within the Howard Sand Plain Site of Conservation Significance. The requirements for rehabilitation which are recommended largely focus upon providing a stable landscape, opposed to promoting biodiversity outcomes.

The Mining Management Plan is a key tool by which the impacts and outcomes mining for extractive minerals can be directed. Mining Management Plans may be given to the Northern Territory Department over seeing natural resource management biodiversity conservation for scrutiny and comment as a part of the approval process.

2.5.1 Extent of impact

The total area of the site of conservation significance is approximately 270km^2. The total area of Sandsheet habitat within the Howard Sand Plains Site of Conservation Significance is approximately 28.6km^2 based on mapping by Hempel, 2003, which is approximately 10.5% of the total area of the site of conservation significance.

There are approximately 86 extractive mining tenements (currently approved as of December 2012) operating within the Howard Sand Plains boundary which in total covers an area of 30km^2. The total current tenement area constitutes approximately 11% of the site of conservation significance. However, the tenements include vegetation types additional to Sandsheet. Of the 30km^2 area currently allocated to sand mining a total of 5.5km^2 or 19% of the total Sandsheet within the site of conservation significance is included within the approved tenements for 2012. These calculations have been based on GIS data for mapping of Sandsheet habitat by Hemple, 2003 and extractive tenements from the NT Department of Resources current as of 2012. It needs to be noted that historic tenement data across all years is not readily available in a digital format and hence examination of the historic extent of impact is not possible.

The area of land cleared in proportion to the volume of fine sand extracted is very high, as on average the sand depth is only 1m and operational constraints generally confine the payable load to 0.5m depth only (Doyle, 2001).

The demand for sand is increasing and set to increase over the longer term as developments expand. The Howard Sand Plain Site of Conservation Significance provides the most abundant source of fine sands in close proximity to Darwin. In 2005 mining for fine sand removed approximately 0.41 km^2 of native vegetation per year, but this was expected to rise by 70% by the year 2020 (Doyle 2001). With a number of significant developments on the horizon, sand mining is destined to apply growing pressure to the remaining conservation values in the Howard Springs area.

2.6 Landscape Scale Processes, Impacts & Management

The conservation values of the Howard Springs area are particularly reliant on broad and fine scale landscape scale processes such as surface flows (frequency and depth), inundation and drainage patterns, depth to the water table, and disturbance by fire. How these processes relate to sustaining the unique biodiversity values is still poorly understood. However, it can be generalised that the topography which sustains a shallow sheet like surface flow (e.g. depths of up to 6cm) in combination with other environmental attributes (such depth of sandy substrate) are important to at least the Howard River Toadlet and the diversity of Utricularia species (Reynolds & Grattidge, 2013 and Liddle et al, 2012). Land use which results in alterations to these key elements and processes are likely to significantly affect the retention or return of these species.

The Howard River Catchment features multiple land tenures. Conservation of the sustaining ecological processes and values for the Howard Sandsheet habitat is influenced by multiple land uses (such as roads, rural and other developments) and not just sand mining alone. Conservation of key values for the Howard Springs area ultimately relies upon setting and upholding thresholds of disturbance which requires the collaboration and participation of multiple stakeholders.

While the greater context for conserving values for the Howard Springs area is recognised, this project focuses only on the impacts and outcomes of sand mining only. This study aims to discern improvements to rehabilitation outcomes from both a whole of landscape scale through to the site scale.

3 Background to Landscape Restoration

3.1 Rehabilitation and Restoration Defined

Rehabilitation and restoration are promoted as strategies for minimising loss of functional ecology (i.e. nutrient cycling and hydrology etc) and loss of biodiversity associated with disturbance such as clearing and mining. The terms rehabilitation and restoration are frequently ill defined or misapplied and plagued with ambitious expectations. Most rehabilitation and restoration strategies tend to feature broad and ambiguous goals and hence criteria of success (Aronson, et al, 1993 and Hobbs and Norton, 1996).

The concepts of reclamation, reallocation, rehabilitation and restoration mark different levels of habitat reconstruction, or outcomes, on a continuum of possibilities (Hobbs and Norton, 1996). Definitions for these terms (adapted from Brown, et al, 1994, Aronson, et al, 1993 and Diggelen, 2001), are provided below and depicted conceptually in Figure 3-1.

Reclamation is the process by which a very degraded site is returned to some level of productivity and a limited range of abiotic and biotic functioning (Brown, et al, 1994).

Reallocation or **Conversion** is a general term applied to areas of the landscape which are assigned new use that does not bear much relationship to the pre-disturbed ecosystem (Aronson, et al, 1993 and Brown, et al, 1994).

Rehabilitation seeks to repair damaged ecosystems to an ecological productive state but does not aim to reinstate habitat quality (in terms of vegetation type, species composition and structure) entirely equivalent to what was present prior to the disturbance. The full range of abiotic and biotic function are reinstated but not the full range of species.

Restoration implies reinstating the disturbed ecosystem to a form and quality (in terms of vegetation type, species composition and structure) that would be present if the disturbance or degrading processes had not occurred. The Society for Ecological Restoration (SER) defines a key goal for ecological restoration is that a resultant ecosystem is resilient and self-sustaining with respect to structure, species composition and function, as well as being integrated into the larger landscape and supporting sustainable livelihoods (SER, 2004).

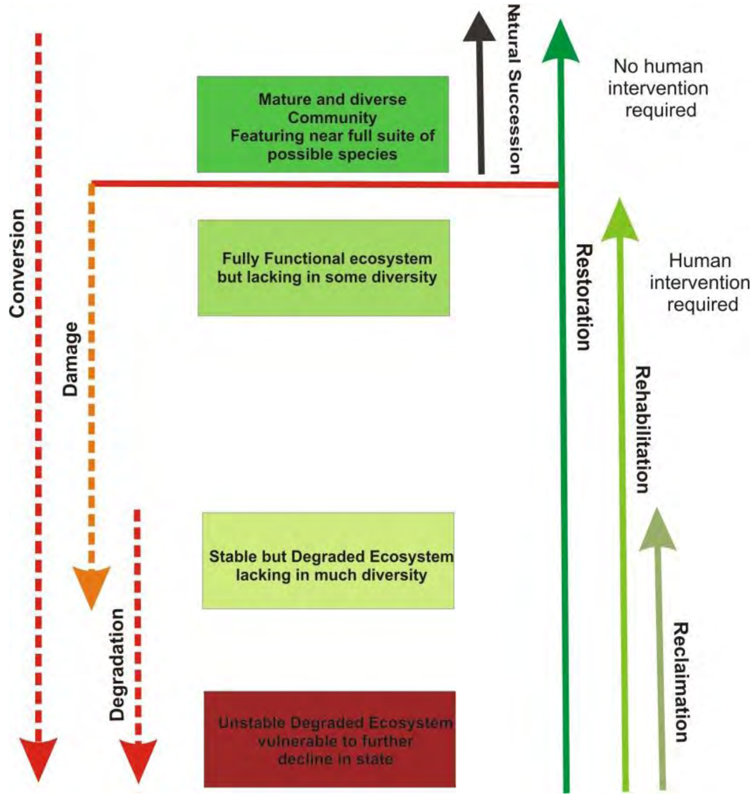


Figure 3-1 A conceptual diagram depicting common terms applied to rehabilitation and restoration (adapted from Brown et al, 1884 and Aronson, et al, 1993)

Habitat restoration is an ambitious goal and there are a limited set of circumstances in which there may be no loss of biodiversity (Gould, 2011). Most rehabilitation projects focus almost entirely on successful vegetation establishment for landform stability (the structure and function of an ecosystem) rather than reconstructing a habitat which ecological similar to the habitat which is lost (Gould, 2011 and Hobbs and Norton, 1996).

The degree to which the functions and habitat qualities of the original landscape can be reinstated largely determines whether reclamation, rehabilitation or restoration is the primary focus (Aronson, et al, 1993 and Hobbs and Norton, 1996). The degree to which a disturbed site may be returned to a state near equivalent to what might have been in place in the absence of such disturbance, depends upon:

- the degree to which the ecology of the pre-existing habitat is understood and can be defined;
- the degree and scale to which the site and surrounding landscape (the matrix) is altered; the complexity of the impacted ecological system and the repair processes; as well as,
- the cost, time, technical and socio-economic requirements and impediments to achieve the desired state (Brown, et al, 1994, Hobbs and Norton, 1996, Diggelen, 2001 and Aronson, et al, 1993 and Aronson, et al, 1995).

Disturbance or stressors (such as soil erosion) which produce an altered resource base and ecological functioning; such as altered soil characteristics, hydrology and processes of resource capture by plants; are likely to have a far greater impact than those which just remove or alter the biotic component (such as through clearing or fire) and are also far more difficult to reverse (Hobbs & Norton, 1996). A consequence of significant earth movement, extraction of substrate or exposure of a different type of substrate is that the post mining environment frequently differs significantly in a range of environmental parameters (slope, soil characteristics and hydrology) compared to the surrounding landscape which is not disturbed on an equivalent scale (Morrison, et al, 2005).

In instances where the ecological functioning is significantly impacted and cannot be readily recreated, rehabilitation to a stable, productive but novel system (possibly using species which are not native to the original habitat but tolerant of the new context) may be the primary goal (Hobbs & Harris, 2001).

Disturbance which is relatively minor (e.g. clearing without significant earth moving), or undertaken in areas with a high conservation value, have a much greater incentive to aim for restoration. However, even when restoration is the goal it is likely that the reinstated vegetation will not necessarily provide a habitat quality that is ecologically equivalent (especially in terms of species composition) to that which was present prior to the disturbance (Gould, 2011 and Hobbs & Norton, 1996).

Evaluation of sand mining restoration efforts for sites at Weipa (North Queensland) and bauxite mining at Gove (Northern Territory) both suggest clear long term residual impacts from mining in terms of the resultant habitat quality and birds species assemblages (Gould, 2011 and Brady & Noske, 2010). Gould, 2011 suggests that rehabilitated sites at Weipa may never be entirely similar to undisturbed reference sites. Restoration strategies may at best only partially make up for the biodiversity losses incurred through disturbance (Gould, 2011 and Hobbs & Norton, 1996).

3.1.1 Landscape and Site Perspectives for Restoration

Rehabilitation or restoration can be perceived from both a whole of landscape scale and the site scale (Hobbs & Norton, 1996). Holl, et al, 2003 defines landscape scale restoration as focusing on landscape patterns (the spatial relationship of ecosystem types) and landscape processes such as the physical flow of resources (e.g. surface waters and sediments) and the movement or dispersal of individuals populations and communities including the flow of genetics. Plant and animal population dynamics can operate at the landscape scale. Some species may exhibit considerable spatial variability and may exist as a series of disjunct sub-populations (or meta-populations) which are separated by unsuitable habitat (Walker, 1998). In these cases management of the species requires a landscape approach to determine the minimum set of habitat patches to sustain the species.

The science of restoring landscapes has evolved in a relatively ad hoc manner and generally a site based approach prevails, opposed to taking a whole landscape management approach (Hobbs & Norton, 1996). Hobbs and Harris, 2001 suggest the separation of a landscape and site perception of restoration is a false dichotomy, as restoration of a site should ideally be placed in the context of sustainable land use and conservation. In addition restoration success at the site scale is influenced by the condition of the surrounding landscape and availability of colonising species (Palmer, et al, 1997). Restoration and rehabilitation should operate across multiple scales and where possible contribute to maintaining or reinstating healthy ecological processes on a catchment scale, such as restoring surface drainage and habitat connectively (Hobbs & Norton, 1996).

A landscape approach to planning for disturbance and restoration involves setting thresholds for disturbance or healthy levels of landscape functionality, productivity and biodiversity retention. The goals for retaining and or reinstating these values at the catchment scale need to be integrated into site based restoration goals, so that there can be an aggregated approach at the whole of catchment scale (Hobbs & Norton, 1996).

3.2 Defining Successful Rehabilitation or Restoration

Hobbs and Harris, 2001 argue that rather than precise definitions for what constitutes rehabilitation and restoration that the definition of goals or endpoints that demark success are the more important element to treating disturbed areas. **Closure** or **Completion Criteria** are goals for rehabilitation or restoration, which are commonly applied by government regulating bodies to define agreed endpoints for some sustainable desired state (Talyer, 2004, Grant, 2006 and Hobbs & Harris, 2001). The selected desired end state demarks the point at which a mining company's legal and financial responsibility over management for a disturbed site ceases (Talyer, 2004, Grant, 2006 and Hobbs & Harris, 2001).

Rehabilitation can be considered successful when the site can be managed for its designated land use without greater management inputs than equivalent undisturbed land designated for the same use (Grant, 2006). Numerous environmental parameters (or attributes) can demark rehabilitation success and hence Closure Criteria (Hobbs and Norton, 1996, Hobbs and Harris, 2001). However, some attributes may be more important than others (Hobbs and Harris, 2001).

The **desired state, outcomes** or **endpoints for rehabilitation** or restoration vary according to the social context, expectations for current and future land use and the plausibility of reinstating processes which may promote the desired end points (Hobbs and Harris, 2001, Brown, et al, 1994 p103). In some contexts a modified or artificial landform (such a lake or modified pasture) may be an acceptable or desired end land use, or all that may be plausibly achieved within an extremely modified environment. In areas with a high conservation value, or where only limited intact ecosystems remain, restoration end points are generally desired and a greater emphasis is placed upon the biological component, to replicate or, on a trajectory to replicating; areas of a similar habitat type which are not disturbed (Hobbs and Norton, 1996).

Defining successful rehabilitation or restoration is not a simple process and reflects the complexity and uncertainty in which ecological systems evolve and vary both spatially and temporally. It is generally accepted that due to the dynamic nature and unique history of ecological systems it is unrealistic to expect that a system can be recreated as it was at a particular point in time (Hobbs & Norton, 1996 and Hobbs & Harris, 2001).

Aronson, et al, 1995 argues that some sort of **reference ecosystem** is needed to establish goals for restoration efforts. Nearby ecosystems of similar land form, soil biotic and climatic conditions can serve as a reference guide or benchmark of success (Hobbs & Norton, 1996). However, this approach alone is fraught with limitations (refer to section 3.4). Setting restoration goals in terms of static attributes is problematic as ecosystems are dynamic entities evolving over time (Hobbs & Harris, 2001). Many processes, individual components and connections (including positive and negative feedback loops) contribute to the formation and functioning of complex ecosystems (Palmer, 1997). An ecosystem can repair in a multiplicity of ways (Brown, et al, 1994). In addition random events (such as weather and fire) can introduce a great deal of spatial and temporal uncertainty and an inability to rigorously predict the future direction of a system and how it may respond to a perturbation (Palmer, et al, 1997). Therefore restoration goals need to account for the changing nature of the environment (Hobbs & Harris, 2001 and Hobbs and Norton, 1996).

Establishing realistic endpoints for restoration requires an understanding of the ecological processes which lead to the characteristics of a particular system, over a long time span (Hobbs, et al. 1996). It is unlikely that ecologists will ever be able to describe the entire suite of components and processes which shape an ecosystem and there is a need to prioritise which attributes are the more critical to restore and how closely these attributes need to resemble a "natural system" to constitute success (Hobbs and Norton, 1996).

The understanding, goals and measures of rehabilitation or restoration success relies upon being guided by **ecological theory** as a general conceptual basis (Palmer, et al, 1997, Hobbs & Harris, 2001). Because restoration ecology focuses on re-establishing multi-species assemblages, consisting of populations of co-occurring species, the theories or conceptual models for species population dynamics and ecological communities and their dynamics are particularly important (Palmer, et al, 1997). However, the theories underpinning understanding of complex ecological systems are far from complete (Palmer, et al, 1997). There is still much to understand about how ecosystems form, the importance of physical conditions in shaping the ecosystem and their dynamics, how communities and combination of species assemble and the role of biodiversity in ecosystem stability (Palmer, et al, 1997).

3.2.1 Key Ecological Theory

Ecosystems are extremely complex. A variety of ecological components have been studied largely separately but have yet to be successfully drawn together to form a coherent body of theory to underpin restoration ecology (Hobbs, 2007). The following presents a number of key ecological theories.

Ecological Resilience

The goals for restoration rely upon understanding the functioning of highly resilient and stable ecosystems and their evolution. A healthy **resilient ecosystem** is defined as one which is able to withstand disturbances and recover without changing in state, functionality and structure (Gunderson, 2000 and Walker, 1998). Ecological resilience can be defined according to productivity, biomass or species composition or a combination of these factors (Walker, 1998).

Resilient ecological systems while considered stable are not static, their attributes or characteristics may vary within an envelope of values in response to climatic change (seasonal and longer term), and patterns of disturbance by fire, cyclone, flooding or variations in grazing intensity (Walker, 1998, Kerans and Barnett, 1998 and Gunderson, 2000). Indeed periodic or regular disturbance or stress to a system can promote a combination of species with life strategies which are adapted to a particular regime of disturbance (Walker, 1989). Resilience may be weakened if such disturbances are radically altered from a pattern which has operated for a considerable time period, such as suppression of fire for a system which has a history of periodic burning (Walker, 1998).

The concept of ecological resilience presumes that ecosystems exist in the form of multiple stable states and that disturbance of sufficient magnitude can shift a system from one state to another, such as from a woodland habitat to a grassland habitat (Gunderson, 2000). Ecological resilience refers to the magnitude of disturbance that can be absorbed before the system redefines in structure and function through a change in variables and processes (Gunderson, 2000).

Alternative stable states and thresholds.

Ecosystems can repair and recover in multiple ways. While the goal for restoration is some desired state, multiple alternative steady states can plausibly result through the recovery process of a perturbed ecosystem, be the perturbation a natural process or largely human directed (refer to Figure 3-2) (Hobbs & Norton, 1996). The state and transition model of succession suggests that a recovering system may reform in a number of different stable states (depending on the success of establishing ecological processes and vegetation and subsequent disturbance) and that there are distinct transitions and thresholds between these states (Hobbs & Norton, 1996).

Thresholds between alternative states represent critical changes in the systems structure or functioning and which result in a stable state (either degraded or desired) and which will require management inputs to shift the system to an alternative state (refer to Figure 3-3). Circumstances which support a transition to a favourable state (e.g. towards the desired state) present a management situation which requires minimal intervention and much reduced opportunity for degradation (Grant, 2006). In contrast, circumstances which support the transition to an unfavourable or degraded state present the need for management interventions, if the system is to be redirected towards the desired state (Grant, 2006). A highly degraded or altered system requires a great deal of energy to drive a transition towards another state (Gunderson, 2000 and Diaz & Cabido, 2001).

In practice it is often difficult to direct the process of rehabilitation to a specific final state (Brown, et al, 1994). A range of potential short and long term outcomes need to be considered for restoration projects (Hobbs & Harris, 2001). The state and transition model can be used to scope potential pathways and options for restoration projects, as well as the management interventions which may be required to direct the development of a system along a desired trajectory (Hobbs & Norton, 1996). Ecological successional theory, which underpins the state and transition model of succession, can assist with understanding some the critical changes in state and function.

