Environmental & Social Consultants

Establishing Self-sustaining and Recognisable Ecological Mine Rehabilitation

AN ACARP FUNDED RESEARCH PROJECT
(ACARP PROJECT C27038)

December 2021

FINAL

ESTABLISHING SELF-SUSTAINING AND RECOGNISABLE ECOLOGICAL MINE REHABILITATION

An ACARP funded Research Project

FINAL

Prepared by

Umwelt (Australia) Pty Limited

on behalf of

The Australian Coal Association Research Program

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Report No.	4218/R01
Date:	December 2021

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Document Status

Rev No.	Reviewer		Approved for Issue	
	Name	Date	Name	Date
1	Travis Peake	1 October 2020	Travis Peake	8 October 2020
2	Travis Peake	23 November 2021	Travis Peake	23 November 2021
3	Travis Peake	20 December 2021	Travis Peake	21 December 2021

Authorship and Citation

This report was prepared by Travis Peake, Trish Robinson, Belinda Howe and James Garnham, with significant contributions by Liza Hill and Amber Wilson and review by Ruth Tapp.

Suggested Citation: Peake, T., Robinson, T., Howe, B. and Garnham, J. (2021) Establishing Self-sustaining and Recognisable Ecological Mine Rehabilitation.

Executive Summary

Introduction

In recent years, there has been an increasing focus from both mining companies and regulatory authorities on the establishment of mine rehabilitation which achieves a certain level of ecological recognisability and function. In some instances, there have been requirements for rehabilitation to meet the diagnostic characteristics of certain vegetation types, threatened and non-threatened. Additionally, legislation in NSW currently provides a pathway for ecological mine rehabilitation to contribute to the biodiversity offsets for new mining projects due to its potential contribution to conservation outcomes in a locality and assumed long-term persistence. Recent progression in environmental legislation, along with accompanying policy and guidelines, is evidence that there is a push within the NSW, Queensland and Commonwealth governments, and likely elsewhere, to allow the use of mine rehabilitation as a biodiversity offset, in the right circumstances. However, there is currently a lack of knowledge and adequate research about the likely success of ecological mine rehabilitation in relation to self-sustainability and recognisability as a documented vegetation community.

Recent studies undertaken by Umwelt indicate that some areas of mine rehabilitation in the NSW Hunter Valley are meeting, or trending towards achieving, the diagnostic criteria of a critically endangered ecological community (CEEC) listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), despite no requirement to achieve such.

This project, undertaken in collaboration with NSW Department of Planning, Industry and Environment (DPIE), focused on determining if mine rehabilitation can form a self-sustaining, recognisable vegetation community using the NSW Hunter Valley as a case study. The Hunter Valley was selected due to the presence of multiple state-listed threatened ecological communities (TECs) and one associated Commonwealth-listed CEEC, within the coal mining district. Umwelt focused primarily on collecting data for the recognisability component of the study while DPIE (Oliver and Dorrough 2019) focused on the self-sustainability component. As such, this report focuses on the recognisability methods, results and discussion, and reports on the overall findings of the self-sustainability component. The full DPIE report is appended.

This study was undertaken in two separate stages. The first stage comprised the literature review, desktop assessments, survey design, collection of data utilising the current PCT classification for NSW, initial analyses and reporting. During the data analysis process, a sub-set of information relating to the forthcoming eastern NSW (ENSW) Plant Community Type (PCT) Classification was provided by DPIE, which, at the time of writing, is due for public release in early-2022. Part of the data provision included access to the draft PCT Assignment Tool developed by DPIE.

A draft report, containing proof-of-concept approaches to assessing PCT recognisability based on a sub-set of the ENSW PCT Classification, was provided to ACARP and industry monitors in October 2020. The second stage of the project involved a re-run of analyses which tested the proof-of-concept approaches, this time utilising the entire ENSW PCT Classification dataset and updating the report to refer to the new PCT names and numbers, to ensure currency at time of report finalisation. In addition to addressing comments received on the first draft report, this stage also included consultation with DPIE and the NSW Resources Regulator regarding rehabilitation objectives, performance indicators and completion criteria for ecological mine rehabilitation. This consultation resulted in some modifications to the assessments of recognisability and self-sustainability for the purposes of assessing the success, or otherwise, of ecological mine rehabilitation. The appended DPIE report of Oliver and Dorrough (2019) remained static through the two stages of the project, however consultation with the authors was ongoing.