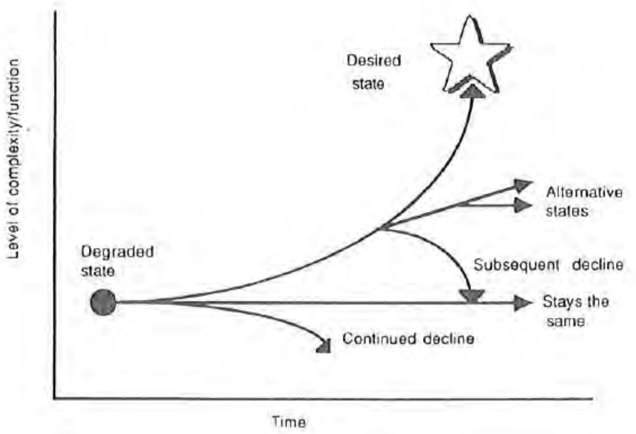


Figure 3-2 A traditional view to options for restoration (from Hobbs and Norton, 1996) illustrating the idea that a system can follow a number of trajectories and the goal of restoration is to hasten the trajectory towards the desired state

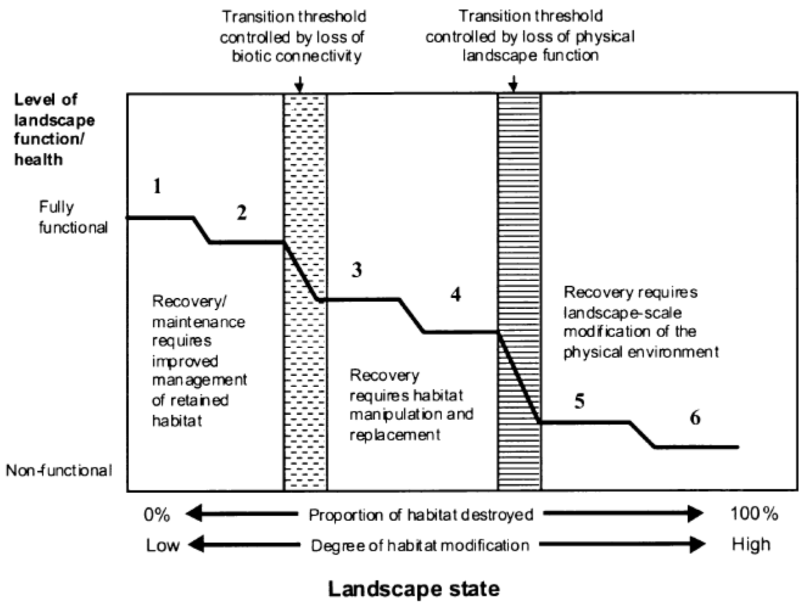


Figure 3-3 A conceptual diagram (from Hobbs and Harris, 2001) illustrating a systems transition between states of varying levels of function, illustrating the presence of two types of thresholds (abotic limitations and biotic interactions)

Successional Theory – abiotic and biotic interactions and transitions

Any particular ecosystem is generally dominated by a few **key physical processes** (or abiotic processes) which govern the **resource base** (inclusive of resource inputs and flow) and which influences the evolving biotic component (Walker, 1998). Soil type, slope, nutrient flow, hydrology and climate are key driving physical and ecological processes which set the foundational framework for an ecosystems functioning and species diversity (Hollingsworth, 2010, Kearns & Barnett, 1998, Walker, 1998, Palmer, et al, 1997, Hobbs and Harris, 2001 p242, Hobbs & Norton p100 and Aronson, et al, 1993 p12). In turn these abiotic aspects may also in part, be influenced by the functions and life strategies of the biotic component (Kearns & Barnett, 1998, Walker, 1998, Palmer, et al, 1997, Hobbs and Harris, 2001, Hobbs & Norton, 1996 and Aronson, et al, 1993).

If a system is degraded due to changes in abiotic features these components need to be corrected prior to focusing upon the biotic component (Hobbs & Harris, 2001). Restoring the processes and patterning of the resource base is an essential first step to instating the conditions which will support or give rise to the species structure and composition typical of the desired resilient ecosystem (Hollingsworth, 2010, Gravina, et al, 2011, Kearns & Barnett, 1998, Hobbs & Harris, 2001 and Palmer et al, 1997).

The theory of ecological succession suggests that disturbed ecosystems successfully rehabilitate following a classic staged process of modification and succession over time (Walker, 1998 and Connell & Slatyer, 1977). According to succession theory, disturbed systems (disturbed naturally or by anthropogenic means) transition over time from an establishing or exploitative phase; characterised by rapid colonisation; through to a mature or conservative phase which is characterised by stability (Gunderson, 2000 and Walker, 1998). The phases of succession are driven by two key processes, biotic response (how species modify the biotic and abiotic environment) and **species interactions** which include competition, facilitation, mutualism and predation (Walker, 1998, Connell & Slatyer, 1977 and Grime, 1977).

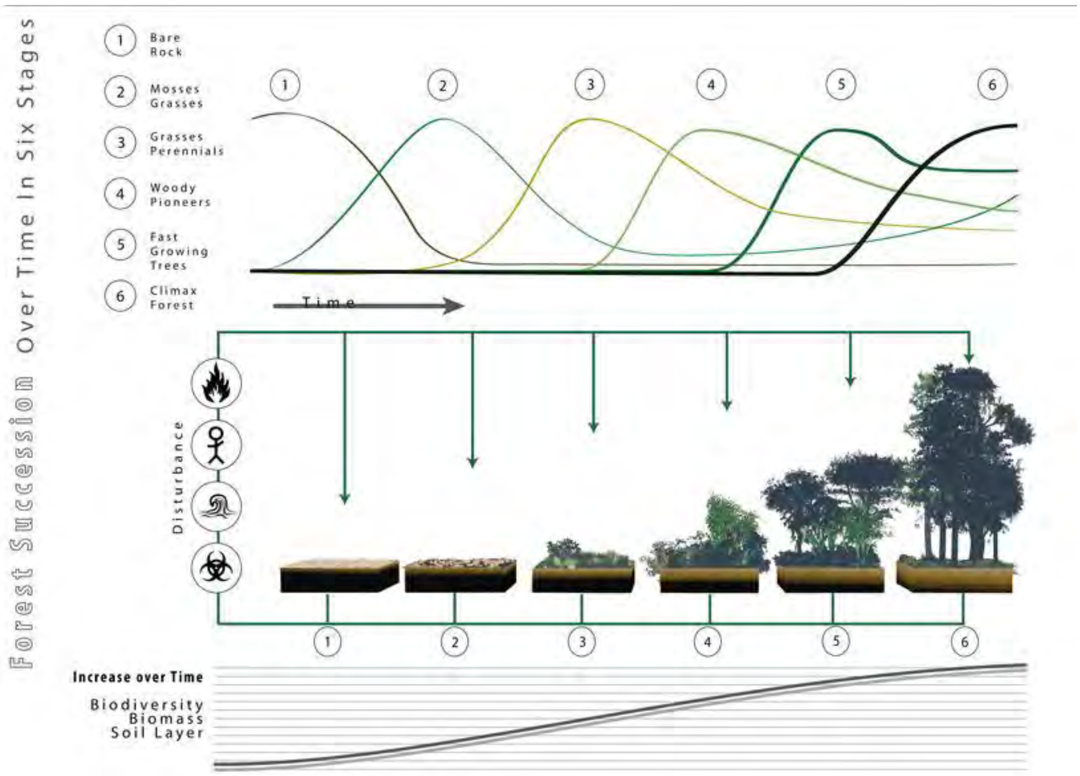


Figure 3-4 A conceptual illustration of species succession over time illustrating the successive waves of species colonisation towards a stable mature forest vegetation type (sourced from Wikipedia, 2012)

Biotic response refers to the effects an organism has on structuring the environment in which it establishes (Walker, 1998). For example some plant species can play a significant role in altering the organic and nutrient content of soils (e.g. through nitrogen fixing or vegetative litter) as well as the infiltration of surface water through the root system (Walker, 1998). Some plant species within an ecosystem may influence the ability of the landscape to carry fire (such as grass species) and hence on-going disturbance (Walker, 1998). The net effect of biotic response is that the very species which establish within an area in the early stages of restoration, alter the nature of the local environment, which in turn creates a spatial distribution of micro-habitats with a varying range of properties (e.g. relief, moisture, nutrient capture and cycling, shade etc.) and promotes the entry and establishment of either an increasing diversity of species or a new suite of species (refer to Figure 3-4) (Walker, 1998 and Connell and Slatyer, 1977).

Competition and species life strategies can result in a transition from predominantly pioneer species; which are characterised by rapid early growth and quick reproduction; to a greater number of slower growing species (Walker, 1998 and Gunderson, 2000). The slower growing species can tolerate limited resources and have the capacity to efficiently extract water and nutrients from the soil and withstand climatic variation such as droughts (Walker, 1998 and Gunderson, 2000).

Vegetation succession is not a linear process (Figure 3-5) feedback between the species composition and ecosystem processes develop over different time scales (Palmer, et al, 1997 and Walker, 1998). The combination of biotic response and interactions leads to an increase in species number and overall biomass over time, eventually levelling out to a species diversity and biomass dictated by the climate, soil and landscape processes (Walker, 1998). Above some minimum level of complexity (inclusive of the resource base, species structure and composition) a system becomes self-regulating and able to resist invasion by weeds (Kerans and Barnet, 1998). An ecosystems' resistance invasion by weeds is thought to be rendered by efficient use of space and resources and that there is tight competition for these resources by the complex of native species (Kerans and Barnet, 1998).

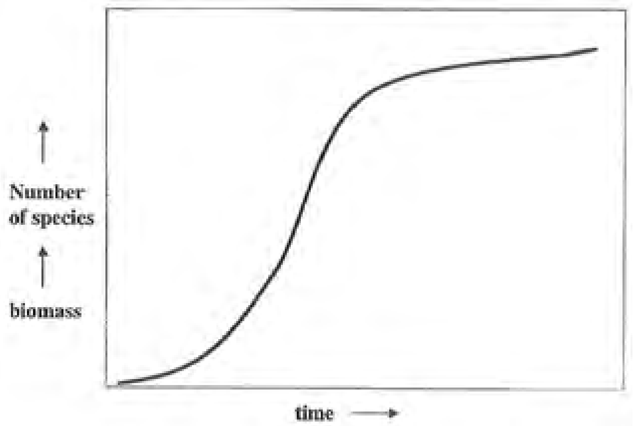


Figure 3-5 A Conceptual model illustrating the increasing species complexity over time (figure from Walker, 1998).

Keystone Species and Functional Types

More often, species are not equally important in their contributions to ecosystem processes, and a few key species (**keystone** or **framework species**) can account for a large portion of an ecosystems' functioning (e.g. resource flows such as nutrient trapping) and hence shape the systems sustainability (Tilman, 1999, Walker, 1998, Palmer et al, 1997 and Diaz & Cabido, 2001).

Plant species can be divided into **functional types** or guilds based on their traits, life strategies and their ecological characteristics or niche, which results in a similar response to the environment and effect on ecosystem functioning (Diaz & Cabido, 2001). There are no consistent processes for categorising plant functionality (Diaz & Cabido, 2001 and Walker, et al, 1999). Walker et al (1999) identify five key traits which can be used to examine and divide plant species into functional categories and these include: height, biomass, specific leaf area, longevity, and leaf litter quality. These qualities in turn determine carbon and water fluxes. Some recognised but general categories of functional groupings include: pioneers (or colonisers), ephemeral annuals and endures (stress tolerant long lived trees and perennial grasses) (adapted from Evenari, 1985 cited in Albrecht and Pitt, 2004)

Walker 1992 (cited in Gunderson, 2000) proposes an analogy whereby functional types can be divided into drivers and passengers. Drivers are the keystone species that control the future of an ecosystem, while the passengers live in but do not significantly alter the ecosystem. Removing the passenger species may have little impact but removing drivers has a large impact on the direction of an ecosystems' function and hence diversity. Ecological sustainability and resilience resides in the diversity of drivers and in the number of passengers which can be potential drivers (Gunderson, 2000).

Ecosystem resilience is strongly influenced by the traits of the dominant or major plant species. Communities dominated by fast-growing plants tend to have a high resilience whereas communities dominated by slow growing plants are less resilient (Diaz & Cabido, 2001). Non-natives and some functional groups consisting of fast growing species (e.g. Acacia species) may have a significant influence on ecosystem processes creating a highly resilient system which is resistant to a change in state; and depending on the desired outcomes; this may or may not be favourable (Diaz & Cabido, 2001).

Resilience and Species Diversity

There remains much controversy regarding the relationship between plant dynamics, diversity of species, ecological succession and resilience or stability of an ecosystem (Diaz and Cabido, 2001). Some of the key theories explaining the linkages between plant diversity and ecosystem stability have been explored by Tilman, 1999 and Diaz and Cabido, 2001.

Diaz & Cabido, 2001 indicate that an increasing number of studies indicate that the **functional diversity** (that is the value and range of functional traits of the organisms within an ecosystem) or the kinds and number of functional types, increases the robustness of ecosystem stability. Walker et al (1999) also suggests that functional similarity between dominant and minor species and among minor species may be equally important in ensuring persistence (resilience) of ecosystem function under changing environmental conditions. Both increased diversity of functional groups and similarity within groups requires an increase in number of species (Walker, et al, 1999).

Tilman (1999) proposes evidence for ecological theories which suggest an increased functional diversity of plants (that is the range of species traits) is accompanied with an increase in ecosystem productivity, and that, increasing diversity of all species leads to increasing stability in the performance of an ecosystem over an extended time. According to Tilman (1999) both overall species diversity and functional type composition are critical elements controlling ecosystem form and functioning. In addition, Tilman indicates that while the total community properties overall may be more stable, through increased diversity, individual species may be less stable and more vulnerable to local extinction (Tilman, 1999).

Gunderson (2000) outlines that species diversity (generated by a diversity of functional types and diversity within these types) contributes to maintaining overall consistency in ecosystem performance independent of wide fluctuations in the individual species. Species combine to form a network of overlapping or complementary biological processes, which explains the systems variability in the acquisition of resources and energy (such as nutrients, light, water and net primary productivity), and also spreads the risks and benefits in the light of disturbance (Gunderson, 2000). In other terms, greater functional richness increases the odds that at least some species will respond similarly and differently to the variable conditions and perturbations and hence provide insurance that the ecosystems' processes will be sustained (Diaz & Cabido, 2001).

While overall species richness and diversity of functional traits are interlinked, a measure of species number or richness alone does not adequately capture the significant role of functional diversity (Diaz & Cabido, 2001 and Walker, et al 1999).

3.2.2 Moving from Ecological Theory to Conceptual Models

Hobbs and Norton (1997) acknowledge that restoration ecology has mostly evolved in a relatively adhoc manner. They propose that restoration projects should follow some key processes such as:

- Identifying processes leading to the degradation or decline;
- Developing methods to reverse or ameliorate the degradation or decline;
- Determining realistic goals for restabilising species and functional ecosystems recognising both the ecological limitations to restoration and the socioeconomic and cultural barriers to its implementation;
- Developing easily observable measures of success;
- Developing practical techniques for implementing these restoration goals at a scale commensurable with the problem;
- Documenting and communicating these techniques for broader inclusion in land use planning and management strategies; and
- Monitoring key system variables, assessing progress of restoration relative to the agreed-upon goals and, adjusting procedures if necessary.

An essential step to implementing Hobbs and Norton's set of key processes is to define successful rehabilitation.

The definition of successful rehabilitation is generally compromised by the lack of understanding of the "natural" ecology of the ecosystem and the greater landscape processes which would have been in place in the absence of the disturbance (Hobbs, et al, 1996). There is seldom sufficient understanding of the structure, species composition, function and historic dynamics of ecosystems to be able to predict the dynamics of a reforming ecosystem, and therefore establish success criteria and their measure against such benchmarks (Hobbs, et al, 1996 p100). Conceptual frameworks, based on integrating ecological theory, more likely present the best approach to forecasting and structuring an adaptive approach to restoration. A conceptual model for restoration can facilitate tying ecological theory to practice and permits feedback between these two entities to improve understanding at both the general and specific scale.

There are a number of conceptual models or frameworks which can potentially guide restoration projects. Two types of models are presented here and they may be combined to assist with: scoping the likely directions (or trajectories) for restoration, prioritising criteria for success and their measure (using vital attributes) at various stages of restoration as well as scoping triggers for management interventions which may be required to direct restoration along a desired trajectory.

Stages of Restoration

The first model is a conceptual hierarchy of discrete rehabilitation stages (Figure 3-6) proposed by Kerans and Barnet (1998). This model is formed as a pyramid to highlight a tiered approach to developing complexity. Each successive stage is built upon the strong foundations of earlier stages and particularly the qualities of land formation. This hierarchy gives some guidance to the general stages of restoration and some to their likely endpoints. It needs to be recognised that not all rehabilitation projects will or can progress through all levels in this conceptual model. In some instances rehabilitation may only be able to achieve a self-sustaining ecosystem (one which does not require an on-going injection of resources) with key framework species representative of the pre-existing habitat or that of an entirely different but regionally acceptable habitat formation.

The goals of rehabilitation can vary depending on land use objectives. In a site of international conservation significance, where biodiversity conservation is an objective, restoration should be the aim to recreate a system as close as possible to that which existed prior to disturbance, opposed to merely creating a stable functional landscape. This is particularly important to sustain threatened species or species with specialist needs (Gould, 2011). However, complete restoration of a natural system can be an unachievable goal so it is necessary to define how close restoration outcomes should approximate the pre-disturbed habitat quality within a reasonable time frame (Hobbs, et al, 1996).

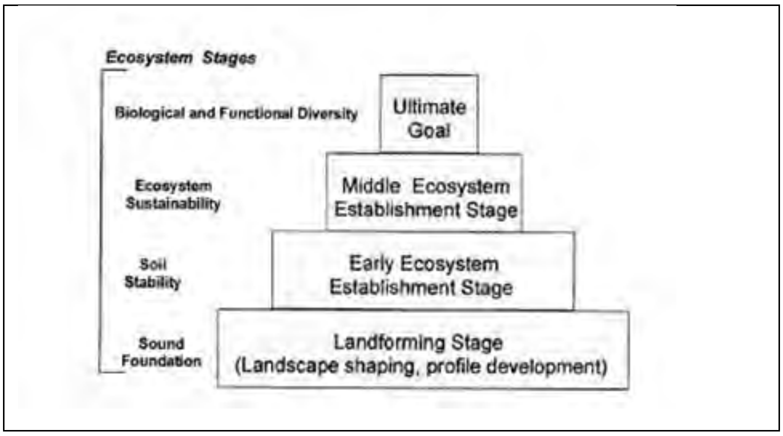


Figure 3-6 A conceptual hierarchy for ecosystem rehabilitation (Kerans and Barnet, 1998).

(Note the hierarchy approach is still quite simple as there are a range of outcomes possible within each tier).

State and Transition Successional Model

The second conceptual model is based on the state and transition successional theory which has been applied to rehabilitation for Alcoa bauxite mining within Jarrah forest in south-west Western Australia (Grant, 2006). The state and transition successional model takes the hierarchy of progressive stages, several steps further by acknowledging a range of potential restoration outcomes which may fall within each of the key stages.

The Western Australia Jarrah forest is of high conservation value; within a globally recognised biodiversity hotspot; therefore restoration to an ecosystem very similar to what was originally in place is the desired goal, rather than just ensuring the reformation of a functional landscape (Grant & Koch, 2007). Because the targeted area is surrounded by urban development and also prized for logging and other uses, multiple land use expectations drive the need for a high level of restoration outcomes. Alcoa defines the desired restored ecosystem for rehabilitated mines with the following broad objective: to meet land use objectives, exhibit sustained growth and development and vegetation which integrates in with surrounding landscape and management (Grant, 2006).

The state and transition successional model used by Alcoa (Figure 3-7) establishes a trajectory from the disturbed state to the desired state which incorporates five desired states at distinct ages or transition. The model also establishes some upper and lower thresholds which demark an acceptable range of natural variation anticipated from fluctuating conditions (Figure 3-7). Several deviated states, which either overshoot or undershoot the desired range of qualities, at each stage of recovery are also acknowledged. These deviated states represent stable and resilient systems (e.g. weed infested or overly dominated by a pioneer species), which require an injection of resources to move them back on to the desired pathway.