Purpose and objectives

The aim of this research project was to determine whether specific ecological communities can be established in mine rehabilitation, such that they are recognisable, as well as self-sustaining. The following objectives were set to achieve this aim:

1. Determine whether mine rehabilitation can support recognisable and self-sustaining ecological communities in Australian temperate woodland environments.
2. Determine whether mine rehabilitation can support a self-sustaining ecological community that is recognisable as the EPBC Act-listed *Central Hunter Valley Eucalypt Forest and Woodland CEEC* and related TECs listed under the NSW *Biodiversity Conservation Act 2016* (BC Act).
3. Determine whether mine rehabilitation can support habitat for a range of threatened fauna species, including birds and mammals.
4. Develop a set of principles to inform the establishment of appropriate rehabilitation objectives, performance indicators and completion criteria for the establishment of recognisable and self-sustaining ecological communities (focusing on temperate woodlands).
5. Provide guidance to industry to inform the establishment of benchmark successional stage criteria and a monitoring program to guide progressive ecological rehabilitation success or adaptive management.

Methods

A desktop analysis was undertaken to collect relevant information from nine coal mines in NSW and Queensland to identify any statutory requirements to establish specific vegetation types as part of current mining approvals. Existing data was collated to determine whether there is any evidence that these mines have been able to achieve, or are on a trajectory toward achieving, recognisable and self-sustaining ecological communities in their rehabilitation areas. The desktop analysis also included the collation of threatened fauna species records from rehabilitation monitoring reports.

Field surveys were conducted between March and May 2019 in the NSW Hunter Valley, during which 45 rehabilitation sites and 48 reference sites were sampled. Rehabilitation data were collected at five open cut coal mines, which were also subject to desktop analysis, and reference site sampling was undertaken in remnant vegetation situated on land managed by the same mines (plus one nearby mine) as well as one conservation area. Data was collected in accordance with the Biodiversity Assessment Method (BAM), a standard sampling approach utilised in NSW, which includes attributes that measure composition, structure and function of an ecological community. Function was also assessed using Landscape Function Analysis (LFA), litter, soil microbiology, soil chemistry, leaf sampling and the presence of flowering and fruiting of flora species.

As previously stated, the timing of this project coincided with a foreshadowed transition from one PCT classification system to another in NSW. At the time of survey, five original PCTs were targeted for sampling (PCTs 1601, 1603, 1604, 1655 and 1691) due to their relationship with three threatened ecological communities (TECs) listed under the BC Act and one listed under the EPBC Act. Following the provision of access to the revised ENSW PCT Classification by DPIE for use in this study, including a draft online PCT Assignment Tool, all sampled sites were allocated to PCTs of the new classification, which resulted in three target ENSW PCTs being identified as equivalent to the original target PCTs, and associated with the target TECs. These were PCT3315 Central Hunter Ironbark-Spotted Gum Forest, PCT3485 Central Hunter Slaty Gum Grassy Forest and PCT3431 Central Hunter Ironbark Grassy Woodland.

The recognisability of rehabilitated sites was assessed in terms of *composition* and *structure*, as well as at the levels of PCT and TEC, which were separated further according to whether the TEC is listed under the BC Act or the EPBC Act. Several analyses were undertaken to assess the compositional and structural recognisability of rehabilitated sites at the PCT level, including comparison to PCT profiles, reference sites and benchmarks, as well as utilising the draft PCT Assignment Tool. Documents that describe the TECs under the BC Act and EPBC Act, being the Final Determinations and Approved Conservation Advices, respectively, were reviewed to identify the key diagnostic characteristics and condition thresholds which must be met for an ecological community to be regarded as recognisable as a particular TEC. The data from rehabilitated sites was analysed accordingly.

Assessments of self-sustainability, or those that focused on *function*, were undertaken by DPIE (Oliver and Dorrough 2019). The assessments were undertaken on the assumption that reference sites are self-sustaining while young rehabilitation sites (<10 years old) are not likely to be self-sustaining. A total of 23 datasets, including 84 variables collected by DPIE and Umwelt, were considered in analyses. Following data reduction, assessments of variable importance and cost-benefit analysis, a probabilistic determination was undertaken to determine whether any rehabilitation sites were likely to be self-sustaining or approaching self-sustainability.