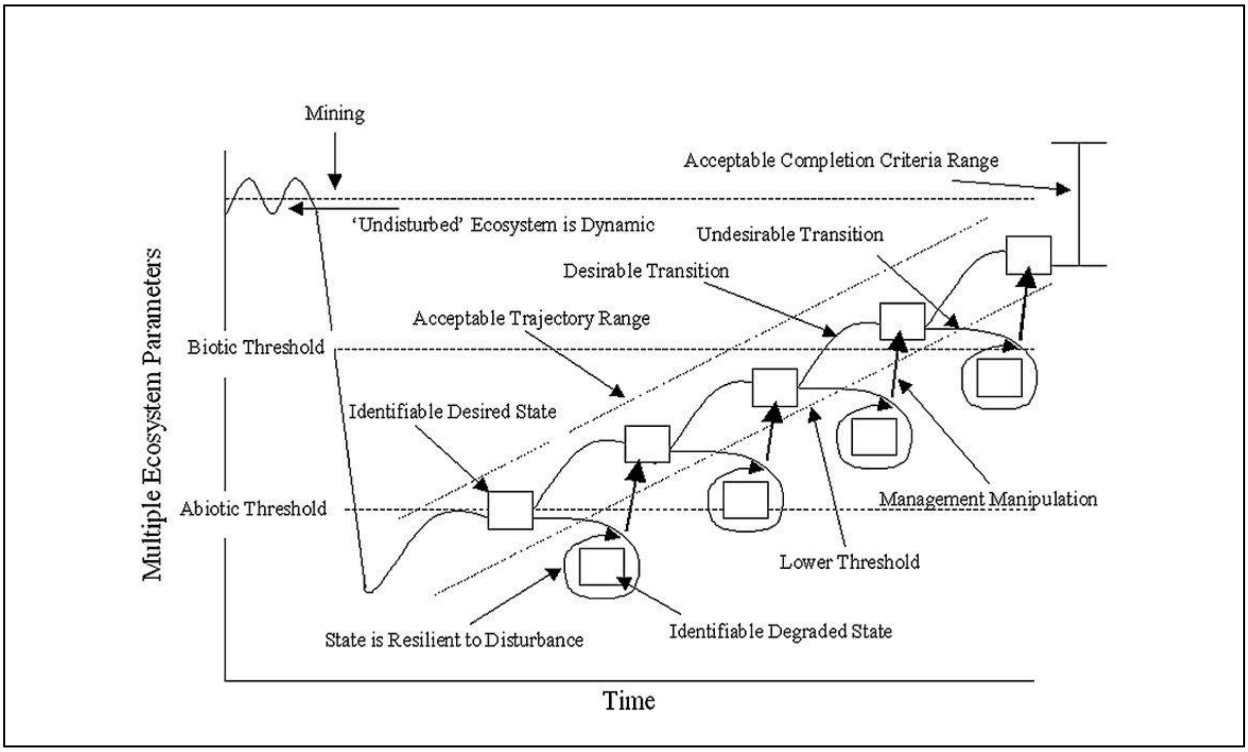


Figure 3-7 A conceptual model demonstrating tracking rehabilitation progress and triggers for further intervention (Grant, 2006)

Abiotic and biotic thresholds represent the intensities of disturbance and the degree of management effort required (Grant, 2006). In the early stages of rehabilitation manipulation of both the abiotic and biotic components are required while later on, when the core abiotic processes are established, the focus is largely on the biotic component.

The state transition model guides the development of success criteria or indicators at each stage and state of recovery (including the final closure criteria) which assists with determining whether the rehabilitated areas are on the desired trajectory or whether management interventions are required (Grant, 2006). Success criteria are general goals which are translated into specific objectives which can be measured and expressed an upper and lower range of an acceptable quality, to allow for natural variation (Grant 2006).

3.3 Success Criteria & Their Indicators

The qualities of restoration success are ultimately determined by the nature of the desired end ecosystem (refer to section 3.2). Restoration success can be defined by both biophysical and sociocultural goals, such as the composition structure and function of the desired ecosystem as well as the functionality and values of the desired end land use (Koch & Hobbs, 2007).

Poorly defined success criteria are a common problem for landscape rehabilitation (Hobbs et al, 1996). There are few established criteria for success in ecosystem restoration beyond very broad objectives which are often pitched with little consideration if they are attainable or measurable (Hobbs & Norton, 1996). A review of the Northern Territory's Extractive Industry performance against Australian Standards of best practice, by Tayler, 2004, indicated a general absence of closure criteria for sand mining in the Northern Territory and that the regulating government provides little expectation nor guidance for their development.

There are currently no agreed standards for measuring rehabilitation success (Gravina, et al, 2011 and Hobbs & Norton, 1996). However, a common approach is to compare rehabilitating sites with a similar reference community, or baseline data for the pre-existing environment, using a number of biophysical attributes, which provide as endpoints or benchmarks for how closely the system is tracking towards the desired end state (Gravina, et al, 2011, Koch & Hobbs, 2007, Palmer, et al, 1997 and Hobbs and Norton, 1996).

The Society of Ecological Restoration International (SER) suggests a list of nine ecosystem attributes as a guideline for measuring restoration success. SER suggests that a restored ecosystem should have the following attributes:

1. Similar diversity and community structure in comparison with reference sites;
2. Presence of indigenous species;
3. Presence of functional groups necessary for long-term stability;
4. Capacity for the physical environment to sustain reproducing populations;
5. Normal functioning;
6. Integration with the landscape;
7. Elimination of potential threats (such as weeds, excessive fire and trampling);
8. Resilience to natural disturbances; and
9. Self-sustainability.

Although this range of attributes could indeed provide a sound assessment of restoration success; if clear measures can be assigned; it is unlikely that many restoration projects would have sufficient resources to be able to measure all of these qualities (Ruiz-Jaen and Aide (2005).

Ruiz-Jaen and Aide (2005) who reviewed over 486 restoration studies suggest that to measure restoration success, at least two variables within each of the three aspects of: ecological processes, vegetation structure and biodiversity are necessary. A typical range of measures which align to each of the three aspects is listed in Table 3-1 below.

Table 3-1 Measures of restoration success aligned to the three ecosystem attributes vegetation structure, ecosystem processes and diversity.

Ecosystem Attributes	Measures
Ecosystem Processes	▪ Nutrient cycling such as soil organic and inorganic components ▪ Coefficient of rainfall efficiency – the amount of water infiltrating to the middle and deep soil layers ▪ Maximum available soil water reserves and length of water availability period ▪ Biological interactions such as mycorrhizae, herbivory, predation and parasitism

Ecosystem Attributes	Measures
Vegetation Structure	▪ Vegetation cover ▪ Woody plant density ▪ Vegetation height, ▪ Basal area ▪ Biomass of vegetation profiles ▪ Litter depth
Diversity	▪ Species richness at various trophic levels (including plants, invertebrates and vertebrates) ▪ Species diversity within functional groups

* Attributes Derived from Aronson el al, 1993 and Ruiz-Jaen & Aide, 2005

The review by Ruiz-Jaen and Aide (2005) indicates that measures of vegetation structure are more often utilised as indicators of restoration success than measures of biological diversity and ecological processes. Vegetation structure is more readily and rapidly measured. In addition this suite of attributes generally features very little seasonal variability (Ruiz-Jaen & Aide, 2005). In contrast elements of diversity and ecological processes are generally more difficult aspects to measure either due to the slow rate of recovery or there is significant season variation (Ruiz-Jaen & Aide, 2005). However, measures from all three aspects (ecological processes, vegetation structure and biodiversity) need to be used in combination; to reflect the recovery trajectory and how well the restored ecosystem is approximating the reference sites.

In addition to measuring the direct results of restoration, a combination of parameters and indicators are also necessary to appreciate the greater context or some of the key drivers of the rehabilitation process such as: the degree of connectivity to nearby intact systems, climate, disturbance and the status of management interventions applied. Table 3-2 below indicates a range of parameters or attributes which may provide as indicators of ecological succession, functioning and biodiversity as well as the key management interventions applied. This list of attributes (which is not exhaustive) has been derived by referring to a number of studies and are arranged in order of significance and timeframes according to the conceptual hierarchy of rehabilitation stages proposed by Kerans and Barnet, 1998.

Arranging the ecosystem attributes according to the hierarchy proposed by Kerans and Barnet (1998), indicates that the different indicators play a more significant role at the different stages of succession. The full list of indicators needs to be prioritised based on the nature of the ecosystem, the level of disturbance and the likely end points (which are aligned with either: reallocation, rehabilitation or restoration).

To be effective, success criteria need to represent measurable variables which are senstive to detecting highly relevant change. They need to be unambiguous, realistic and achievable in terms of the knowledge base and the restoration techniques available as well as the logistics and costs in realistically measuring, analysing and interpreting the key parameters in an effective and timely manner. To be effectively applied the indicators of success need to be able to be consistenly measured over time and by different operators and provide as a key communication link between science, the managers and stakeholders (Tongway & Hindley, 2004).

Table 3-2 Vital attributes for successful rehabilitation and restoration aligned to a hierarchical model for rehabilitation

Conceptual Stage in Rehabilitation	Key Management Actions	Measures of Vital Attributes for Successful Rehabilitation
Landforming stage	• Contouring with the surrounding landscape • Lowering Batters • Drainage construction • Deep ripping	▪ Soil type and characteristics – structure, depth, pH, Phosphorous and Nitrogen and organic matter etc. ▪ Elevation or depression – compared to the surrounding and previous landscape ▪ Slope gradient aspect ▪ Contour ▪ Surface Drainage – degree of ponding and free drainage
Soil Stability	• Ripping • Application of top soil • Application of seeds and fertiliser • Mulching with fallen trees	▪ Microtopograhy – surface roughness and influence on surface water flow and infiltration ▪ Soil Properties - Top soil depth (time in storage and timing of application), soil organic matter. ▪ Litter cover - relative to bare ground ▪ Surface resistance to erosion - erosion features (nature and severity), stability or dispersiveness of the surface soils, evidence of sediment movement
Ecosystem Sustainability (Functionality and Resilience)	• Application of seed or tubestock to manipulate species composition • Weed & fire management	▪ Vegetation Structure – Structural classification, Cover and height for the upper, mid and ground strata ▪ Keystone or framework species – presence and abundance or cover (this may include some fauna species such as ants or decomposers) ▪ Life form spectrum - Diversity of Plant Functional Groups – and species diversity within the key functional groups ▪ Adequate regeneration or reproduction of desired plant species ▪ Invasive species – absence ▪ Connectivity to similar vegetation types
Biological and Functional Diversity (Complexity and Resilience)	• Manipulation for establishing recalcitrant or focal species • Fire management	▪ Overall Species Diversity – flora and fauna alpha diversity (the number of species at a habitat or local scale) ▪ Focal species – presence, absence of threatened or rare species ▪ Disturbance regime – frequency of fire and other natural disturbances ▪ Resilience to disturbance such as fire and weeds

(Vital Attributes adapted from: Grant & Koch, 2007, Aronson, *et al*, 1993, Bell, 2001, 1993 and Morrison, *et al,* 2005).

Development of effective success criteria involves moving from broad goals to very specific measurable and time oriented benchmarks (Grant & Koch, 2007). For example a goal to establish the overstorey is converted to a specific benchmarks or milestone that rehabilitation areas must have 600-2500 stems per hectare at a particular stage of development (Grant and Koch, 2007).

Alcoa's bauxite mining within Jarrah forest in south-west Western Australia provides some examples for specific targets or thresholds for different stages in the successional process. Some of these success criteria and thresholds are shown below as taken from (Grant, 2006):

- 9 months – the early establishing phase in recovery.
  - A landscaped pit, ripped on the contour to greater than 1.2m deep; and
  - Greater than 90% topsoil cover.
- 0-5 years – rehabilitated pit with scrub vegetation dominated by Eucalypts and Acacias.
  - Minimal weed invasion, moderate to high species richness (>50% of the reference sites);
  - A range of 500-2,500 stems per hectare); with
  - 13000 stems/hectare of Eucalypts, and
  - A minimum of 1legume /m^2 (0.5-2 legumes/m^2).
- 15 years recovery state – at this stage trees in the rehabilitated area have bark that is sufficiently thick to survive high intensity fires so mortality to prescribed burning should be low.
  - Pole sized Eucalypts with senescent Acacias understorey;
  - High fuel loads;
  - Two tiered vegetation structure;
  - Moderate to high species richness (>50% of the reference sites); and
  - Less than 5% tree deaths following burning.

Alcoa bauxite rehabilitation is held in high regard as a leading model for operating in a high conservation value area and much research has underpinned teasing out the critical phases in succession and the most effective indicators (Grant, 2006 and Gravina, et al, 2011). Alcoa's rehabilitation research has highlighted that reinstating a Jarrah forest system, similar to that which was present prior to disturbance, is a realistic goal (Koch & Hobbs, 2007). However, it is accepted that removal of the bauxite duricrust means the reforming ecosystem will never be identical to the pre-mining state but is likely to be a modified Jarrah forest. The following aspects are critical to achieving this goal:

- Overcoming soil compaction through deep ripping is one the most important abiotic thresholds to be overcome before biological processes can occur;
- Top soil handling plays a key role in the initial floristic composition establishing and that this initial floristic composition largely determines the successional trend;
- Key hydrological processes underpinning success is the ability of the deep soil profile to store winter rainfall;
- Ecosystem structural complexity increases progressively over a 10-15 year time scale;
- If rehabilitating sites are burnt by wildfire within 5-15 years of age they temporarily drop out of the desired successional trajectory, however, some sites can be quite resilient to fire at a young age; and

- After 15 years the tree bark is generally sufficient thickness to provide resilience to wildfire.

Alcoa's approach has highlighted that establishing high level goals promotes research to improve the rehabilitation techniques and in turn improved rehabilitation techniques and research permits setting higher level and more specific targets (Grant, 2006).

Bauxite mining, due to the higher value of the commodity compared to sand, can afford a greater level of research and experimentation. Alcoa reports that the average cost of rehabilitation per hectare is $34,000 (Koch & Hobbs, 2007). Rehabilitation efforts for sand mining may need to take what learning which is readily transferable from the better resourced industries rather than attempt to emulate an equivalent investment in knowledge building.

Ecological Function Analysis

Land Function and Ecological Function Analysis have been used as a means of measuring progress for mining rehabilitation, including several cases for sand, gravel and bauxite extraction (Koch & Hobbs, 2007, Bell, 2001 and Gould, 2012). Ecological Function Analysis consists of three interrelating parts: Landscape Function Analysis (LFA), Vegetation and structure composition and habitat complexity. The measures of Ecological Functional Analysis and their indices are compared with control or reference sites.

Land Function Analysis was developed by Ludwig and Tongway of CSIRO as means of assessing landscape reformation resulting from mining and particularly for the semi-arid rangelands. The assessment technique was developed as a result of the minerals industry recognising the need for commonly agreed indicators of ecosystem rehabilitation success (Bell, 2001). Land Function Analysis assesses the ability for a rehabilitating landscape to capture and retain resources. These resources include seed pools, organic matter, soil particles and water (Koch & Hobbs, 2007). Accumulation of these materials accelerates the vital processes of germination, nitrogen fixation, microbial activity and soil nutrient transformation (Koch & Hobbs, 2007). The assessment method uses 11 visually assessed field measures to produce three indexes – stability, infiltration and nutrient cycling (refer to Figure 3-8) (Koch & Hobbs, 2007). A transect approach is used to gather the data, with a particular focus placed on measuring patches which obstruct and accumulate resource flow and inter-patches where the resources are mobile (Figure 3-9).

Land Function Analysis provides an indication on whether the functionality of the ecosystem is reforming rather than an indication of the components of biodiversity. The method was developed during an era when restoring functional landscapes was the primary focus. Vegetation structure and composition and habitat complexity assessment were added later as the focus on restoration of ecosystems, similar to what was present prior to disturbance, gained a greater priority (Kearns and Barnett, 1998). Vegetation structure and composition is assessed using characteristics such as canopy dimensions, height, and diameter at breast height by species, with particular attention being paid to keystone species (Bell, 2001). Habitat complexity uses a scoring system for five features, namely: canopy cover, shrub cover, ground vegetation cover, the amount of litter, fallen logs and rocks and free water availability (Bell, 2001).

Koch & Hobbs (2007) suggest that Land Function analysis combined with indicators of biodiversity may provide as a single assessment method for rehabilitation. While Ecological Functional Analysis was developed to provide as a common set of indicators for measuring mining rehabilitation it is unlikely to be applied across the board due to the costs for small operators to employ consultants to apply the method (Randall, 2004). In addition specific ecosystems may require unique indicators and means of knowledge generation to ensure the rehabilitation approximates the original ecosystem.

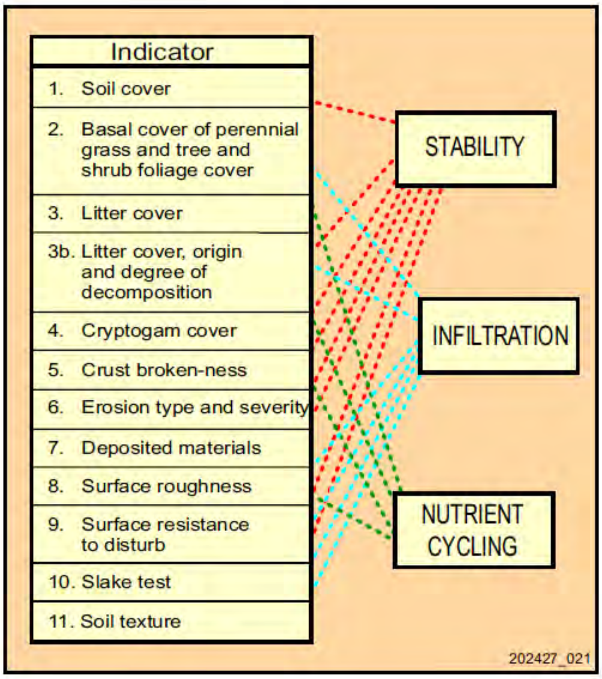


Figure 3-8 Land function field indicators and their relation to indices (Tongway & Hindley 2004)

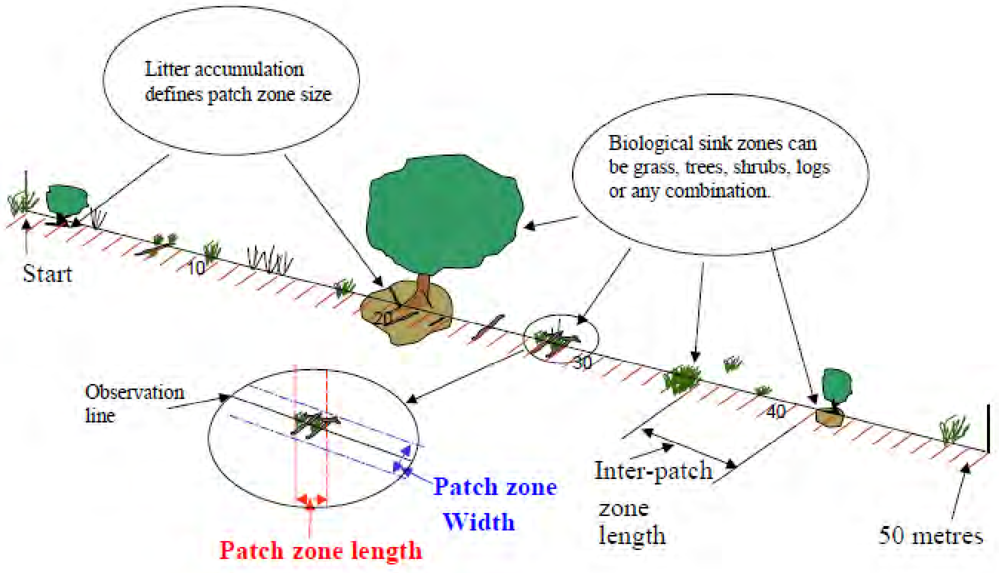


Figure 3-9 Land function analysis transect highlighting zones of resource capture and leakage (Tongway & Hindley 2004)

3.4 Key Challenges in Evaluating Rehabilitation against a Reference

There is little advice on how to nominate and satisfy rehabilitation closure criteria in the absence of ‘reference’ sites (Norris, et al, 1997 cited in Morrison, et al, 2005). Reference sites or nearby ecosystems can guide restoration planning as long as they are based on similar landform, soil, biotic and climatic conditions and the range of system dynamics is recognised (Hobbs, et al, 1996). Care needs to be exercised in selecting appropriate reference sites particularly when the post mining landscape differs significantly from the original ecosystem (Morrison, et al, 2005).

Undisturbed landscapes, which may be used as potential reference sites, are inherently dynamic and may have endured various levels of anthropogenic and natural disturbance in the past (Gravina, et al, 2011). To accommodate the natural variation in the landscape, ideally a number of un-mined reference sites need to be monitored over a relatively long time frame to ensure the natural variability (both spatially and temporarily) is adequately captured (Ruiz-Jaen & Aide, 2005). Grant, 2006 also recommends that closure and success criteria should be proposed with minimum and maximum limits to reflect this dynamic nature. In addition the closure criteria need to be reviewed regularly to accommodate improvements in ecological knowledge and also responses to influences such as climate change (Gravina, et al, 2011).

While reference communities (consisting of un-mined areas) symbolise the long term objectives of a mine sites rehabilitation they do not represent the progressive stages in succession involving transitions between alternative stable states. Immature vegetation communities will more often exhibit different qualities to the mature state (e.g. structure and species composition) therefore direct comparison with a mature stand is not likely to be directly meaningful in terms of assessing the trajectory of these immature sites (Parkes, 2003).

To track progress with the progress stages of rehabilitation it may be more appropriate to propose and measure interim criteria representing the successional trajectory rather than focusing on the endpoints (or closure criteria) alone (Gravina, et al, 2011). This requires an in depth understanding of recovery processes and alternative states, including the less desired but stable states (Brown & Lugo, 1994 and Grant 2006). Such interim criteria can be derived from studying recovering mine sites at various stages. However, this approach will also be complicated by the fact that restoration knowledge and methodologies generally change and improve over time (Gravina, et al, 2011).

The Alcoa bauxite restoration for south-west Western Australia’s Jarrah forest has in part accommodated interim indicators, by proposing targets which are a percentage of final completion criteria (Grant, 2006 and Grant & Koch, 2007). This approach may suffice for some but not all parameters, and particularly if there are some marked transition states.

Even when based on ecological principles, the conceptual understanding of how an ecosystem will reform after disturbance relies on a lot of assumptions on how the ecosystem works (Palmer, et al, 1997). Reliance on comparison with a reference community will generally not be sufficient to fill significant knowledge gaps (Brown & Lugo, 1994). Often the knowledge of transition states, the role of keystone species and the successional process vegetation recruitment follows, is obscure (Palmer, et al, 1997). If the restoration goals are related to management of endangered species there is also a need to understand how ecological processes and biodiversity influences the establishment and persistence of these focal species (Palmer, et al, 1997). Research and monitoring may be needed to fill these types of knowledge gaps.

Rehabilitating areas can take decades or longer to develop the floristic and structural complexity of nearby unmined ecosystems (Gravina et al, 2011). An appropriate time frame to which the rehabilitating areas may approximate an equivalent undisturbed environment is not clear. More often mining rehabilitation attempts to measure success over a relative short time frame which is reflective of the project driven needs rather than the complexity of re-creating a complex ecosystem (Morrison et al, 2005 and Gravina, et al, 2011).

Establishing effective closure criteria and measure of the successional pathway is complex. Completion criteria should reflect a range of values that might be expected in reference communities, while also allowing for multiple end point states, depending on disturbances and climatic events that may influence the trajectory of a rehabilitating system (Gravina, et al, 2011). There is no sure method and approach to create certainty in the outcomes. Rather, the aim is to build in mechanisms to appreciate and accommodate the complexity and the uncertainty which is a feature of natural and dynamic systems (Gravina, et al, 2011). This can be achieved by establishing mechanisms for learning as one goes through a process of adaptive management and keeping this learning alive in an ever changing and dynamic social and environmental context (Gravina, et al, 2011).

3.5 Adaptive Management

As the field of ecology is extremely complex and still evolving, there is a need to ensure feedback between the conceptual framework, the developing ecological theories and the specific lessons learnt through restoration practices in the field. Restoration projects provide ideal experiments for testing some key theories and in doing so contribute to improving the overall understanding of system dynamics (Palmer, et al, 1997).

"Adaptive management acknowledges that our ability to predict the future key drivers of any given ecosystem, as well as system behaviour and responses, is inherently limited. As a result, management must include the ability to change management practices by incorporating the insights gained from past experience" (Pahl-Wostl, et al, 2007).

- In terms of ecological management the Adaptive Management approach entails:
- setting environmental goals for an ecological system through establishing dynamic thresholds (upper and lower limits) for key environmental parameters;
- establishing the means of measuring and detecting change in these parameters;
- setting thresholds for when an alternative management response is required to attain the set goals;
- applying management strategies;
- monitoring and responding to feedback information;
- as well as refininng the overarching management approach (Pahl-Wostl, et al, 2007, and Kingsford & Biggs, 2012).

An adaptive approach can support dicerning when restoration can be achieved through removal or rectification of stressors and when this alone is not sufficient and further intervention is required thorugh the development of thresholds between stable states (Hobbs & Norton, 1996).

The process of adaptive management recognsises that in the absence of tested theories and complete information to be able to predict the pathway for a dynamic system (for ecolgocial sytems the information will never be complete- Schaffer, 1995 cited in Aronson et al, 1993), management strategies and even goals, may need to be adapted as new information and understanding becomes available (Pahl-Wostl, et al, 2007).

A key aspect of the adaptive approach is the quality of the process, the diveristy of stakeholders and the types of information taken into account. Pahl-Wostl, et al, 2007 indicate that the ability to be adaptive relies upon the following qualities:

- New information must be available and/or collected for example performance indicators and indicators of change that may lead to desirable or undesirable effects, and these indicators must be monitored over appropriate time scales (generally longer than those mandated by short-term political objectives).
- The actors in the management system must be able to process this new information and draw meaningful conclusions from it. This can be achieved if a learning cycle and negotiation process

unite the actors in all phases of assessment, policy implementation, and monitoring. Because varous actors pursue different and changing political interests, transparency and leadership are of major importance to make such multiparty negotiation processes work.

- Change must be possible in ways that are open and understandable to all the actors. Managers must be able to implement change based on new information, processed in a transparent manner, that makes it clear who decides how and when to change management practices and what evidence was used to make this decision. To do this, it is necessary to strike a balance between continuity and flexibility, because some management strategies may take one or more decades to be implemented and tested.

Gravina, et al, 2011 indicate that on-going intensive adaptive management is required to maintain the progress of a stable landscape to the final success criteria, establishing an appropriate native vegetation community. This has implications for the land manager who may inherit the rehabilitating site upon post-relinquishment (Gravina, et al, 2011).

3.6 Best Practice Rehabilitation Techniques Promoted for Shallow Strip Mining in the Tropics

Hobbs and Norton, 1996 suggest that in general the methodologies for restoration projects are largely ad hoc and site specific. They also indicate there is little attempt to generalise from one site or system to another and there is seldom effort invested in incorporating restoration into land and planning strategies.

The Northern Territory, at best, has a few dated guidelines for best practice rehabilitation for sand and gravel pits and these include:

- Applegate, RJ. 1983. Guidelines for effective rehabilitation of borrow pits in the top end. Technical Report - no. 13 Conservation Commission of the Northern Territory, Jabiru, NT.
- Haylock, WJ. 1981. Guidelines for efficient operation and rehabilitation of borrow pits. Soil Conservation Technical Bulletin Number One, April, 1981. Conservation Commission of the Northern Territory, Jabiru, NT.
- *Errity, MA.1986? Guidelines for the Location, Operation and Rehabilitation of Borrow Pits Department of Mines and Energy Inspection and Safety Branch.

*Note the year of this publication is not known but it is accessible through the NT State Library

In addition the Department of Resources provides some practice guidelines in the following Advisory Note:

- DOR. 2010. Advisory Note - Extractive Operations Mining Management Plan (MMP) Structure Guide for Extractive Operators. Northern Territory Government Department of Resources.

Some of the site practices recommended in the Mining Management Plan Structure Guide, may be open to interpretation by individual assessors and auditors and some of these practices (for example buffers between pits) may no longer be required or enforced.

Tayler (2004), who reviewed the performance of the Northern Territory Extractive Industry Performance against Australian standards for best practice in mined land rehabilitation, found that a general absence of formal guidelines and policy has resulted in poor industry performance.

There are no guidelines for best practice minimal disturbance and rehabilitation for sand and gravel extraction operations within a site of conservation significance. Kakadu National Park has some guidelines for sand and gravel pit placement and rehabilitation; however, these are largely based on the generic and dated guidelines which apply to the whole of the Northern Territory.

There has been very little research conducted with regard to improving the knowledge and understanding underpinning rehabilitation for gravel and sand extraction. However, there have been two field based studies of interrogating the outcomes of sand and gravel rehabilitation and these include:

- Setterfield, S. Cook, G. Williams, D & Duff, G. 1993. Rehabilitation of Borrow pits in Kakadu National Park. A final report to Australian Nature Conservation Agency. CSIRO. And
- Price, O., Milne, D. and Tynan, C. 2005. Poor recovery of woody vegetation on sand and gravel mines in the Darwin region of the Northern Territory. Ecological Management and Restoration Vol. 6 No. 2. pp 118-123.

Setterfield *et al* (1993) carried out an assessment of over 500 rehabilitation sites for lateritic gravel borrow pits in Kakadu National Park which were identified from 1991 aerial photography. The majority of burrow pits in Kakadu were within Eucalypt Woodlands. On ground assessment of 10% of the total number of burrow pits found that the regeneration of woody species, particularly Eucalypts, was very poor (Setterfield et al, 1993). Setterfield et al (1993) found that rehabilitation procedures had prompted either extensive ponding, or alternatively, the establishment of Acacia species and ground species which promoted fire and that this limited the success of moving to a Eucalypt dominated vegetation type that previously existed.

Price *et al,* 2005 investigated the regeneration of woody species for sand and gravel extraction site within the Greater Darwin areas (with several sites being fine sand extraction within the Howard Sand Plains) also found that regeneration of the woody species, in terms of both structure and species composition, was much less than that exhibited for reference sites which were not disturbed. Sand extraction sites in the study by Price *et al* (2005), on average exhibited a structure (indicated by basal area, canopy cover and stem count), of 50% or less than that exhibited for reference sites which were not disturbed. For the same sites the woody species composition was 35% less than the reference sites (Price, et al, 2005).

Both Setterfield et al, 1993 and Price et al, 2005 focused on woody overstorey species as a key indicator and did not examine the rehabilitation of the ground layer species. In both situations, Kakadu and the Howard Sand Plains, recovery of the ground layer for extractive sites is likely to have been very poor, as in both locations removal of the extractive material resulted in ponding and an altered hydrological regime to what was present prior to disturbance (Setterfield, et al, 1993 and Price et al, 2005). The ponding of water greatly reduces the species which can inhabit the area.

Setterfield et al (1993) found that revegetation of the burrow pits in Kakadu was influenced by recolonisation from the surrounding vegetation. Due to the patchy nature of the Sandsheet habitat it may be best to assume that colonisation from nearby Sandsheet habitats, particular the diversity of ground species such as the Utricularia species, may be very limited.

Although the Sandsheet habitat is a different vegetation type to the lateritic land type; interrogated by Setterfied in Kakadu and other studies in other localities; it is likely that the recommended techniques for improved vegetation response equally apply to increasing the success for Sandsheet vegetation. The following lists some key findings which are most relevant.

- Based on the study of burrow pits for Kakadu, Setterfield et al (1993) recommends two key means of improving rehabilitation outcomes for gravel burrow pits. These recommendations include: storing the top soil for a minimal period and sowing the rehabilitation site with an appropriate mixture of seed immediately after site preparation and laying the top soil to promote the generation of woody species.
- Revegetation trials for bauxite mining in Weipa (Qld) and Gove (NT) indicate that removing the top soil during the late dry season or build-up maximises the presence of seed and propagules (Setterfield, et al, 1993).

- Restoration projects for Bauxite mining in sout-west Western Australia by Alcoa suggests that establishing the full suite of species early on in the process of rehabilitation is desirable. This goal ensures keystone species establish, dominance by pioneer species is reduced and avoids costs and challenges of introducing species to a relatively established vegetation community later on. However, some specific work may be required to re-introduce recalcitrant species (Grant, 2006 and Grant & Koch, 2007).

A checklist of best practice methods for sand mining in the Howard Sand Plains can be compiled from the existing Northern Territory Guidelines for Burrow Pit placement and rehabilitation and the research which is available for mining rehabilitation; either gravel burrow pits, sand or bauxite mining in Northern Australia and other locations. This checklist is presented in Table 3-3 below. This list is not exhaustive and can be improved with further monitoring and appreciation of the dynamics of the Sandsheet habitat and some of the potential rehabilitation trajectories.

Table 3-3 A generic checklist of best practice methods for sand mining rehabilitation for the Howard Sand Plains

Rehabilitation Stage	Description
Pre-disturbance Survey	- *Pre-disturbance surveys should indicate if and where any threatened species populations should be avoided and if there are any populations in nearby areas of Sandsheet.
Buffers	- Each borrow area shall be confined to an area of not more than one (1) hectare. - #Natural vegetation strips not less than twenty-five (25) metres in width shall separate each borrow area from an adjacent area.
Stripping vegetation and top soil	- *Where possible patches of Sandsheet habitat should be left intact to assist with recruitment from these areas to the rehabilitating site. - Vegetation should be stripped post wet season (to avoid soil erosion concerns) and near as possible to the commencement of mining. The cleared vegetation should be retained and stockpiled (in a cleared area but not in the surrounding vegetation) for mulching upon site closure after the deep ripping. However, if the cleared vegetation is burnt the ashes should be stockpiled separately for re-spreading with the topsoil. - No less than and preferably not more than 100mm of topsoil should be removed during the time of greatest seed set, during the build-up (October to December). Stripping and replacement of top soil during the build-up has been found to promote 2-3 times the greater establishment of seedling than stripping in the early dry season for bauxite mining in Weipa (Setterfield, 1993). - If the subsoil it to be removed in addition to the topsoil this should be removed and stored separately.
Storage of top soil	- Top soil should be stored away from drainage lines. Top soil should be stored in low piles (preferably less than 1m) high, as anaerobic conditions develop at depths greater than a meter altering the chemical, physical and

Rehabilitation Stage	Description
	biological qualities of the soil. - Top soil should be stored for a shorter time period as possible and preferably less than a year. Where several pits are being worked in close proximity concurrently, progressive rehabilitation should involve using the top soil from an adjacent pit so as to ensure the top soil is stockpiled for as shorter time period as possible. - Topsoils and subsoil stocks should be managed for weeds. - Threshold time periods for which the bulk of seeds and propagules remain viable in top soil stock piles are not known.
Seed Collection	- Where appropriate seeds from nearby Sandsheet species (particularly the dominating upper and ground species) should be collected once the mine site is ready for rehabilitation and if there is scope for appropriate seed storage.
Stabilise the site through the wet season	- If a site needs to shut down for a period during the wet season it needs to be stabilised to avoid ponding and soil erosion. - Emphasise shaping the sites topography to ensure it as free draining as possible and putting sediment traps in place to contain sediments from the stockpiles and pit if required.
Reconstruction of Landform – and road closure	- Immediately following completion of mining the site should be reshaped and contoured to tie into the surrounding landscape with a particular emphasis on drainage patterns approximating the surrounds as much as possible. - Where possible creating closed depressions (e.g. the water cannot readily flow out) should be avoided. - The edges of the pit should be battered down to at least 3:1 (horizontal: vertical) (Applegate, 1983). - *Land shaping should attempt to maximise areas without ponding to greater than 30% of the entire site area.
Deep ripping	- *Deep ripping increases water infiltration and plant root penetration. Ripping depth should be 1-1.5m, parallel to the contour, using a winged tyne with the tyne intervals less than 2m apart. To minimise topsoil and seed falling below a 10cm depth into deep furrows created during ripping, a heavy bar can be dragged behind the tynes to smooth over the soil surface.
Replacement of Topsoil	- *Topsoil should be evenly respread across the site at no more than 10cm thick, immediately after the deep ripping and then shallowly tyned along the contour to loosen the surface.

Rehabilitation Stage	Description
	- *Where ponding may be unavoidable, the ponded areas will not be able to support establishing the full diversity of seed stock in the topsoil so it may be better to use the topsoil allocated to this area to either other pits nearby or experiment with creating some low broad mounds in the areas which will be less inundated.
Direct Seeding	- *Where native, and preferably locally provenance, seed stock is available this should be spread across the soil surface immediately following the seed bed preparation and preferably during the building up period (September to early December) (Setterfield, et al, 1993). - The seed mix used should reflect the land type or vegetation type to be re-established. Where ponding is unavoidable a much a reduced range of species will be applicable. - The amount of seed required will depend on the length of storage of the topsoil and quality of the remaining substrate (e.g. depth of sand and proximity to the basement). At least 0.5-0.7kg of seed per ha is recommended (Setterfield, et al, 1993). - In terms of species composition the aim should be to establish the full suite of species within the first couple of years rather than intervention to establish species as the vegetation community matures (Grant, 2006 and Grant &Koch, 2007).
Fertilizer	- Plant establishment for disturbed areas can be limited by lack of nutrients. - However low soil nutrients are a feature of Sandsheet habitat. - The value and use of fertiliser requires further examination (Tayler, 2004).
Fire and Weed Management	- In the early phases of rehabilitation (1-3 years) it is critical to supress fire and ensure weed species do not establish. - Sites which may result in unavoidable ponded areas may be able utilise these areas a fire breaks.

*note these suggested practices vary from the DOR (2010), Mining Management Plan Structure Guide.

a practice featuring in the DOR (2010), Mining Management Plan Structure Guide, which does not appear to be recommended nor enforced any longer.

The next section of this report draws upon the review of the underpinning ecological theory and current knowledge of restoration practices for mining rehabilitation, to propose an overarching approach or framework to improving the rehabilitation outcomes for mining of Sandsheet habitat in the Howard Sand Plain Site of Conservation Significance.

4 Proposed Framework for Improved Rehabilitation Outcomes

4.1 Overarching Approach

The following outlines a proposed stepped procedure to guide the sand extractive industry with improved rehabilitation goals and tracking performance of disturbed sites at both the landscape and the site scale of management. The procedure involves 6 key steps as depicted in Figure 4-1 and briefly outlined below.

4.1.1 Step 1. Establish Landscape Goals

A first step in establishing rehabilitation goals for mining within a site of conservation significance starts at the landscape scale. Key areas which need to be conserved in order to sustain identified values, and the processes which support these values (such as hydrological regimes) need to be identified at the landscape scale. Once conservation areas and key processes are clarified, acceptable thresholds of disturbance by mining can be more clearly identified and hence the range of rehabilitation outcomes which may be acceptable from the perspective of accumulative impacts at the landscape scale.

Establishing thresholds of disturbance at the landscape scale requires an overall assessment of all areas which have been disturbed, the quality of existing rehabilitation outcomes and the impacts on the values and processes which are targeted to be retained at the catchment scale of management.

4.1.2 Step 2. Conduct Pre-disturbance Assessments

Pre-disturbance assessments should be conducted for any potential new sand mining site to identify local values (particularly if they feature the focal species such as the diversity of bladderworts or the Howard River Toadlet) to be either retained (as a first preference) or reinstated. This form of assessment can also assist with determining benchmarks for the pre-existing environment and hence the expectations for rehabilitation outcomes.

Pre-disturbance assessment should place a site within a landscape context by identifying the site specific and regional values inclusive of the level of disturbance surrounding the site or the level of connectedness to nearby patches of intact Sandsheet, which may provide as a colonising source to the rehabilitating site.

4.1.3 Step 3. Determine Rehabilitation Endpoints with Success Criteria and Measures of Progress

Based on the combined Landscape and site scale assessment of a values and expectations, realistic endpoints or goals for re-establishing functional ecosystems and species diversity can be established. The final goals for rehabilitation need to give recognition to socioeconomic and cultural expectations as well as the ecological and technical feasibility; or limitations; to achieving restoration. While rehabilitation endpoints are constrained by the available rehabilitation techniques, ambitious goals can drive improvements for the current knowledge base and practices.

Likely rehabilitation endpoints and trajectories can be scoped using conceptual models, such as successional modelling and a state – transition model, to forecast likely patterns and options (including undesirable states) for rehabilitation. Success criteria should be developed for critical stages in rehabilitation together with triggers for management intervention should a less desirable state result.

Success criteria for a range of attributes at each stage in the rehabilitation process should be quantified or qualified through the development of a set of easily observable measures as well as standard processes for their measure.

The benchmarks for success should be established using reference sites for intact Sandsheet habitat and other vegetation communities which may scoped as acceptable endpoints.

4.1.4 Step 4. Develop Practical Techniques for Implementing the Rehabilitation Goals

The range of best practice approaches to achieve the set rehabilitation endpoints; including management interventions should a less desired state result; needs to be documented within a rehabilitation plan.

Rehabilitation practise can be refined over time through targeted experimentation, monitoring and knowledge sharing.

4.1.5 Step 5. Monitor, Assess, and Track Rehabilitation Practices & Outcomes.

Key management practices applied at the site scale (along with any significant disturbance such as fire) should be tracked using a checklist approach. Progress with the actual rehabilitation outcomes should be assessed by monitoring the success criteria (key attributes) at the site scale for critical stages in rehabilitation progress and comparing with the reference sites for the agreed endpoints.

Monitoring of the success criteria needs to be carried out over a period until rehabilitation is declared as meeting the elected endpoints. In addition the reference sites need to be monitored over a long time frame to ensure the success criteria capture the natural variation for Sandsheet habitat over time and in response to various weather patterns and regimes of disturbance.