Finally, the outcomes of the recognisability and self-sustainability assessments were used to inform the development of draft rehabilitation objectives, performance indicators and completion criteria for ecological mine rehabilitation, with the goal of using measures that are cost-effective, utilise standard approaches and produce results that are easily interpreted.

Results

The results of the desktop review indicate that the rehabilitation sites located at the seven NSW mines investigated could be developing towards recognisable plant communities. Based on the information available for two Queensland mines subject to the desktop review, there is little evidence that the mine rehabilitation will develop toward recognisable plant communities in the absence of management intervention due to low native flora species diversity. For all seven mines investigated, based on the desktop review alone, there was not enough information available to determine whether the rehabilitation was likely to be trending toward self-sustainability. However, the desktop review confirmed that threatened fauna species are utilising the habitats present in rehabilitation at several Hunter Valley coal mines.

Using the outputs of the draft PCT Assignment Tool, 45 out of 48 (94%) reference sites were assessed as *very strongly* recognisable as the 'best fit' PCT compared with 15 out of 45 (33%) of rehabilitation sites. A further three (6%) reference sites and nine (20%) rehabilitation sites were assessed as *strongly* recognisable. There was found to be no correlation between the age of rehabilitation and the level of compositional recognisability.

A higher level of recognisability was observed at sampling sites that recorded higher numbers of species from the draft PCT profiles. Similarly, sites which recorded higher numbers of native species in common with reference sites, also recorded a higher level of recognisability.

The results from the structural recognisability analysis at the PCT level indicate that ecological mine rehabilitation can achieve vegetation structure comparable to intact vegetation when each attribute is assessed individually. However, no sites were identified as *very strongly* or *strongly* recognisable for all nine structural attributes (per cent foliage cover of four dominant growth forms (native grass and grass-like, forb, shrub and tree); and tree stem abundance within the five smallest DBH size classes (<5 cm, 5-9 cm, 10-19 cm, 20-29 cm and 30-49 cm)). The structural recognisability results of this study were variable for all 45 rehabilitation sites. The majority (69%) of rehabilitation sites recorded all four levels of structural recognisability across the nine attributes, from *weak* to *very strong*, while 29% recorded three levels of recognisability and a single site recorded two levels of recognisability.

The assessment of a rehabilitation site's recognisability as a TEC was relatively straightforward where the documents that describe the listed entity contain prescriptive criteria that must be met, which is often the case for EPBC Act listed TECs. Applying the EPBC Approved Conservation Advice resulted in 40% of rehabilitation sites being assessed as recognisable as the *Central Hunter Valley Eucalypt Forest and Woodland CEEC*. Assessing the recognisability of the rehabilitation sites as TECs listed under the BC Act is not as straightforward as assessing the CEEC listed under the EPBC Act, the latter being supported by more prescriptive diagnostic criteria and condition thresholds. A *canonical analysis of principal coordinates* (CAP) identified that 92% of reference sites and 57% of rehabilitation sites allocated to PCT3315 most strongly aligned with the *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* and 100% of reference sites and 64% of rehabilitation sites allocated to PCT 3431 most strongly aligned with *Central Hunter Grey Box – Ironbark Woodland EEC*. In contrast, the CAP identified that only 25% of reference sites and 20% of rehabilitation sites allocated to PCT3485 were most strongly aligned with *Hunter Valley Footslopes Slaty Gum Woodland VEC*. The low percentages recorded are most likely due to the provision of only a small number of plots which are representative of the VEC (n = 4), which indicates that this was a not a reliable approach to assessing recognisability.

Recognisability as TECs listed under the BC Act was further explored using an analysis of the proportion of characteristic species listed in the Final Determination for each TEC which were present at each site, compared to the proportion recorded at plots which form part of the vegetation mapping units which are cited in the Final Determinations as being representative of the TECs. All reference and rehabilitation sites allocated to PCT3315 recorded proportions within the range observed at cited *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* plots. For PCT3431, 94% of reference sites and 54% of rehabilitation sites fell within the range of values recorded at cited *Central Hunter Grey Box – Ironbark Woodland EEC* plots. However, only 33% of reference sites and 10% of rehabilitation sites were within the range of proportions recorded at cited *Hunter Valley Footslopes Slaty Gum Woodland VEC* plots. Further investigation revealed that the cited TEC plots were collected from a shrubby form of the community (which has also presumably influenced the species assemblage provided in the Final Determination), which was structurally and floristically different to the plots sampled for this study.

The self-sustainability analyses identified two rehabilitation sites (both 21 years old) that were likely to be self-sustaining to the same extent as reference sites and a third site (12 years old) which was assessed as approaching self-sustainability (Oliver and Dorrough 2019). Nine variables were identified by Oliver and Dorrough (2019) as potential performance indicators for measuring self-sustainability at rehabilitation sites. These variables are:

1. litter cover (BAM function)
2. coarse woody debris (CWD) (BAM function)
3. exotic species cover (BAM function)
4. number of native plant species flowering/fruiting (addition to BAM floristics)
5. total organic carbon (MIR or LECO)
6. fungal:bacterial biomass (PLFA)
7. total microbial biomass (PLFA)

8. number of native plant species (BAM floristics)
9. nutrient cycling index (LFA).

Oliver and Dorrough (2019) also recommended the inclusion of tree recruitment as the tenth potential performance indicator, which was omitted from analysis due to miscommunication about data availability.

Development of ecological rehabilitation objectives and completion criteria

Several performance measures were identified as suitable in assessing the compositional and structural recognisability of ecological mine rehabilitation as target vegetation types, including:

- the use of the PCT Assignment Tool
- the presence of species listed in a Final Determination, in appropriate density and strata (for TECs listed under the BC Act)
- direct application of the diagnostic and condition criteria provided in an Approved Conservation Advice (for TECs listed under the EPBC Act)
- cover of specific growth forms, and
- tree abundance.

Additional measures were assessed as potentially suitable, depending on the specific circumstances. Potential self-sustainability (function) performance measures identified by Oliver and Dorrough (2019) were further investigated as part of this study, and the majority of those identified were assessed as suitable for use in completion criteria. Reasons for measures not being recommended for inclusion in completion criteria related to the duplication of a compositional recognisability measure, the potential physical and cost impracticalities of emplacing CWD across rehabilitation areas, and potential challenges in data collection and analysis.

Proposed rehabilitation objectives, completion criteria and performance indicators for ecological mine rehabilitation were developed using the results of this study, to assist with the development of more prescriptive project-specific completion criteria, based on the target vegetation types to be established in rehabilitation. This study identified that the requirement to meet all the completion criteria relating to *structure* and *function* may be unnecessarily prohibitive for these reconstructed ecosystems, therefore an approach is proposed where a select proportion of completion criteria should be met for the corresponding rehabilitation objective to be satisfied.

Conclusions and recommendations

A range of conclusions were drawn from the study, including the applicability of the draft PCT Assignment Tool, developed by DPIE, in identifying the most similar PCTs to the sampled vegetation, as well as providing a measure of similarity that can be readily incorporated into analyses of PCT recognisability. The use of 'secondary' ENSW Classification plots to develop 'strong', 'moderate' and 'weak' levels of recognisability also shows promise. Using these approaches, it was found that mine rehabilitation can support ecological communities which are recognisable as three different PCTs in the NSW Hunter Valley and the results are promising in relation to the likelihood of establishing recognisable ecological rehabilitation elsewhere in temperate woodlands in Australia.

Several potential performance indicators were identified as suitable for assessing structural recognisability at the PCT level, including cover of specific growth forms and tree abundance. The results for foliage cover of tree species and tree stem counts by size class also highlighted the need to consider both attributes when assessing the upper strata of rehabilitation, in order to identify situations where tree density may be higher than optimal. Furthermore, the requirement for a rehabilitation site to meet each individual performance measure was identified as potentially too prohibitive for reconstructed ecosystems. The results also indicated that the class level benchmarks applied as part of the BAM (including those for drought affected vegetation) were unsuitable performance indicators across all three target PCTs.

Substantial differences to assessing the presence of TECs listed under the EPBC Act and BC Act exist, as demonstrated by this project. The way TECs are legally defined and described largely determine the criteria and attributes of the community that can be used to assess recognisability at this level. For TECs listed under the BC Act, descriptions contained in Final Determinations typically include a level of flexibility so as to accommodate natural variability that exists within communities. In contrast, the prescriptive diagnostic criteria and condition thresholds that typically exist for EPBC Act listed TECs, such as those contained in Approved Conservation Advices, generally leave little room for interpretation.