Rehabilitation outcomes can be tracked at the landscape scale through GIS mapping.

4.1.6 Step 6: Review & Adapt

At the site scale, monitoring which detects rehabilitation deviating towards an undesired state should trigger management interventions in attempt to reinstate the desired direction.

At the landscape scale mapping the progress or results of rehabilitation can guide detecting disturbance thresholds and also inform future expectations for disturbance and rehabilitation outcomes.

Feedback from monitoring at site scale and collectively at the landscape scale should assist with reviewing the overarching industry approach as well as the knowledge base and capacity which underpins and defines successful rehabilitation.

4.1.7 Implementing the Framework

The next section elaborates upon these six key steps through detailing some of key processes which contribute to implementing the overarching approach.

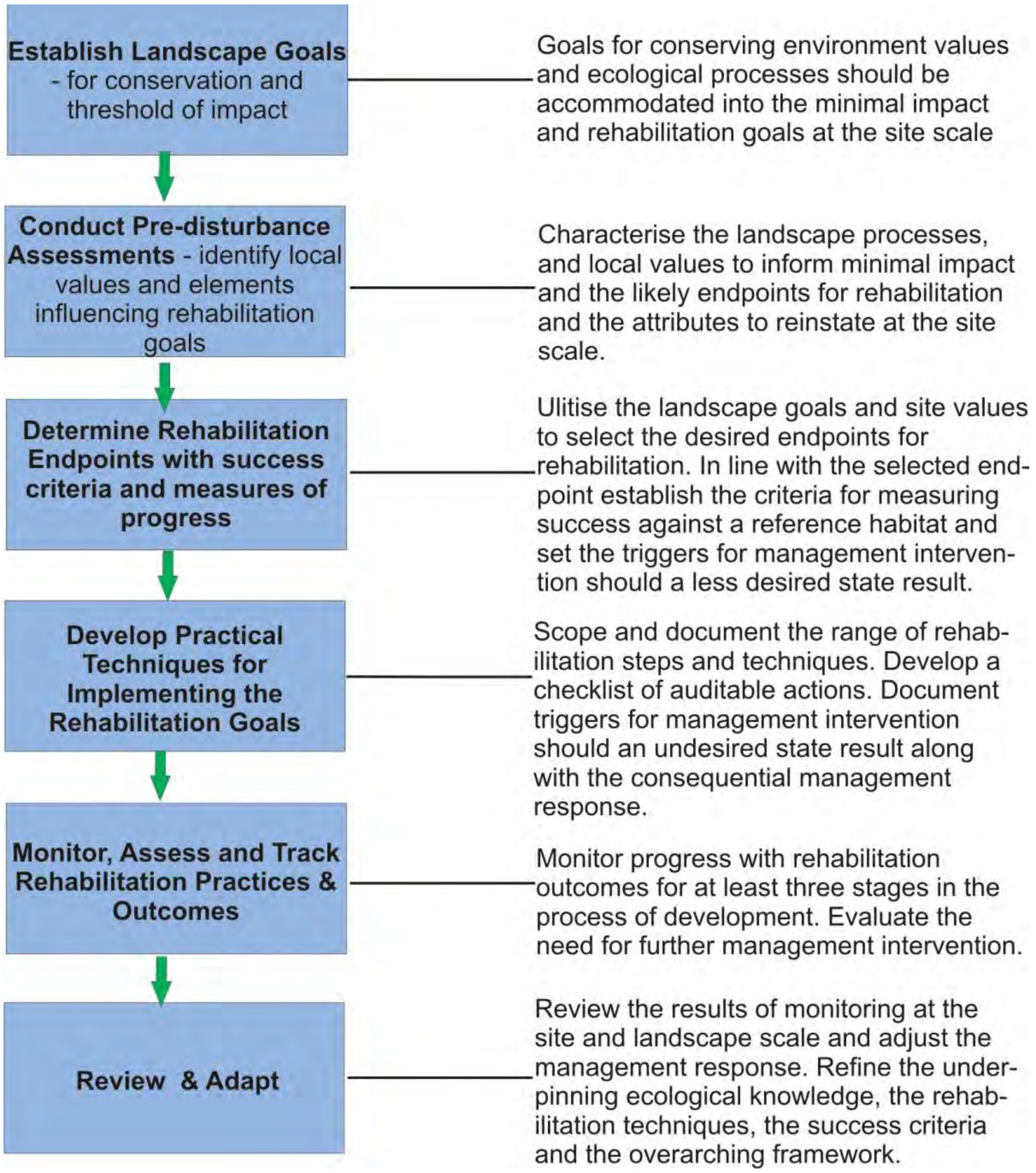


Figure 4-1 An overarching approach to improving rehabilitation outcomes for the Howard Sand Plains Site of Conservation Significance.

5 Establish Landscape Goals

As the Howard Sand plain is an area targeted for multiple land uses (road infrastructure, urban and rural development as well as sand mining) the Sandsheet habitat (which is a very limited component of this landscape) is at risk from a lack of a planned approach to conserve its key values.

Establishing landscape goals entails examining the range of values and key ecological processes (such as hydrological flows) which should be retained, conserved or reinstated at the catchment scale. An appreciation of how the landscape or catchment functions can inform the level of disturbance or alteration that may be tolerated before key values and processes are significantly compromised.

GIS mapping at the landscape scale enables combining a range of information about the environment and examination of a range of aspects which collectively influence the overall state or health of the catchment and status of the Sandsheet habitat. Mapping at this scale can capture which areas are of greatest value to biodiversity and sustaining ecological processes, which areas remain intact, their condition and connectivity, which areas have been transformed or significantly altered and which areas have been disturbed and their rehabilitation outcomes. An overarching understanding and plan for the catchment heath and conservation values can be built by bringing this range of information together. The state of the catchment and the Sandsheet habitat very much influences the rehabilitation expectations for mining activities.

Establishing landscape goals is a high level responsibility of government which needs to be considerate of the needs and expectations of a range of stakeholders and land uses, but also mediate these expectations with the needs for conserving ecosystem services and biodiversity for future generations.

Management at the landscape scale is an evolving process which requires regular review with changes in the knowledge base and changes in social attitudes and values. More often the necessary knowledge to establish landscape goals is lacking. At present, there are few explicit landscape goals for conserving the Howard Sand Plains and its sustaining processes.

As a result of the Caring for Country project; which has scoped some of the high value areas with regards to threatened Howard River Toadlet and the highly diverse group of Utricularia's; there are some clear priority areas for conserving these focal species. These areas trigger the need for particular care in minimising impact and also rehabilitation outcomes which match as closely as possible to the Sandsheet habitat. However, there remains significant knowledge gaps on how resilient the focal species are to disturbance, the minimum ecological processes required to sustain these species (e.g. conservation of land area and processes such as surface water flows, which goes beyond the immediate Sandsheet habitat they may occur within) and how these species may be returned to disturbed sites.

Knowledge generated through experimentation with rehabilitation can make significant contributions to the knowledge base which is necessary to underpin a landscape approach to conserving this limited habitat type and the focal species of particular concern.

6 Pre-Disturbance Assessment

Pre-disturbance assessments are necessary to determine whether a site features high profile species (such as the Howard River Toadlet and the diversity of Utricularia) as well as determine the character of a site. An assessment prior to disturbance enables minimal impact techniques to be proposed, therefore maximising the opportunity for retaining the high value areas or aspects of a tenement. In addition the likely rehabilitation expectations, and hence closure criteria can be scoped. Photo monitoring sites established prior to mining also greatly assist with tracking landscape change as a result of disturbance as well as contribute to benchmarking habitat restoration success.

Sites located in the vicinity of priority areas of conservation for the Howard River Toadlet (Figure 6-1) and the Utricularia and Thyphonium species (Figure 6-2) should trigger the need for a pre-disturbance assessment. These assessments are needed not only to discern the presence of these species on site but also to examine the value of the Sandsheet and its surrounds in terms of sustaining ecological processes (e.g. surface flows) and connectivity between habitat and populations which may be important to retaining Sandsheet habitat and the focal species in the near vicinity.

For rehabilitation to meet the objectives of conserving landscape scale values and processes it is necessary to gauge the value of an area in the greater landscape context.

Table 6-1 proposes a set of criteria which can be used to score the landscape or habitat value for an area proposed to be disturbed. The range of parameters to be examined aims to assist with placing a site in a regional context as well as gathering key attributes which can inform the rehabilitation goals and endpoints.

As the catchment overall becomes more disturbed it will become increasingly more difficult or simply not possible to reinstate Sandsheet habitat. The proposed scoring process will be more effective if it is used with a landscape based approach to discerning values to be conserved and establishing targets for acceptable levels of disturbance and rehabilitation outcomes across the landscape as a whole.

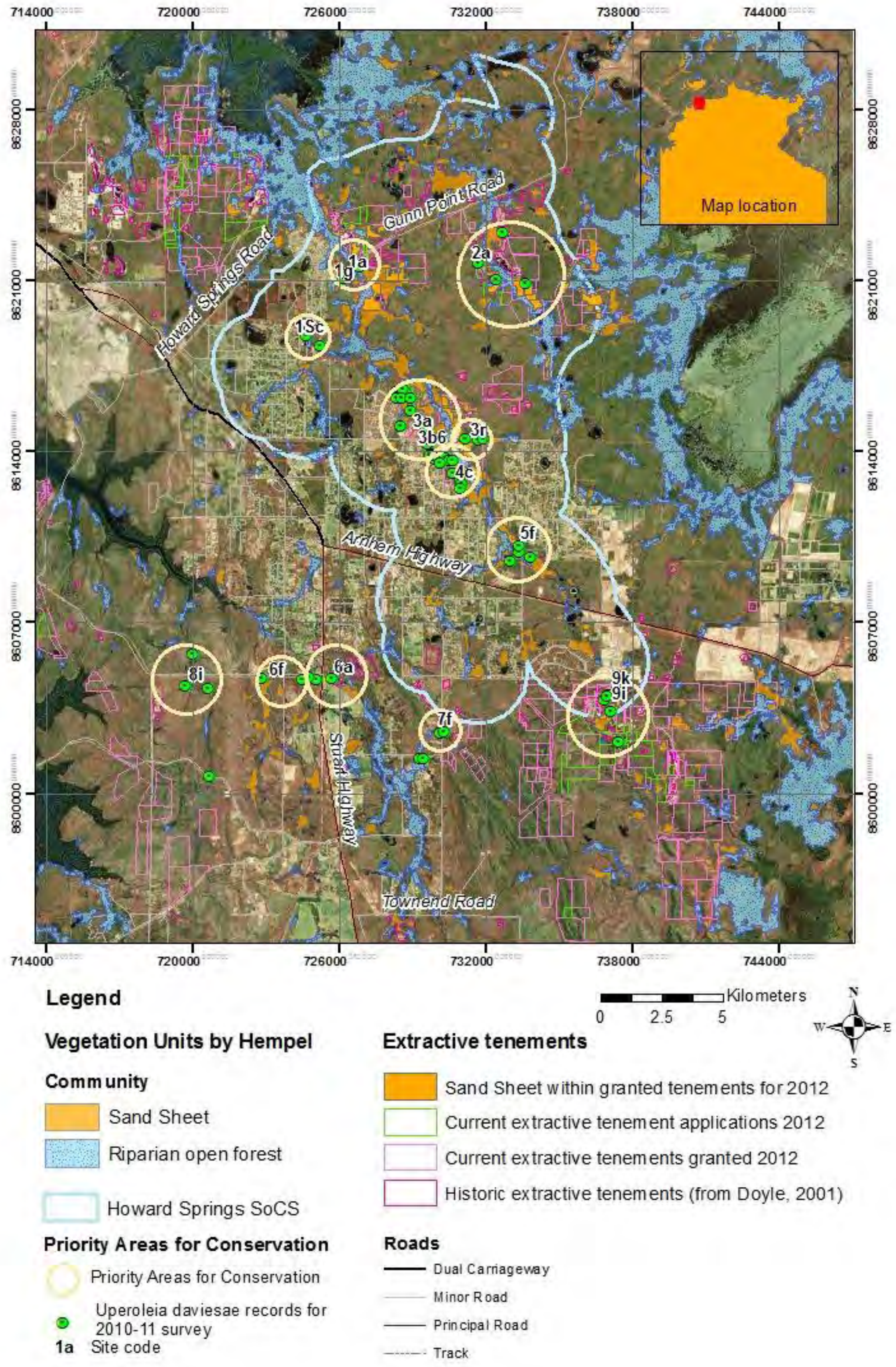


Figure 6-1 Priority areas for conserving the Howard River Toadlet

(Refer to Reynolds & Grattidge, 2013)

Refer to

D.T. Liddle, P. Harkness, J. Westaway and D.L. Lewis (2012) Vegetation communities and biodiversity values of the seasonally saturated lands of the Howard Sand Plains Site of Conservation Significance in the Northern Territory of Australia.

Figure 6-2 Priority areas for conserving a diversity of Utricularia and the Typhonium species

Table 6-1 Criteria for Scoring Habitat Value and Character

Criteria Category	Attributes
Vegetation Type	Sub category of Sandsheet vegetation type NVIS vegetation category (refer to Liddle, et al, 2012).
Landscape Value	Patch shape: Square, roundish, rectangular
	Patch size m^2
	Distance from edge to the core
	Proximity to major drainage
	Distance to the nearest Sandsheet vegetation type
	Number of Intact Sandsheet>xm^2 within 50-100m and 500m distance Number of disturbed Sandsheet >xm^2 within 50-100m and 500m distance *Rank the nearby disturbed or rehabilitating sites according to their rehabilitation goals and/or progress (Sandsheet goals, intermediate or modified)
	Size of area to be disturbed
	Proportion of the total patch to be disturbed
Landform Aspects	Slope and Aspect
	Depth of soil and depth to basement
	Drainage: Rapid to Moderately well, Imperfect to poor, poor to very poor (seasonal water logging or inundation most years)
Microrelief	Mounds (height) and average distance between mounds
Surface cover	% cover for vegetation, litter, bare, gravel, pebble, rock, logs
Habitat Complexity and Condition	Structure: Height range and average, Overall canopy cover for each vegetation strata (upper, mid and ground) Stem density:
	Species Composition: Upper storey: Foliage cover and height for each dominant species (cover > 5%) and average diameter at breast height. Mid storey: Foliage cover and height for each dominant species (cover > 5%) Ground storey - Cover and height for each dominant species (cover > 5%)
Focal species	
	Utricularia or Typhonium sp (refer to specific survey protocols)
	Howard River Sandsheet Frog (refer to specific survey protocols)

7 Determine Rehabilitation Endpoints with Success Criteria and Measures of Progress

Pre-disturbance assessments together with a conceptual model, which captures the range of alternative rehabilitation states and pathways, may be the best approach to determining appropriate rehabilitation endpoints and success criteria. The following outlines a state transition conceptual model together with some of the vital attributes for describing success and also detecting a deviation from the successional pathway towards the desired endpoints (or states).

7.1 A Conceptual Model for Sandsheet Rehabilitation

Three key rehabilitation endpoints have been identified from examining a number of sites from both aerial imagery and on the ground.

The three dominant endpoints include:

- **Rehabilitated or restored Sandsheet system:** which may or may not be connected to nearby Sandsheet vegetation types. (Note this endpoint may need to acknowledge the various Sandsheet sub types);
- **An intermediate system:** Melaleuca swamp with the extent of the rehabilitated area featuring > 40% ponded water but with sustainable contiguous patches of Sandsheet (>10m^2) which may or may not be connected to nearby Sandsheet vegetation types; and
- **A modified system:** Melaleuca swamp with the extent of the rehabilitated area > 40% ponded water.

These three endpoint categories are depicted in Figure 7-1.

Rehabilitated or restored Sandsheet is largely absent from the range of rehabilitation outcomes currently exhibited within the Howard Spring Site of Conservation Significance, however it remains the ultimate desired end state to aim for.

The two end points, Melaleuca swamp with sustainable patches of Sandsheet and a modified system consisting of Melaleuca swamp, both dominate the rehabilitation outcomes. These two states, although functional ecosystems, are not desired end points but in some situations may be all that is possible given the level of disturbance and rehabilitation techniques and knowledge which has been available at the time. Consequently, these two less desired states may be considered “Acceptable end points” depending on the landscape and social context. That is, they may be considered acceptable states as long as the key values and uses of the Howard Sand Plain, at the local land landscape scale, are not compromised.

The degree to which rehabilitation states, that are alternative to restored Sandsheet, remain acceptable over the longer term is dependent upon: the proportion of Sandsheet remaining intact and in good condition (both within the near vicinity of the area in question and on a whole of catchment basis); social acceptance of these less desired states and the cost/benefit involved in improving the quality of rehabilitation outcomes.

If less desired states are elected as the rehabilitation goals for rehabilitation it should be because the desired state (restored Sandsheet) is not achievable due the considerable investment of effort or lack of techniques. In any case it is preferable to avoid extended ponding of water for a range of ecological and social justifications (e.g. increased habitat for cane toads and mosquito breeding).

Due to a constraints in restoring Sandsheet habitat (which is part due to lack experimentation as well as a significantly altered substrate and landform) a fourth rehabilitation outcome may need to scoped, one which is more evenly drained and begins to approximate Sandsheet habitat as least in terms of landscape functionality and greater proportion of Sandsheet species. This potential rehabilitation endpoint is included in Figure 7-1 but has not been characterised yet.

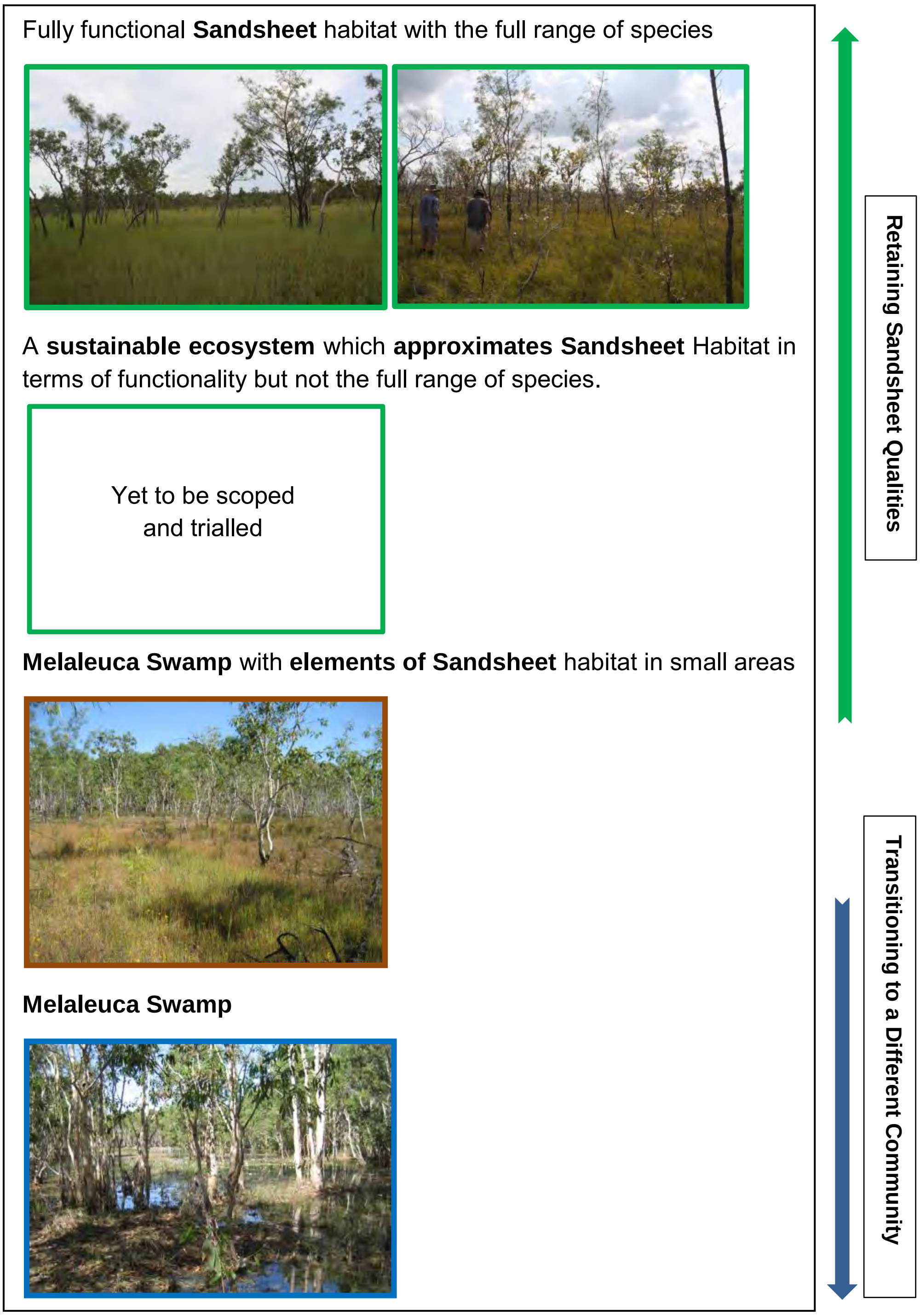


Figure 7-1 The most likely spectrum in rehabilitation outcomes for sand mining in the Howard Sand Plains

A state-transition model similar to that used by Alcoa's Bauxite mining in Western Australia can be applied in a simplified manner to construct a preliminary guiding model for the desired and acceptable pathways for rehabilitation (Figure 7-2). This model can be applied to any of the three to four likely end states.