The assessment undertaken by Oliver and Dorrough (2019) showed that ecological mine rehabilitation could achieve levels of self-sustainability over a 21-year timeframe, and show strongly positive trends over much shorter periods. A range of variables were tested, and further refined to take into account their practicality and cost-effectiveness. From their assessment, this report suggests five performance measures for inclusion in ecological rehabilitation objectives and completion criteria.

Failure to meet or exceed a completion criterion would indicate that additional time or management intervention is required, depending on the attribute. However, Oliver and Dorrough (2019) demonstrated that a site may not perform well for every functional attribute measured, but it can still be assessed as achieving, or approaching, self-sustainability.

The ecological rehabilitation objectives and completion criteria put forward in this report are expected to be a useful starting point for the regular and accurate quantitative assessment of performance. Refinement will be required to take into account locally-occurring plant communities, TECs and target project outcomes, and ensure application to each specific setting. The principles established by the objectives, performance indicators and completion criteria should be applicable across temperate Australian woodlands, particularly NSW and Queensland.

A range of recommendations have been proposed to support mines to maximise the possibility of achieving recognisable and self-sustaining ecological communities in mine rehabilitation. Recommendations for further investigations are also presented, based on data gaps that could not be addressed by this study.

Glossary

BioBanking Assessment Method (BBAM)	A method established under section 127B of the *NSW Threatened Species Conservation Act 1995* for assessing biodiversity on a subject site in NSW (prior to the introduction of the Biodiversity Assessment Method, which has replaced BBAM).
Biodiversity Assessment Method (BAM)	A method established under section 6.7 of the *NSW Biodiversity Conservation Act 2016* for assessing biodiversity on a subject site in NSW.
Bootstrapping	A statistical random sampling with replacement method used to assign measures of accuracy to sample estimates by constructing a number of re-samples in a dataset.
Completion criteria	Target levels, values or standards that are measured to quantitatively demonstrate the progress and success of a biophysical process, as stated in the Rehabilitation Management Plan for the mine site (Department of Planning and Environment 2018).
Direct seeding	A method commonly used in mine site rehabilitation establishment. This method involves taking a seed mix and broadcasting it evenly and randomly onto newly formed landscapes.
Ecosystem credit	Under the BAM, a measurement of the value of threatened ecological communities, threatened species habitat for species that can be reliably predicted to occur with a Plant Community Type (PCT), and PCTs generally. Ecosystem credits measure the loss in biodiversity values at a development site and the gain in biodiversity values at a biodiversity stewardship site.
Environmental offset	Measures that compensate for the residual adverse impacts of an action on the environment. Offsets provide environmental benefits to counterbalance residual impacts (Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) 2012).
Final land use	The final land use(s) and landform(s) on a mine site following the completion of rehabilitation (Department of Planning and Environment 2018).
Foliage cover	The percentage of the sampling area (e.g. plot) covered by a vertical projection of all attached plant material of all individuals of a species (DPIE 2020a).
Function (ecosystem)	An ecosystem's dynamic attributes, including interactions between its biotic and abiotic components (SER 2004). Examples include nutrient, water and energy cycling through the ecosystem.
Groundcover	Refers to foliage cover of attached living vascular vegetative material within the ground stratum (DPIE 2020a).
Growth form	The form that is characteristic of a flora species at maturity, as defined by the BAM. The BAM has six growth forms to which all species native to NSW have been allocated: tree (TG), shrub (SG), grass and grass-like (GG), fern (EG), forb (FG) and other (OG) (Oliver et al. 2021).
LECO	A laboratory analysis that uses combustion for determining the concentration of elements within a sample
log+1 transformation	Data transformation method used to transform zero inflated data to approximately conform to normality.
Natural recruitment	The process by which new individuals naturally (i.e. without human assistance) establish a population or are added to an existing population (Eriksson and Ehrlén 2008).

Performance indicator	A biophysical attribute that can be measured, audited and used to approximate the progression of a biophysical process and thereby the progress of an aspect of rehabilitation towards a completion criterion (Department of Planning and Environment 2018).
Reconstruction (ecosystem)	A restoration approach where the appropriate biota need to be entirely or almost entirely reintroduced as they cannot regenerate or recolonise within feasible timeframes, even after expert assisted regeneration interventions (McDonald et al. 2018).
Regeneration	Recovery or recruitment of species from a germination or resprouting event. A 'natural regeneration' approach to restoration relies on spontaneous or unassisted natural regeneration as distinct from an 'assisted natural regeneration' approach that depends upon active intervention (SER 2004).
Rehabilitation	The process of reinstating a level of ecosystem functionality on degraded sites where ecological restoration is not the aspiration, as a means of enabling ongoing provision of ecosystem goods and services. Rehabilitation areas are mined or overburden areas that have been re-contoured to an approved profile and revegetated with native or exotic plants (SER 2004; Nussbaumer et al. 2012).
Rehabilitation objectives	Objectives that describe the qualities or features that must be demonstrated through the rehabilitation process to achieve the final land use, as stated in the rehabilitation management plan for the mine site (Department of Planning and Environment 2018).
Restoration (ecosystem)	The process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (note: single species restoration can be considered complementary and an important component of ecological restoration). Restoration lands are non-mined areas impacted by previous land use, usually with a long history of agricultural land use and past clearing of vegetation), that are being managed (and typically enhanced) with vegetation and features such as waterbodies to increase habitat value. The objective is to return them to diverse native ecosystems and landscapes (SER 2004; Nussbaumer et al. 2012).
Revegetation	Establishment, by any means, of plants on sites (including terrestrial, freshwater and marine areas) that may or may not involve local or indigenous species (SER 2004).
Species credit	Under the BAM, the class of biodiversity credits created or required for the impact on threatened species that cannot be reliably predicted to use an area of land based on habitat surrogates.

Acronyms and Abbreviations

ACARP	Australian Coal Association Research Program
BAM	Biodiversity Assessment Method
BAM-C	Biodiversity Assessment Method Calculator
BBAM	BioBanking Assessment Method
BC Act	*Biodiversity Conservation Act 2016* (NSW)
BC Regulation	Biodiversity Conservation Regulation 2017 (NSW)
BCT	Biodiversity Conservation Trust
BOS	Biodiversity Offset Scheme
CAP	canonical analysis of principal coordinates
CEEC	critically endangered ecological community
CHGBIW	*Central Hunter Grey Box – Ironbark Woodland EEC*
CHISGGBF	*Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC*
CWD	coarse woody debris
DES	Queensland Department of Environment and Science
DIIS	Former Commonwealth Department of Industry, Innovation and Science
DPE	Former NSW Department of Planning and Environment
DPI	NSW Department of Primary Industry
DPIE	NSW Department of Planning, Industry and Environment
EDS	ecosystem dynamics simulator
EEC	endangered ecological community
EFA	Ecosystem Function Analysis
EG	'fern' BAM growth form group
EIS	Environmental Impact Statement
ENSW	Eastern New South Wales
EO Act	*Environmental Offsets Act 2014* (Qld)
EP&A Act	*Environmental Planning and Assessment Act 1979* (NSW)
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Cwth)
FG	'forb' BAM growth form group
GG	'grass and grass-like' BAM growth form group
GLM	General Linear Model
HVFSGW	*Hunter Valley Footslopes Slaty Gum Woodland VEC*
IBRA	Interim Biogeographic Regionalisation for Australia (Version 7)
IQR	interquartile range
LECO	A type of laboratory analysis that uses combustion for determining the concentration of elements within a sample
LFA	Landscape Function Analysis