At least 3-4 critical stages in rehabilitation are proposed and these include:

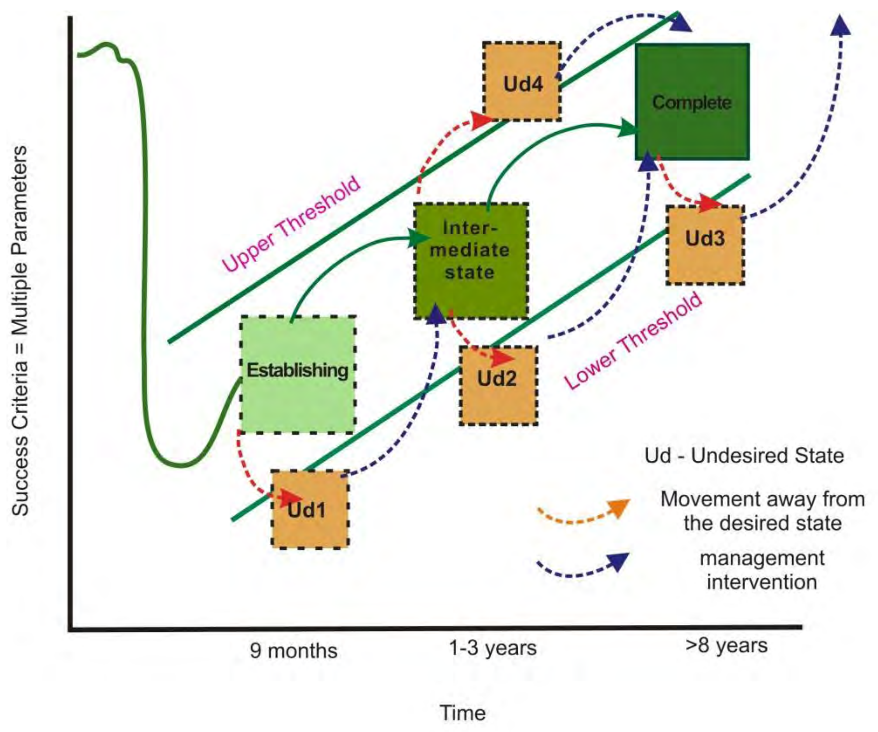
- First Establishing: 6-9 months,
- Establishing: 1-3 years
- Established: 5-8 years and
- Complete: > 8 years

These stages are likely to feature different characteristics and also opportunities to rectify significant deviation from the desired state. For instance the first 6-9 months are critical to establishing an appropriate landform, drainage pattern and soil stability. As the age of the rehabilitating site increases it is increasingly more costly and disruptive to correct these factors.

Similar to the model used by Alcoa, some of the likely undesirable transitions or states can be incorporated into Sandsheet State-Transition model. The character of these undesired states can indicate when management action should be considered to move rehabilitation back onto the desired path.

The most obvious undesirable states are sites which have excessive ponding or an inappropriate landform or substrate (as defined by critical thresholds for the desired states); those which become weed infested (and particularly with landscape changing weeds such as gamba grass); or exhibit excessive disturbance impacting on the establishing vegetation such as fire in the early stages of establishing or frequent trampling by off-road vehicles.

Figure 7-2 State-transition model for rehabilitation of Howard Springs Sandsheet habitat



The proposed State-Transition Model (Figure 7-2) provides the guide to setting success criteria for the desired state, the stages of rehabilitation development as well as states or conditions which trigger a need for further investment in management intervention to achieve the set rehabilitation goals. The following sections scope out some of the vital attributes which can contribute towards defining rehabilitation success and a deviation from the desired state.

7.2 Vital Attributes

It is not economical to measure the full range of parameters which may indicate how closely a rehabilitating site is replicating a standard for the desired state. The following outlines five groups of vital attributes: Landform & Ecological Processes, Soil Stability and Ground Cover, Species Composition and Disturbance; which play a key role in defining rehabilitation success. These vital attributes are then pulled together into a framework of measurable success criteria for three key stages in development towards the desired end states. The end states examined include: the desired state of restored Sandsheet habitat and a currently tolerable end state of Melaleuca swamp with elements of Sandsheet habitat.

7.2.1 Landform & Ecological Processes

As indicated in the background review of rehabilitation and restoration in this report, key ecological processes; such as substrate character, hydrology and nutrient flow; govern the resource base and hence the type of vegetation community which may establish within a disturbed area. Landform character largely influences the state of these ecological processes. The aim for restoration is to reinstate a landform and landscape processes (e.g. surface drainage pattern and entrapment of sediments and nutrients) which are as close as possible to what was originally in place, very early on in the process of rehabilitation.

As indicated by a study by Bowman & Minchin (1987) of vegetation patterns for Berry Springs, a significant proportion of compositional variation in vegetation can be explained by edaphic conditions. Bowman et al (1987) suggest that the land form components of soil characteristics and drainage primarily direct the vegetation composition and structure through two key aspects (1) the availability of water during the dry season and (2) the severity of inundation in the wet season.

Some of the key aspects for restoration to Sandsheet habitat (or a system approximating Sandsheet) include:

- the slope and aspect ties in with the surrounding landscape (to reinstate or conserve the natural surface flows);
- the depth of the remaining sand substrate is >0.4m to the basement;
- the soils of the rehabilitating site are deep ripped to avoid soil compaction, aid infiltration of water and also assist with creating a microtopography of mounds approximately 6-20cm in height and 0.4-2 meters apart;
- topsoil covers over 90% of the area (where inundation is avoided) at a depth of 15-30cm;
- the resulting drainage pattern across the site supports a shallow sheet surface flow (<6cm in peak wet season flows); and
- there is minimal water ponding, that is <15% of the area exhibits seasonal inundation (>25cm deep) for extended periods (several months).

These aspects are approximated from limited field observations and can be improved with measurement for a broader range of Sandsheet types.

Setterfield et al, 1993 emphasises the need to avoid water ponding as this restricts the type of vegetation which can establish and indeed the character of the resultant vegetation community. All rehabilitation works should aim to construct a free draining landform.

The landform character and bulk of the ecological processes are established in the very early phase of rehabilitation. However, ecological processes will evolve over time as the ecosystem matures.

7.2.2 Soil Stability & Ground Cover

A critical component of rehabilitation is to ensure the site is stable and can withstand disturbance such as high rainfall events without accelerated erosion or sediment movement. The landform character and surface drainage plays a key role in determining susceptibility to erosion. A minimum ground cover of 30% across the entire site is recommended to avoid water and wind driven erosion (Dilshad, et al, 1994).

7.2.3 Vegetation Structure

Vegetation structure refers to way in which individual plants in a vegetation community are arranged in a three dimensional space (Garner, 2006). A range of parameters can be used to characterise vegetation structure such as the strata or layers in vertical plains (using measures of height and cover), biomass and woody plant density (e.g. density of tree trunks over 10cm diameter at breast height) (Ruiz-Jaen & Aide, 2005b).

Vegetation structure is a key component to describing vegetation types (Hnatiuk, et al, 2009). Variation in structure can reflect the age of an establishing community and also the impacts of human or natural induced disturbance (Hnatiuk, et al, 2009). Vegetation structure influences a range of habitat qualities, such as the variety of microclimates, shade, leaf litter, soil temperature and fuel loads for fire. It is assumed that recovery of fauna and ecological processes will follow the complexity of the vegetation structure which establishes (Ruiz-Jaen & Aide, 2005b).

Measures of vegetation structure can be obtained relatively easily and rapidly with very little seasonal variation, that is the measures are consistent within a year (Ruiz-Jaen & Aide, 2005b). Some of the key measures considered important to tracking the restoration for Sandsheet habitat are suggested to be:

- density of woody plant species (or basal area);
- distinction of at least two strata (ground and upper);
- canopy height and cover; and
- ground cover forming mounds (the height and distance between ground cover forming clumps/or mounds)

7.2.4 Species Composition

Species composition refers to diversity of both the vegetative and fauna components for the rehabilitating ecosystem (Ruiz-Jaen & Aide, 2005b). Species diversity is a challenging aspect of ecosystems to measure but reflects the ultimate goal for the restored system to resemble that of a mature Sandsheet habitat.

Species diversity within functional groups can be a key attribute of the systems resilience and approximation to a mature Sandsheet habitat. However, further work is required to develop an appreciation of plant groups for the Sandsheet, and their role in structuring the functioning of this system, to be able to use this parameter as a key indicator.

Two key areas of measure are proposed for tracking restoration efforts for Sandsheet habitat and they include:

- vegetation floristics using the presence or absence of characteristic and associated species; and

- the presence or absence of focal species and their high value areas which were present prior to disturbance (e.g. the Howard River Toadlet and diversity of Utricularia species).

These two aspects are elaborated upon further below.

Vegetation Floristics - Characteristic and Associated Species

The diversity of species for the vegetation component of a system is a key component to describing a vegetation community (Brocklehurst, et al, 2007 and Hnatiuk et al, 2009). Vegetation types are generally characterised by a suite of species, of which a small selection exert a dominating influence on the structure, character and functioning on the system (Palmer, et al, 1997, Walker, et al, 1999 and Diaz & Cabido, 2001). The keystone or characteristic species which feature in mature Sandsheet and Melaleuca Swamp habitat along with some of their ecological qualities are presented in Table 7-1. This species list has been compiled from data associated with vegetation mapping of Sandsheet habitat which can in part indicate the most common species present based on their frequency of occurrence (>30% occurrence in vegetation survey sites). Refer to Liddle, et al, 2012 for more detailed information about the suite of plant species characteristic of the Sandsheet habitat.

Keystone or Characteristic species are those which dominate the vegetation character and or its functioning and are always present (Walker, et al, 1999 and Diaz & Cabido, 2001). For the purpose of this report **Associated** or **Minor species** are referred to as those species which do not play such a dominating role in defining the vegetation type's character nor functioning and are generally present but not always (Walker, et al, 1999 and Diaz & Cabido, 2001).

It is important to note that the flora establishing immediately after the rehabilitation commences, has the greatest influence on future shifts in dominance, with various species becoming dominant successively over the life history of the site (Grant, et al, 2006 and Grant & Koch, 2007).

Two key measures are proposed for tracking vegetation floristics for rehabilitating Sandsheet and these include:

- species composition of the upper storey (both associated and characteristic species) >50% than an equivalent reference habitat.
- species composition of the ground layer (both associated and characteristic species) is >50% than an equivalent reference habitat.

Table 7-1 Dominant species for Howard Springs Sandsheet habitat

Scientific Name	Stratum Lifeform	Characteristic or Associated species		Life Strategy Attributes
		Sandsheet	Mel. swamp	
Grevillea pteridifolia	U /Tree	C		Fire killed obligate seeders. A good indicator of fire history Germinates from fresh seed promoted by fire. Tolerant to a range of soils including swampy areas (DEHP, 2012).
Melaleuca viridiflora	U-M/ Shrub/Tree	A	C	Highly tolerant of inundation

Scientific Name	Stratum Lifeform	Characteristic or Associated species		Life Strategy Attributes
Melaleuca Nervosa	U-M/ Shrub/Tree	A	C	Highly tolerant of inundation
Pandanus spiralis	U-M/ Shrub/Tree	A	A	Highly tolerant of inundation
Lophostemon lactifluus	U-M/ Tree	A		Epicormic resprouter in response to fire
Terminalia grandiflora	U-M/ Tree	A		
Hakea aborescens	U-M/ Shrub/Tree	A		
Banksia dentata	U-M/ Shrub/Tree	C		Responds to bushfire by resprouting for a woody lignotuber.
Verticordia cunninghamii	M/ Shrub	C		Fire may induce several large stems to emerge from the lignotuber
Acacia latescens	M/ Shrub	A		
Acacia plectocarpa	M/ Shrub	A		
Acacia leptocarpa	M/ Shrub	A		
Ground Layer				
*Dapsilanthus spathaceus	G/Sedge like	C		Creates small mounds in the micro-topography. Resprouts from a basal lignotuber Life span 1-5 years Seeds after 2-3 years old (Northern Land Manager, 2012)
*Xyris complanata	G/Sedge like	C		
Alloteropsis semialata	G/Grass	A		
Sacciolepis indica	G/Grass	A		
Germainia grandiflora	G/Grass	A		
Eriachne triseta	G/Grass	A		
Scleria pygmaea	G/Sedge	A		
Fimbristylis pallida	G/Grass	A		
Fimbristylis pauciflora	G/Sedge	A		
Sorghum intrans	G/Grass	A		
Heteropogon triceus	G/Grass	A		

Scientific Name	Stratum Lifeform	Characteristic or Associated species		Life Strategy Attributes
Cartonema trigonospermum	G/Forb	A		Unlikely to be to a key species shaping the systems functionality
Lindernia lobelioides	G/Forb	A		Unlikely to be to a key species shaping the systems functionality
Buchnera gracilis	G/Forb	A		Unlikely to be to a key species shaping the systems functionality
Drosera dilatatopetiolaris	G/Forb	A		Unlikely to be to a key species shaping the systems functionality
Drosera dilatatopetiolaris	G/Forb	A		Unlikely to be to a key species shaping the systems functionality
Sowerbaea alliacea	G/Forb	A		Unlikely to be to a key species shaping the systems functionality
Eriocaulon fistulosum	G/Aquatic forb	A	A	Unlikely to be to a key species shaping the systems functionality

Stratum: U - Upper, Mid – Mid, G – Ground *species strongly associated with focal species –Howard River Sandsheet Frog or Utricularia's habitat

C- Characteristic species for Sandsheet habitat A – Associated species for Sandsheet habitat

nk – not known

"The established view of ecological succession is that following a disturbance, several assemblages of species progressively occupy a site, each giving way to its successor until a community finally develops which is able to reproduce itself indefinitely" Noble and Slayter, 1980. An appreciation of the ecological characters for the key species which play a role in the successional development and the final mature state for the two primary end points (Sandsheet and an approximation) can greatly facilitate establishing success criteria and also the means of gauging whether a rehabilitating site is on the trajectory towards the desired state.

Noble and Slayter, 1980 recommends examining the vital ecological attributes of key species and mapping their successional process and requirements to scope the likely dynamics in species composition and dominance over time.

The vital attributes which can strongly influence a species performance in succession include:

- the method of arrival or persistence of the species at a site during and after disturbance;
- the ability of the species to establish and grow to maturity in a developing community; and
- the time taken for the species to reach critical life stages (Noble and Slayter, 1980).

Some of the ecological characters of the dominant species and their plausible ecological establishment (such as germination requirements and tolerance to inundation and fire) are included in Table 7-1 where these qualities are known. However, this list needs further work to be comprehensive. The requirements and successional process of the range of Sandsheet species, and particularly the focal species (Utricularia species and Howard River Toadlet) needs further examination to highlight their ecological requirements and hence helping and hindering factors for their establishment and persistence.

Focal Species and High Value Areas

Sites targeted for disturbance, which feature high values areas such as: populations of threatened or rare species (several of the Utricularia species, Thyphonium taylori and the Howard River Toadlet) or a high diversity of the Utricularia species should incorporate appropriate success criteria to:

- retain these high value species and their habitat areas in a functional state (e.g. the ecological processes sustaining these values are not compromised); and/ or
- reinstate these values through rehabilitation.

Two key measures are proposed for tracking success with retaining or re-establishing the focal species for Sandsheet and these include:

- the key habitat requirements for the focal species are retained or established (refer to landform & ecological processes and vegetation structure); and
- the focal species are present within the rehabilitating site (or intact vegetation) over several years.

To achieve the goals of retaining or reinstating the high value areas for these focal species requires a closer examination of their ecological requirements to establish and persist within an altered landscape. The reader is referred to the following reports which are also associated with the overall Caring for Country Project:

- Reynolds, S & Grattidge, A 2013, Distribution, Status and Habitat Requirements of the Howard River Toadlet (a Sandsheet Frog) Uperoleia daviesae (Anura: Myobatrachidae). and
- Liddle, DT, Harkness, P., Westaway, J & Lewis, DL 2012, Vegetation communities and biodiversity values of the seasonally saturated lands of the Howard Sand Plains Site of Conservation Significance in the Northern Territory of Australia.

Minimal information is known about the ecology for the threatened species of the Howard Sandsheet habitat. Many of the factors which contribute to sustaining or reintroducing the focal species into rehabilitating Sandsheet area are reliant upon the landform, ecological processes and the vegetation structure.

The Utricularia's and Thyphonium taylori, being carnivorous plants, require a low nutrient environment and possibly shallow surface flow of water, or seepage from the surrounds, which creates a moist environment through to the early dry season (pers. comm. David Liddle Dec, 2012). Other vital aspects supporting these species are relatively unknown. The Howard River Toadlet requires some similar conditions including a shallow sheet flow of surface water (approximately <6cm deep), and likely a small mounded micro-topography (6-20cm high mounds and spaced approximately 40cm-2m apart) which largely form at the base of Dapsilanthus, Xyris and various sedges (pers. comm. Steve Reynolds, Dec, 2012)..

Further work is required to ascertain the vital attributes for retaining and establishing the Utricularia's, Thyphonium taylori and the Howard River Toadlet within a disturbed environment, whether it is the very populations of threatened species or their near surrounds which are disturbed.

7.2.5 Disturbance

Disturbance, such as fire, can be a key ecological process which sustains the structure, function and species composition of an ecosystem. However, when disturbance exceeds a threshold it can steer an ecosystem towards an alternative (and less desired) state. The following outlines some of the key disturbances for Sandsheet habitat and their significance to tracking restoration success.

Key measures of success with regards to disturbance levels for restoration of Sandsheet include:

- An absence of weed species and particularly landscape changing weeds; and
- An absence of fire within the first 3 years of rehabilitation.

Weeds species

Disturbed areas are prime sites for the establishment of weeds. Landscape changing weeds in particular; those which significantly alter functioning of the landscape such as nutrient cycling and fire regime; have the greatest potential to compromise a site in achieving the elected success criteria. The most significant weeds which are a threat to rehabilitating Sandsheet include: Mission Grass (annual and perennial), Gamba Grass and Urochloa humidicola otherwise known as Tully Grass. Any degree of presence of these weed species should demark an undesired state and trigger remedial work for their removal. However, it is acknowledged that should the tenement be surrounded by weed infestation on surrounding land tenure, which are unmanaged, this becomes an on-going management issue which affects clarity in the decision points for when rehabilitation is complete.

Fire and other Disturbance

Disturbance such as fire is a part of the natural dynamic for native vegetation in the Northern Tropics. A likely acceptable fire regime which would sustain Sandsheet is one which burns early in the dry season and at least less frequently than every one to two years.

A transition of disturbed sites to Melaleuca Swamp is likely to alter the fire regime on a broad scale as the seasonally inundated areas are largely vegetation free or there is no ground cover during the dry season and therefore cannot generally carry fire.

During the early stages in establishment disturbance, such as fire, is recommended to be kept to a minimum.

Off - road vehicle movement is also recognised as a potential and undesirable disturbance which is extremely challenging to manage.

7.3 Success Criteria & Measures

The proposed state transition model (outlined in section 4.2) has been used to suggest success criteria for the desired state of restored Sandsheet habitat (Table 7-2) and also the less desired state of a modified system consisting of Melaleuca swamp with elements of Sandsheet (Table 7-3).

The trajectory towards these end states recognises three key stages in development:

- First Establishing: 6-9 months,
- Establishing: 1-3 years
- Established: 5-8 years and
- Complete: > 8 years

Note: these recommended stages may need further refinement upon monitoring of rehabilitating sites over a number of years and as the understanding of successional ecology improves.

A framework of success criteria is proposed for each of the key stages in rehabilitation development and these criteria are hierarchically structured using the five vital attributes: Landform & Ecological Processes, Soil Stability and Ground Cover, Vegetation Structure, Species Composition and Disturbance.

Where possible the success criteria have been quantified with values in line with an adaptive management approach. These threshold values are a starting point only and need to be refined with the assessment of reference sites (refer section 7.4) as well as monitoring of rehabilitating sites. The range of success criteria and their quantification may need to be altered depending on the landscape context for restoration efforts. For example a highly disturbed regions featuring significant alterations to catchment processes, such as surface flows and very little intact Sandsheet habitat nearby, may need to relax some of the success criteria as the opportunity for restoration (opposed to rehabilitation) is much reduced. In addition the subtype of

Sandsheet which is targeted for disturbance and that which exists nearby (as Sandsheet can present as a variation of subtypes) may influence the quantification of some success criteria.

Sites which are intended to transform to an intermediate system, consisting of Melaleuca swamp with sustainable patches of Sandsheet (>10m^2), will feature predominantly Melaleuca swamp. Success Criteria for these Intermediate systems largely refer to the quality of Melaleuca swamp. However, to ensure the patches of the rehabilitating Sandsheet can be tracked and managed appropriately the success or closure criteria for these sites should also include the breadth of criteria suggested for the Sandsheet land type. However, the quantification of these success criteria will be dependent on the size of the Sandsheet habitat reforming as this will influence key attributes such as stem density, canopy and diversity of species.

Table 7-2 Proposed success criteria for the desired end point of rehabilitated or restored Sandsheet habitat at key stages for rehabilitation

Desired End Point: Rehabilitated or Restored Sandsheet Habitat		
Stage of Rehabilitation: 6-9 months after rehabilitation (following the first early first wet season)		
Aspect	**Weighting Out 100**	**Proposed Success Criteria**
Landform	35	Slope and Aspect: resembles pre mining situation and ties in with the surrounding landscape and drainage. Depth of remaining substrate: is >0.4m to basement. Microrelief: ripped mounds 10-15cm height and 0.4 – 2m apart. Top soil: covers at least 90% of the site at a depth of 15-30cm. Drainage: shallow sheet surface flow (<6cm in peak wet season flows), and <15% of the area features water ponding (>25cm deep).
Soil Stability & Ground Cover	25	Absence of active erosion or accelerated sediment movement % vegetation cover > 30% to supress erosion
Vegetation Structure	0	Strata - vegetation establishing in the ground layer Stem Density – no set benchmark Canopy Cover - no set benchmark
Species Composition	15	Vegetation species Composition: Species diversity for all associated and characteristic species – if readily identifiable from ground cover measures are establishing at a diversity which is >20% that of reference sites.
Disturbance:	25	Absence of weeds Absence of fire

Desired End Point: Rehabilitated or Restored Sandsheet Habitat		
Stage of Rehabilitation: 1-3 years after rehabilitation (following at least two wet seasons)		
Aspect	**Weighting Out 100**	**Proposed Success Criteria**
Landform	10	Microrelief: the vegetation is contributing to creating mounds 10-15cm height and 0.4– 2m apart. Drainage: Shallow sheet surface flow (<6cm in peak wet season flows), and <15% of the area features water ponding (>25cm deep).
Soil Stability & Ground Cover	20	Absence of erosion or accelerated sediment movement % Bare ground < 50% of average for reference sites % vegetation cover > 45% of average for reference sites % litter > 20% of the average for reference sites
Vegetation Structure	15	Strata: at least an upper and ground layer can be distinguished Total Stem Density: recovery > 35% of average for reference sites (Total Stem count for trees and shrub with a DBH >2cm divided by area for a 100m belt transect x 10m wide) Canopy Cover > 40% of the average for reference sites (unburnt) Canopy Height >30% of reference sites (unburnt)
Species Composition	30	Vegetation species Composition: Upper Strata: the diversity of Associated and characteristic species is > 50% the average for reference sites Ground layer: the diversity of associated and characteristic species is >35% the average for reference sites. Focal Species: present if previously present prior to disturbance – specific survey techniques will be required
Disturbance:	25	Absence of weeds Absence of fire

Desired End Point: Rehabilitated or Restored Sandsheet Habitat		
Stage of Rehabilitation: 5-8 years after rehabilitation (following at least five wet seasons)		
Aspect	**Weighting out of 100**	**Proposed Success Criteria**
Landform	10	Microrelief: The ground cover creates mounds 10-15cm height and 0.4 – 2m apart. Drainage: Shallow sheet surface flow (<6cm in peak wet season flows), and <15% of the area features water ponding (>25cm deep).
Soil Stability & Ground Cover	20	Absence of erosion or accelerated sediment movement % Bare ground < 30% of average for reference sites % Ground vegetation cover > 60% of average for reference sites % litter > 50% of the average for reference sites
Vegetation Structure	15	Strata: Three strata can be distinguished Upper, Mid and ground Total Stem Density: recovery > 50% of reference sites (Total Stem count for trees and shrubs with a DBH >2cm divided by area for a 100m belt transect x 10m wide) Canopy Cover > 50% of the average for reference sites (unburnt) Canopy Height Range >50% of the average for reference sites (unburnt)
Species Composition	30	Vegetation species Composition: Upper Strata: the diversity of Associated and characteristic species is > 60% the average for reference sites Ground layer: the diversity of associated and characteristic species is >50% the average for reference sites. Focal Species: present (if previously present prior to disturbance) over several years – specific survey techniques will be required
Disturbance:	25	Absence of weeds Fire frequency (< once every year)

Table 7-3 Proposed success criteria for the acceptable end point of a modified system consisting Melaleuca swamp and elements of Sandsheet at key stages for rehabilitation

Less Desired End Point: Modified System Consisting Melaleuca swamp and elements of Sandsheet		
Stage of Rehabilitation: 6-9 months after rehabilitation (following the first early first wet season)		
Aspect	**Weighting Out 100**	**Proposed Success Criteria**
Landform	35	Slope and Aspect: at least some areas (>10m^2) resembles pre mining situation and ties in with the surrounding landscape and drainage. Depth of remaining substrate: is >0.4m to basement Microrelief: Ripped mounds 10-15cm height and 0.4 – 2m apart. Depth of top soil: 15-30cm (for areas less likely to be regularly inundated). Drainage: no more than 40% of the site features water ponding or annual inundation to 0.4-1m deep. Areas intended to establish Sandsheet habitat features shallow sheet surface flow (<6cm in peak wet season flows).
Soil Stability & Ground Cover	25	Absence of active erosion or accelerated sediment movement % vegetation cover > 30% at least for areas which are not regularly inundated to supress erosion
Vegetation Structure	0	Strata - vegetation establishing in the ground layer for areas which are not regularly inundated to supress erosion Stem Density – no set benchmark Canopy Cover Range - no set benchmark
Species Composition	15	Vegetation species Composition: Species diversity for all associated and characteristic species – if readily identifiable are establishing at a diversity which is >20% that of reference sites (Melaleuca swamp and Sandsheet)
Disturbance:	25	Absence of weeds Absence of fire

Less Desired End Point: Modified System Consisting Melaleuca swamp and elements of Sandsheet		
Stage of Rehabilitation: 1-3 years after rehabilitation (following at least two wet seasons)		
Aspect	**Weighting Out 100**	**Proposed Success Criteria**
Landform	10	Microrelief: for areas which are not inundated regularly the vegetation is contributing to creating mounds 10-15cm height and 0.4– 2m apart. Drainage: areas which are not inundated regularly feature a shallow sheet surface flow (<6cm in peak wet season flows), No more than 40% of the total site area features water ponding (>25cm deep).
Soil Stability & Ground Cover	20	Absence of erosion or accelerated sediment movement % Bare ground < 50% of average for Melaleuca swamp reference sites % vegetation cover > 40%
Vegetation Structure	15	Strata: for inundated areas 1 strata and for areas which are not inundated at least 2 strata may be discernible - an upper and ground layer. Total Stem Density: recovery > 35% of average for reference sites (Total Stem count for trees and shrub with a DBH >2cm divided by area for 100m belt transect x 10m wide) Canopy Cover > 40% of the average for reference sites (unburnt) Canopy Height Range >30% of reference sites (unburnt)
Species Composition	30	Vegetation species Composition: Upper Strata: the diversity of Associated and characteristic species is > 50% the average for reference sites Ground layer: the diversity of associated and characteristic species is >35% the average for reference sites. Focal Species: present (if previously present prior to disturbance) over several years – specific survey techniques will be required.
Disturbance:	25	Absence of weeds Absence of fire

Less Desired End Point: Modified System Consisting Melaleuca swamp and elements of Sandsheet		
Stage of Rehabilitation: 5-8 years after rehabilitation (following at least five wet seasons)		
Aspect	**Weighting Out 100**	**Proposed Success Criteria**
Landform	10	Microrelief: Ripped mounds 10-15cm height and 0.4– 2m apart. Drainage: Shallow sheet surface flow (<6cm in peak wet season flows), <15% of the area features water ponding (>25cm deep).
Soil Stability & Ground Cover	20	Absence of erosion or accelerated sediment movement % Bare ground < 30% of average for reference sites % Ground vegetation cover > 60% of average for reference sites % litter > 50% the average for reference sites
Vegetation Structure	15	Vegetation strata: at least two strata is discernible for the areas reforming as Sandsheet Total Stem Density: recovery > 50% of average for reference sites (Total Stem count for trees and shrub with a DBH >2cm divided by area for 100m belt transect x 10m wide) Canopy Cover > 50% of reference sites (unburnt) Canopy Height >50% of reference sites (unburnt)
Species Composition	30	Vegetation species Composition: Upper Strata: the diversity of Associated and characteristic species is > 60% the average for reference sites Ground layer: the diversity of associated and characteristic species is >50% the average for reference sites. Focal Species: present (if previously present prior to disturbance) over several years – specific survey techniques will be required.
Disturbance:	25	Absence of weeds Fire frequency (< than once every year)

7.4 Reference Sites

Two primary vegetation types, Sandsheet vegetation type and Melaleuca swamp featuring elements of Sandsheet are both identified as the currently accepted key endpoints for rehabilitation. Success for rehabilitation needs to be compared against these vegetation types or any other vegetation type which is accepted as a desired endpoint (e.g. a vegetation type approximating Sandsheet).

The aim of establishing reference sites is to provide a benchmark for all attributes which can then be used to gauge whether the trajectory for individual rehabilitation sites is trending towards the desired or acceptable states. The reference sites need to be monitored over the longer term to discern the natural variability both spatially and temporally.

At least three reference sites should be established for both Sandsheet and the Melaleuca swamp vegetation types. Replication of reference sites for each major vegetation type should account for some of the variation in the landscape (e.g. soils, topography and moisture) and disturbance. A number of reference sites permits averaging values and therefore establishing acceptable upper and lower limits for some of the key attributes. Thresholds for some of the key attributes may be at least initially established from a selection of sites which were established for fine scale vegetation mapping (refer to Liddle, et al, 2012).

Fine scale mapping of the Howard Springs Sandsheet, a component of the Caring for Country Project (Extractives Industry Improved Response to Biodiversity for the Howard Springs Sand Plains), indicates that there are several subtypes of Sandsheet (Liddle, et al, 2012). To account for this variation; but depending on the resources available; it may be necessary to place a number of reference sites (at least 3) within each significant subtype.

It may not be possible to readily establish reference sites for the potential acceptable endpoint consisting of a mixture of Melaleuca swamp with elements of the Sandsheet vegetation type. The outcomes for this end point may need to be extrapolated from the reference sites for the two separate vegetation types. However, adjustments will need to be made for the quantitative values for the success criteria so as to account for the smaller area of Sandsheet (e.g. species diversity, stem density etc).

It is not possible to set up reference sites for the different phases of rehabilitation. However, some regular monitoring of a sample of rehabilitating sites (reflecting the spectrum of endpoints) may permit discerning key patterns of regeneration, particularly in the establishing phase. Monitoring of rehabilitation sites can lead to improved understanding of the ecology of a variety of species, as well as the process of succession over time, response to disturbance and what factors may help and hinder the rehabilitation process. In turn an improved understanding of the ecology can assist with future design of rehabilitation techniques and improve the types and values of the set success criteria.

7.5 Methods for Measuring Success Criteria

Given the proposed set of success criteria for different stages of rehabilitation (outlined in section 7.3) this section of the report suggests some standard methods for quantifying and measuring the range of success criteria associate with each vital attribute. The same methods are to be used for tracking change with the rehabilitation sites over time as those used to measure variation with the reference sites over time.

There is no one standard method for measuring the range proposed indicators of success for each of key attribute areas. However, a standardised approach will facilitate comparison between sites on a catchment scale and collective learning to refining the appropriate approach to rehabilitation.

The methods proposed below draw upon range methodologies which are more commonly used to measure landscape and vegetation change over time. A high priority has been place on rapid assessment techniques due the large number of sites requiring monitoring, the capacity and skills available and the costs involved compared to the cost of the commodity (sand). The following methods are a rough guide only and a pilot study of the overarching approach to rehabilitation is necessary to provide more detail as well as highlight improvements (including simplification) to the success criteria and also the methods for their measure.

7.5.1 Photo monitoring

Photo monitoring of sites both prior to disturbance, during site preparation and as rehabilitation progresses over time will greatly assist with tracking and interpreting landscape change as a consequence of mining practices. Photo monitoring involves setting up permanent points from which landscape photographs are taken on a regular basis for comparison over time. The reader is referred to the following reference (NRM,

2012) and other references for detailing how to establish photo monitoring sites. A key aspect to photo monitoring is ensuring the photographs are filed and archived for future use.

7.5.2 Site Dimensions and Context

The area of the rehabilitating site should be recorded so as to provide a means of calculating other parameters such as the percentage area featuring ponding. A review of the checklist for scoring habitat value and character (Table 6-1) carried out prior to disturbance can provide much of the context for the site. However, any surrounding disturbance needs to be updated, particularly if the distance to the nearest in intact Sandsheet habitat is affected.

7.5.3 Landform Features

Landform characters primarily need to be assessed in the very early stage of rehabilitation. Key aspects inclusive of the depth of the depression, slope, aspect and depth of remaining substrate, need only be measured once during the rehabilitation process. Depth of the depression (compared to the surrounding ground level), and slope (as a percentage) can be measured using a clinometer and the predominant aspect can be indicated using a compass.

Establishment of a shallow sheet flow of surface water can be judged largely from the above parameters but needs to quantified by estimating the area and percentage of the rehabilitating site for which this feature is establishing. In addition the percentage of the rehabilitating site featuring ponding and the depth of this ponding needs to be recorded.

The formation of the micro-topography consisting of mounds can be gauged using photo quadrat monitoring along the transect for qualifying soil stability and ground cover as outlined below. Alternatives to this method include recording mound formation (width and height) along the soil stability and ground cover transect. Further work is required to discern a rapid but effective approach to measuring this indicator.

7.5.4 Soil Stability & Ground Cover

Significant signs of erosion (such as riling and gullies) are best detected by visual assessment of the entire site and photographing and recording their location, character and likely cause.

Parameters for soil stability, ground cover and some indication of the ecological process forming over time can be measured using a landscape function analysis approach. This approach can entail a transect approximately 50m long, traversing down slope parallel to the aspect and placed centrally within the rehabilitation site. The location of the transect should be marked so the same transect can be measured over time. Along the length of the transect the width of patches (vegetation, logs, earthen mound and litter) and inter-patches (bare areas or stony soil) should be recorded continuously (refer to Figure 3-9 and Tongway & Hindley, 2004). The cover width (e.g. at right angles to the transect) and length (e.g. along the transect) as well as their type (plant species, litter or log) should be recorded for the patches.

The data collecting through this method can in part be used towards the measure of ground cover and bare ground as a percentage of the transect). The plant species contributing to the bulk of the ground cover can contribute to the measures for species composition.

7.5.5 Vegetation Structure and Composition

The following approach is recommended to capture most of the vegetation structural and compositional measures. To permit some historic comparison with the study by Price et al, 2005 establishing a 100m belt transect which is 10m wide, traversing along the diagonal of the site (down slope) is recommended.

Along the 100m transect 2 quadrats of 20m^2 (at one end and central to the transect) should be used to record the following:

- the number of strata (upper, mid and ground);
- the height range (upper and lower) and average for each strata using a clinometer or using set height intervals and vertical sighting tube to permit rapid assessment but maintain consistency; and
- the total canopy cover (estimated using some visual standards) and the canopy cover for all species contributing greater than 5% canopy cover within each strata.

The reader is referred to the Northern Territory Guidelines and Field Methodology for vegetation survey and mapping (Brocklehurst, et al, 2007) for further details on how to measure these parameters with consistency. However, some modifications may be required to ensure a rapid process.

Recording the canopy cover by species within each strata for each of the 20m^2 quadrats should be adequate to estimate the species composition with sufficient detail to indicate if the main groups of species are establishing.

The total stem count and basal area for wood species can be calculated (as per the method used by Price et al, 2005) whereby the all trees and shrubs with a diameter at breast height (dbh, 1.3m above ground level) greater than 1cm are recorded within the 10m belt transect, noting the species and dbh. The dbh for each stem is recorded for multi-stemmed species. It needs to be tested whether a method using four basal sweeps at 25m intervals along the transect using a basal wedge may prove to be more rapid and just as effective.

The basal area is calculated using the total Stem count for trees and shrub with a dbh>2cm divided by area for the 100m belt transect by 10m wide.

*Note: there is room to simplify the above monitoring procedures with further trials and experimentation with which parameters reveal the most critical aspects of the rehabilitation pathway.

7.5.6 Detection of Focal Species

Assessment for the presence of the focal species (The Howard River Toadlet, Utricularia and Typhonium species) will require the application of a specific survey protocol. If the disturbed site featured any of the focal species prior to disturbance, rehabilitation objectives should incorporate either retaining or re-introducing these species. The focal species are more likely to be responsive to the landform character, surface hydrology, micro-topgraphy and the ground layer vegetation which establishes.

7.5.7 Disturbance

Weeds species may be recorded opportunistically while inspecting for erosion and notes should be made of the species present, abundance and where they are situated on site. If weed species are common, the soil stability and ground cover (or land function transects) will give some indication of their overall contribution to the percent ground cover.

The fire history for the site should be recorded as indicated by an estimate of the time since the last burn, by scorch height on trees and condition of species which are susceptible to fire such as Grevillea pteridifolia.

7.5.8 Implications and Refinement of the Methods

The nature of the rehabilitating site, particularly if it features ponding will have a significant impact on the assessment methods and placement of transects. Further trials are necessary to determine how the assessment approach can be standardised when there is a high degree of variation in the resultant landforms. This problem will be removed if rehabilitation aims to eliminate ponding and ensure all sites are free draining.

The methods outlined above need to be trialled for efficiency and effectiveness using limited resources.

8 Develop Implementation Techniques

With the desired endpoints for rehabilitation established, a rehabilitation plan should document and present a layout map of the proposed rehabilitation works and a schedule for their timing. The rehabilitation plan should describe the techniques to be applied at various stages in the rehabilitation process with a particular emphasis on the early establishment, which includes landscaping, erosion controls and establishing vegetation. Table 3-3 provides a generic checklist of best practice rehabilitation methods. The rehabilitation plan should scope the possible undesired states which may result from rehabilitation efforts. The triggers for management intervention, should an undesired state result, and the consequential management response need to be documented.

Depending on the endpoints for rehabilitation which are elected, a degree of experimentation may be necessary to assist with scoping improvements to currently nominated best practice rehabilitation techniques. This experimentation should be factored into rehabilitation plans by detailing the on-ground work and the means of collecting and analysing the data. Particular areas which require further investigation include:

- The minimum retention of intact Sandsheet on site to assist with recruitment from these populations to the disturbed site;
- Management of top soil – particularly to maximise efficient use (e.g. effective storage to maximise viability of the plant propagules) and efficient use in the land forming process.
- Land forming techniques to achieve a free draining landform with a similar surface flow to the Sandsheet habitat; and
- Ripping and direct seeding to encourage a broad range of species to return early on in the rehabilitation process.