LFSC	landscape, function, structure and composition
LGA	Local Government Area
LLS	NSW Local Land Services
MBB	modified Braun-Blanquet
MIR	mid-infrared
MOP	Mining Operations Plan
MTO	Mount Owen Mine
MTW	Mount Thorley Warkworth Mine
NPWS	NSW National Parks and Wildlife Service
OEH	Former NSW Office of Environment and Heritage
OG	'other' BAM growth form group
OGM	Organic Growth Medium
OTU	Operational Taxonomic Unit
PCoA	principal coordinate analysis
PCT	Plant Community Type
PCT3315	Central Hunter Ironbark-Spotted Gum Forest PCT (ENSW PCT Classification)
PCT3431	Central Hunter Ironbark Grassy Woodland PCT (ENSW PCT Classification)
PCT3485	Central Hunter Slaty Gum Grassy Forest PCT (ENSW PCT Classification)
PLFA	Phospholipid Fatty Acids
RCP	Region of Common Probability Profile
R1.110	Central Hunter Spotted Gum – Ironbark Forest PCT (Draft ENSW PCT Classification)
R6.107	Central Hunter Slaty Gum Grassy Forest PCT (Draft ENSW PCT Classification)
R6.35	Central Hunter Grey Box – Ironbark Woodland PCT (Draft ENSW PCT Classification)
SER	Society for Ecological Restoration International Science and Policy Working Group
SERA	Society of Ecological Restoration Australasia
SEVT	Semi-evergreen Vine Thicket
SG	'shrub' BAM growth form group
SSA	Soil Surface Assessment
TEC	threatened ecological community
TG	'tree' BAM growth form group
TSC Act	*Threatened Species Conservation Act 1995* (NSW)
TSSC	Threatened Species Scientific Committee
UHSA	Upper Hunter Strategic Assessment
VEC	vulnerable ecological community
VI	Vegetation Integrity
VIS	Vegetation Information System
VM Act	*Vegetation Management Act 1999* (Qld)
WA	Western Australia

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Appendices

Acknowledgements

Firstly, we would like to thank ACARP for providing key funding this project and ACARP representatives Patrick Tyrell and Keith Smith for their guidance and support throughout the project. We are also very appreciative of the ongoing support that the ACARP industry monitors Nigel Charnock (Glencore) and Bill Baxter (Mount Thorley Warkworth – Yancoal) provided prior to and for the duration of the project. Jonathon Deacon (BHP) also assisted as an ACARP industry monitor during Stage 2 of the project. Significant additional funding was provided by Glencore and Mount Thorley Warkworth – Yancoal. Umwelt supported this project with a significant financial contribution, as well as the provision of time and resources.

We wish to thank the people and organisations who supported Umwelt's application for funding for this study, including Nigel Charnock (Glencore), Bill Baxter (Yancoal), Claire Doherty (NSW Minerals Council), Jamie Lees (Peabody) and Daniel Yates (Idemitsu).

Thank you to all the mine staff who assisted with providing information for the desktop review of all the mine sites involved in this project: Bill Baxter (Mount Thorley Warkworth), Damien Ryba (Mangoola Coal), Ned Stephenson (Mt Owen Complex), Tom Scott (Bulga Coal), Sean Piggott (United Mine), Linda Lunnon (Thiess – Mt Owen), Daniel Martin (Boggabri Coal), Justin Vohland (Burton Coal), Jeremy Duncan (Rolleston Open Cut) and Joshua Frappell (Wilpinjong Mine).

We acknowledge and thank those who facilitated access to sites for this study, including Bill Baxter (Mount Thorley Warkworth), Damien Ryba (Mangoola Coal), Ned Stephenson (Mt Owen Complex), Tom Scott (Bulga Coal), Sean Piggott (United Mine), Brent Frondall (Wambo Coal), Carmen Castor (CSER Research), Linda Lunnon (Thiess – Mt Owen) and Ashley Deveridge (NPWS). Thank you to Laura Kuginis (DPIE), Carmen Castor (CSER Research) and Ian Oliver (DPIE) for your camaraderie and patience over several weeks of field survey, your assistance with field data collection and your sharing of knowledge and ideas.

Thank you to DPIE (formerly OEH) for significant funding support for the self-sustainability attribute collection and processing and to DPIE staff who assisted with several aspects of this project and who provided fundamental support, knowledge and expertise. Staff from the Restoration Science Team, comprising Ian Oliver, Josh Dorrough, David Eldridge and Laura Kuginis, were collaborators on this project and led the self-sustainability assessment for this project, as well as providing extensive insightful advice regarding data analyses and completion criteria for the recognisability assessments. Samantha Travers also provided support for statistical analyses during Stage 2. DPIE's analyses were invaluable and underpin the self-sustainability assessment. In respect of this significant contribution, their work (Oliver and Dorrough 2019) is provided in full as an appendix to this report, lest any of its integrity be lost through selective citation and quotation in the main report. We are extremely indebted for their work on this critical element as well as access to draft manuscripts which directly relate to this work. Daniel Connolly, Tim Hager, Charles Huxtable, Ron Avery and Elizabeth Magarey generously provided early access to select data from the revised ENSW PCT Classification, draft PCT Assignment Tool and BioNet, which was relied upon for this project. We are extremely indebted to all DPIE staff, but particularly Ian Oliver for his persistent drive and enthusiasm to improve the collective understanding of ecological restoration. The collaboration demonstrates the significant steps in knowledge and understanding that can be attained through good will and sharing of information and ideas.