Where several sites, in close proximity to each other, may be undertaking rehabilitation in a similar time frame, it will be more effective if the individual rehabilitation plans are designed to complement each other. This can be accommodated by incorporating actions to reinstate values at the landscape scale as well as undertaking monitoring of success at a similar time.

8.1.1 Checklist of Management Strategies and Actions

To discern the history and practices applied for the rehabilitating mine site as well as triggers for further intervention the following table (Table 8-1), proposes a list of minimum management actions to be audited and provide context for the rehabilitating site. This context can assist with interpreting the results of monitoring the rehabilitation success criteria.

Table 8-1 Checklist of management strategies and actions for each auditing phase in rehabilitation

Rehabilitation Stage	Key steps	Checklist of Management Actions	Compliance		
			Yes	No	comments
Pre-disturbance	Pre-disturbance surveys	- *Pre-disturbance surveys have been applied if the tenement is within the vicinity of priority zone			
		- The character of the site is established so that rehabilitation outcomes can be informed			
		- Areas of Sandsheet Habitat (at least 5x10m) nearby (e.g within meters of the disturbance areas) to be left intact and serve as seed source are identified in the MMP.			
		- Minimal impact techniques to retain critical Sandsheet values (namely focal species and drainage patterns) are incorporated into the MMP and rehabilitation plan			
Disturbance phase	Buffers and areas of intact Sandsheet habitat	- Each borrow area is confined to an area of not more than one (1) hectare.			
		- Patches of Sandsheet habitat are left intact (particularly if they feature any of the focal species) to assist with recruitment from these areas to the rehabilitating site.			
		- #Natural vegetation strips not less than twenty-five (25) metres in width shall separate each borrow area from an adjacent area.			
	Stripping vegetation and top soil	- Vegetation is stripped post wet season (to avoid soil erosion concerns) and within two months of commencement of mining.			
		- The cleared vegetation is retained and stockpiled (in a cleared area not in the surrounding vegetation) for mulching upon site closure.			
		- If the cleared vegetation is burnt the ashes should be stockpiled separately for re-spreading with the topsoil			

Rehabilitation Stage	Key steps	Checklist of Management Actions	Compliance		
			Yes	No	comments
		- No less than and not more than 100mm of topsoil is be removed and stockpiled for rehabilitation.			
		- Top soil is removed at the time of greatest seed set, during the build-up (October to December).			
		- If the subsoil it to be removed in addition to the topsoil it is removed and stored separately.			
	Storage of top soil	- Top soil is stored away from drainage lines in low piles (preferably less than 1m).	-	-	-
		- Top soil is stored less than a year.	-	-	-
		- Topsoils and subsoil stocks are managed for weeds.	-	-	-
	Seed Collection	- Where appropriate seeds from nearby Sandsheet species (particularly the dominating upper and ground species) should be collected once the mine site is ready for rehabilitation and if there is scope for appropriate seed storage.	-	-	-
	Stabilise the site through the wet season	- If a site needs to shut down for a period during the wet season it is stabilised to avoid ponding and soil erosion.	-	-	-
		- Shaping sites matches the local topography to ensure the site it as free draining as possible.	-	-	-
		- Sediment traps are put in place to contain sediments from the stockpiles and pit.	-	-	-
Establishing Phase	Reconstruction of Landform – and road closure	- Immediately following completion of mining the site is reshaped and contoured to tie into the surrounding landscape with a particular emphasis on reinstating natural drainage patterning	-	-	-
		- The edges of the pit should be battered down to at least 3:1 (horizontal: vertical) (Applegate, 1983).	-	-	-
		- *Land shaping ensures that >60% of the site does not feature ponding.	-	-	-

Rehabilitation Stage	Key steps		Checklist of Management Actions	Compliance		
				Yes	No	comments
	Deep ripping	-	Sites are deep ripped to a depth of 1-1.5m, parallel to the contour, using a winged tyne with the tyne intervals less than 2m apart.	-	-	-
	Replacement of Topsoil	-	*Topsoil is evenly respread across the site at no more than 10cm thick, immediately after the deep ripping and then shallowly tyned along the contour to loosen the surface.	-	-	-
		-	*Where ponding may be unavoidable, topsoil allocated to these areas is either used for rehabilitating other pits nearby or experimented with creating some low broad mounds in the areas which will be less inundated.	-	-	-
	Direct Seeding	-	*Where native, and preferably locally provenance, seed stock is available this should be spread across the soil surface immediately following the seed bed preparation and preferably during the building up period (September to early December) (Setterfield, 1993).	-	-	-
		-	If direct seeding is used the mix reflect the land type or vegetation type to be re-established.	-	-	-
		-	Direct seeding applies at least 0.5-0.7kg of seed per ha is recommended (Setterfield, 1993).	-	-	-
	Fertilizer	-	*No recommendations until the value and impact is established*	-	-	-
	Disturbance Management	-	Fire breaks are established (ponding areas may function as fire breaks.	-	-	-
		-	The site is managed to eradicate all weeds	-	-	-
		-	The site is managed to avoid trampling by vehicles	-	-	-
1-3 Years & the Maturing Stage	Manage Disturbance	-	The site is manage to meet the fire frequency success criteria	-	-	-
		-	The site is managed to meet the weed success criteria	-	-	-

Rehabilitation Stage	Key steps	Checklist of Management Actions	Compliance		
			Yes	No	comments
	Monitor rehabilitation outcomes	- The site is monitored for rehabilitation success against the nominated criteria for the stage of rehabilitation development	-	-	-
	Assess rehabilitation progress against the success criteria	- Performance against the success criteria is evaluated for whether a need for further management intervention is triggered	-	-	-
	Respond to triggers for management intervention	- Triggers for management intervention are acted upon to steer the site towards the desired state.	-	-	-
	Document the lessons learnt	- Observations regarding response to management techniques is recorded	-	-	-
		- Observation regarding the successional patterns for plant species and ecological processes is documented	-	-	-

* Practices which are not currently listed in DOR's Site Practices Fact Sheet but are suggested by other studies or anecdotal information. Some of these management practices require further investigation and experimentation to determine their broad scale inclusion in best practice guidelines.

9 Monitor, Assess and Track Rehabilitation Practices & Outcomes

9.1 Tracking Rehabilitation at the Site Scale

Monitoring can be a costly exercise. However, if restoration is a primary goal it is essential to provide rapid feedback (particularly if further management is required to steer the reforming ecosystem in a desired direction) as well as increase the appreciation of the key drivers and ecological understanding which underpin success.

Monitoring should coincide with at least the first three phases in the rehabilitation process:

- First Establishing: 6-9 months;
- Establishing: 1-3 years; and
- Established: 5-8 years.

In addition to monitoring at the site scale, reference sites should also be monitored to provide the benchmarks for success over time.

It may be possible to reduce the costs of monitoring by a central service undertaking the reference site monitoring to provide dynamic benchmarking over a longer time frame.

9.2 Score Carding Parameters of Success

A score card approach aims to amalgamate the results for the diversity of success criteria across all vital attributes into a single score. A potential scoring process (suggested in Table 9-1 below) is based upon a scoring system used by the habitat hectares assessment method (Parks, et al, 2003) and a system used by Koch and Hobbs, 2007. It utilises a percentage assessment for meeting all success criteria for a vital attribute area (e.g. if 3 out of 4 criteria are met the percentage is 75%) and applying a weighting to the percent score for this aspect, to reflect its significance of the vital attribute for the particular phase of rehabilitation (refer to section 7.3) and then tallying the total score. The maximum score possible is 100. This weighted scoring process enables a relative comparison between sites. Score carding coincides with the key phases in the rehabilitation process.

9.3 Triggers for Management Intervention

Thresholds of performance against individual success criteria or the overall score (using the score card approach) can delineate triggers for further management intervention. For instance any failure against the success criteria for weeds should trigger a management intervention.

The first 6-9 months for a rehabilitating sites (the first build up or wet season experienced) is most critical as the foundations of landform and stability, absence of ponding (where possible) erosion and weeds are critical to all prospective biodiversity outcomes. Early intervention within the first year is likely to pay considerable dividends in reduced maintenance costs and maximising biodiversity results with minimal input. Failure to meet the success criteria within the first year of rehabilitation should trigger a need to review the land formation of rehabilitating site and possibly the general approach to this stage in rehabilitation.

Figure 9-1 Potential site scoring process using multiple weighted parameters using an example for the 0-9 month phase in rehabilitation

No.	Vital Attribute	Success Criteria	Max score 100%	Actual Score	Weighting (out of 100) *(refer to 6-9 Months phase)*	Weighted score
1.	Landform	Meets all Landform success criteria for the 6-9 months phase of rehabilitation	100% Meets all success criteria for Landform	x	35	Weighting by actual score (e.g. 0.75 x35)
2.	Soil Stability & Ground Cover	Meets all Soil Stability and Ground Cover success criteria for the 6-9 months phase of rehabilitation	100% Meets all success criteria for Soil Stability and Ground Cover	x	25	
3.	Vegetation Structure	na	na	x	0	
4.	Species Composition	Meets minimum level of species diversity for the 6-9 months phase of rehabilitation	100% Meets all success criteria for Species composition	x	15	
5.	Disturbance:	Acceptable levels of disturbance for the 6-9 months phase of rehabilitation	100% Meets all success criteria for disturbance	x	25	
Total Score						The maximum score is 100

*Note the weighting and % judgement for meeting the success criteria needs to be adjusted as per the phase of rehabilitation refer to tables Table 7-2 and Table 7-3.

9.4 Tracking Rehabilitation at the Landscape Scale

It will be beneficial to track rehabilitation at the landscape scale and indicate what endpoints are desired in particular locations and whether these sites are on track to meeting the matching success criteria for these endpoints. This type of information could be recorded using a GIS framework. Such a mapping framework would need to be dynamic as sites will transition between phases of establishment over time. Sites which are not performing well can be highlighted for management intervention, or it can be clearer which areas are deemed to have changed to a less desired state and therefore the effect on the overall catchment goals for sustaining a healthy network of intact Sandsheet habitat.

9.4.1 Mapping Rehabilitation Progress at the Landscape Scale

Mapping of the status of rehabilitation for tenements in reference to their elected endpoint can provide as a means of tracking the degree of disturbance and progress with rehabilitation across the whole landscape. Prior to ranking a tenement they should be mapped and coded for the elected rehabilitation endpoint. Table 9-1 details a proposed means of mapping and ranking sites for their progress with rehabilitation.

Because the first 9 months is critical to the success of all preceding stages of rehabilitation (because eit includes the one off process of land shaping and laying of top soil –which cannot be readily adjusted) it is suggested that all success criteria are met in this stage to be deemed successful.

Table 9-1 Mapping classification for rehabilitation outcomes

GIS Coding	Rehabilitation Stage	Category of Rehabilitation	Description
1	Establishing (6-9 months)	Establishing according to identified success criteria for the early phases of rehabilitation	All success criteria are met – weed free.
2a	Establishing (1-3 years)	Establishing according to success criteria for establishing years (1-3)	Scores >80% most success criteria are met – weed free. No remedial work was required for the establishing 6-12 months phase
2b	Establishing (1-3 years)	Establishing according to success criteria for establishing years (1-3) post remedial work.	Scores > 80% most success criteria are met – weed free. Remedial work required within the 6-12 months phase.
3a	Established (5-8 years)	Established according to success criteria for establishing years (5-8)	Scores > 80% most success criteria are met – weed free. No remedial work was required for the establishing 1-4 years.
3b	Established (5-8 years)	Established according to success criteria for establishing years (5-8) post remedial work.	Scores >80% most success criteria are met – weed free. Remedial work required for the establishing 1-4 years.
4a	Complete > 8 years	Established according to success criteria	Scores >80% most success criteria are met – weed free.
4b	Complete > 8 years	Established according to success criteria but resilience is compromised	Scores >80% most success criteria are met – but resilience is compromised with the presence of surrounding weeds or other excessive disturbance.
Undesired States			
D0	Disturbed (0 months or more)	Disturbed site which has not yet had the basic rehabilitation techniques applied.	Basic rehabilitation techniques have not been applied (refer to checklist Table 3-3)

GIS Coding	Rehabilitation Stage	Category of Rehabilitation	Description
UD1	Undesired Establishing State 1a (6-9 months)	Not establishing according to success criteria requires remedial work	1 or more success criteria are not met indicating a need for remedial work
UD2a	Undesired Establishing State 2a (1-3 years)	Establishing according to success criteria but requires weed or fire management	Scores >80% most success criteria are met – but weeds are present and or excessive fire or other disturbance. Management of threatening processes is required to realign with success criteria.
UD2b	Undesired Establishing State 2b (1-3 years)	Not establishing according to success criteria for 1-3 years requires remedial work	Scores < 80%– Further landform management is required (e.g. soil erosion measures) or further planting is required along with management of threatening processes such as weeds and fire
UD3a	Undesired Established State 1a (5-8 years)	Establishing according to success criteria for 5-8 years but requires weed or fire management	Scores >80% most success criteria are met – but weeds are present and or excessive fire or other disturbance. Management of threatening processes is required to realign with success criteria.
UD3b	Undesired Established State 1b (5-8 years)	Not establishing according to success criteria for 5-8 years requires remedial work	Scores <80% – Further landform management is required (e.g. soil erosion measures) or further planting is required along with management of threatening processes such as weeds and fire
UD4a	Undesired Complete State >8 years	Establishing according to success criteria but requires weed or fire management	Scores >80% most success criteria are met – but weeds are present and or excessive fire or other disturbance. Management of threatening processes is required to realign with success criteria.
UD4b	Undesired Complete State >8 years	Not established according to success criteria	Scores <80% Unlikely to meet fully meet all success Criteria.
UD	Requires significant intervention to realign with success criteria		

10 Review and Adapt

10.1 Review and Adapt at the Site Scale

Rehabilitation outcomes can be refined for individual sites, in a timely manner, with regular review of the progress against the success criteria for each key stage in the rehabilitation process. If the assessment indicates a deviation away from the desired state this should alert the manager to refer to triggers for management intervention and implement the allocated response as scoped in the rehabilitation plan. The most critical phase to review progress with the site is at the land forming stage.

If the need for management intervention is regularly triggered for several sites, and particularly at the land forming stage, this should indicate the need to review whether the rehabilitation plan is being implemented correctly or whether it is the rehabilitation methods in general which need to be revised.

10.2 Review and Adapt at the Landscape Scale

Tracking progress with rehabilitation outcomes at the landscape scale (using the scoring process or other means) can inform whether the Landscape goals for conservation and thresholds of disturbance are still appropriate or whether they need to be altered. Continual low performance for rehabilitation against landscape goals may suggest a need to target areas for improvement or a need to revise the thresholds of disturbance if the quality of rehabilitation cannot be improved.

10.3 Review and Adapt the Framework

Rehabilitation and restoration is a complex process and especially so when:

- the ecological knowledge features substantial gaps; and
- the management context is complicated by the need for a high level of performance yet the economy and skills of the impacting industry cannot afford a high level of research and sophistication.

Any effective approach to guiding ecosystem restoration and rehabilitation needs to be dynamic and refined over time to keep pace with the ever changing context and extension of knowledge. The overarching approach to improving rehabilitation outcomes, along with its key components need to be regularly reviewed and refined over time.

A methodical approach to restoration and rehabilitation permits scoping studies and experimentation to fill vital knowledge gaps either about the ecology of the ecosystem, practical rehabilitation techniques and also management systems. This knowledge can then be used to refine the overarching framework and body of knowledge and consequently shared amongst the industry as a whole.

10.3.1 Recommended Pilot Study

The proposed overarching approach to improving rehabilitation outcomes for the sand extractive industry in the Howard Sand Plain Site of Conservation Significance is presently a conceptual model which has not been trialled for its practicality and efficiency. This study recommends that the proposed framework is piloted, at least in part, within some prime conservation areas for the focal species. However, it is accepted that removal of the bauxite duricrust means the reforming ecosystem will never be the identical to the pre-mining state but is likely to be a modified Jarrah forest.

However it is accepted that removal of the bauxite duricrust means the reforming ecosystem will never be the identical to the pre-mining state but is likely to be a modified Jarrah forest.

These priority areas are where the outcomes for rehabilitation most need to be improved through minimal impact and effective rehabilitation practices.

The following components are some of the critical first steps to progressing refinement of an overarching framework:

- Defining endpoints for rehabilitation based on refined landform criteria and techniques and particularly a plausible outcome which features an absence of ponding and vegetation type closer that of Sandsheet habitat;
- Setting the minimum area of intact Sandsheet which should be retained in the vicinity of mine sites to ensure adequate recruitment of Sandsheet Species and the degree of connectivity of these retained areas to nearby areas of Sandsheet to retain their viability.
- Experimenting with and refining land forming techniques to achieve a free draining landform with a similar surface flow to the Sandsheet habitat;
- Refining an approach using ripping and direct seeding to encourage a broad range of species to return early on in the rehabilitation process and also reinstating a micro-topography (of small mounds) which is a common feature of Sandsheet;
- Optimal topsoil management (e.g. storage time and utilisation on site after the land forming process);
- Refining the ecological knowledge of the key species contributing to reformation of Sandsheet habitat and factors contributing to their establishment and succession over time;
- Testing the range of success criteria proposed in this framework to ensure the approach is simple yet effective;
- Testing monitoring methods for the success criteria to maintain effective feedback but maximise the efficiency with limited finances, time and labour involved;
- Establishing clear triggers for when further management intervention is required and particularly within the first 9 months of establishment;
- Responding with appropriate management action if monitoring indicates a deviation away from the desired state and triggers a need for further intervention; and
- Establishing clear timeframes and expectations for when the responsibility for rehabilitation outcomes may be considered complete.

Several of these components may be explored at once and refined through some coordinated and experimental trials.

The trials and framework may be best reviewed and refined with the input of a multi-skilled team consisting of those with both practical and technical expertise.

11 Conclusions

The six step assessment framework outlined in this report is intended to provide a guide to developing a standardised and systematic approach to improving the biodiversity outcomes for the sand extractive industry as a whole. The approach aims to build linkages between the landscape scale of conservation through to the sites scale and it brings together several components (scientific knowledge, practical management practices and feedback through monitoring) into a complete system. A key purpose to this framework is to strengthen practices through setting goals and benchmarks and learning through experience.

At the landscape scale there is a need to discern conservation goals and tolerances to disturbance for the Howard Sand Plain Site of Conservation Significance. More work is required and the whole of landscape scale to set minimum thresholds of intact system (with a considerable buffer) which is necessary to retain the core conservation values and the essential ecological processes (e.g. water and nutrient flows) at a range of scales (catchment wide to sub-catchments). In the interim the suite of subprojects undertaken through the Caring for Our Country Grant has identified some priority areas for conserving the key focal species. In these locations extractive operators should aim to place a high priority on pre-disturbance assessment for the focal species, identify areas which should not be disturbed and target rehabilitation for restoration rather than rehabilitation.

At the site scale some generic improvements can be achieved by all operators through applying following:

- Assessment of sites prior to disturbance to document habitat quality and key ecological processes (e.g. surface and ground flows) to inform potential impacts and management objectives.
- Apply minimal impact techniques for to retain conservation values at the first instance such as retention of pockets of intact Sandsheet habitat in the near surrounds to assist with species recruitment.
- Scope and set realistic end states for rehabilitation and measures of success. In addition where possible support a collaborative or an aggregated approach to rehabilitation objectives and actions (e.g. where several disturbed areas are nearby ensure the rehabilitation goals are complimentary).
- Manage and utilise topsoil stocks efficiently and so as to retain the maximum viability of seeds and propagules;
- Apply, experiment with and refine the best practice techniques to achieve the selected closure criteria. In particular avoid end land formations which result in ponding ;
- Apply a collaborative fire, weed management and off road vehicle management;
- Monitor rehabilitation progress at the site scale and implement remedial action if a less desired state results; and
- Share new learning and knowledge to improve the rehabilitation practices and the overarching approach.

At present the overarching framework to improving rehabilitation and the individual components presented in this report are a conceptual model only. The approach is by no means definitive and there is the need for a pilot study to determine how key areas can be best refined to produce a lean but effective means to facilitating continual learning and on-going improvement to rehabilitation practices for biodiversity outcomes.

A multi-skilled team may be the best means of guiding the next steps and review of this framework.

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