We wish to thank those who attended the industry workshop on completion criteria and provided valuable feedback, including Nigel Charnock (Glencore), Bill Baxter (Mount Thorley Warkworth/Yancoal), Paul Amidy (Glencore), Tom Scott (Bulga/Glencore), Ned Stephenson (Glencore), Joshua Frappell (Peabody/Wilpinjong), Nathan Lane (Glencore/Mangoola), Tasman Willis (Bulga/Glencore) and Craig Milton (NSW Minerals Council).

We are also appreciative of the valuable feedback received from stakeholders during Stage 2 consultation, including DPIE representatives Kate Newman, Ian Oliver and John Seidel, and representatives of NSW Resources Regulator Matthew Newton and David Humphris.

Part One – Introduction and Background

Over the last 30 years mining companies and regulatory authorities have demonstrated an increasing interest in the establishment of mine rehabilitation that demonstrates a certain level of ecological recognisability and function. In certain instances there have been requirements for rehabilitation to meet the diagnostic characteristics of certain vegetation types, threatened and non-threatened. In addition to this, there are policy and legislative provisions in some Australian jurisdictions for rehabilitation to be used to offset, or to mitigate, ecological impacts arising from mine development. However, its use as such is restricted in part due to a lack of knowledge and inadequate research about the likely success of rehabilitation in relation to self-sustainability and recognisability as a documented vegetation community.

An intersection of both need and opportunity exists which could drive the establishment of recognisable and self-sustaining ecological rehabilitation. The need stems from the diminishing extent of, and increasing threat to, native ecological communities, and the desire for coal mining proponents to minimise exposure to costly biodiversity offsets. The opportunity is driven by the anticipated ability of mining proponents to reconstruct relatively complex ecological systems, as well as the proposition that substantial ecological benefit can be derived from the re-establishment of substantial areas of native ecosystems.

For the intersection of need and opportunity to be optimised and realised in practical terms, appropriate and scientifically robust and measurable ecological rehabilitation objectives, completion criteria and performance indicators must be developed. To facilitate this, research has been needed to further understand the pre-existing ability of mine rehabilitation to achieve a recognised vegetation community within a self-sustaining system, and to predict future capability in this area. To date there have not been any published studies that demonstrate the function or self-sustainability of coal mine rehabilitation in Australia, addressing the establishment of native ecological communities or listed threatened ecological communities.

Recent studies undertaken by Umwelt indicate that some areas of mine rehabilitation in the NSW Hunter Valley were meeting, or were trending towards achieving, the diagnostic criteria of a critically endangered ecological community (CEEC) listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), despite there being no planning, design or requirement to achieve such. The opportunity for mine rehabilitation to contribute toward biodiversity offset obligations, when applied to the NSW Hunter Valley, has the potential to aid the rehabilitation of multiple state-listed threatened ecological communities (TECs) and one nationally-listed CEEC. Within this locality there are numerous coal mine approvals and associated rehabilitation activities with more recent requirements to rehabilitate specific recognised vegetation communities.

The aforementioned investigations, while providing valuable information on the current state of mine rehabilitation, were either lacking in adequate replication and consistency in data collection methods to comprehensively investigate recognisability of mine rehabilitation, or were not able to adequately address the essential question of whether mine rehabilitation can be self-sustainable. This ACARP-funded project, in collaboration with NSW Department of Planning, Industry, and Environment (DPIE) (formerly the NSW Office of Environment and Heritage (OEH)), builds upon these investigations by completing a research project focused on determining if mine rehabilitation can form a self-sustainable, recognised vegetation community. Based on studies conducted by Umwelt to date, it is hypothesised that mine rehabilitation can support ecological communities which are recognisable and self-sustaining.

1.0 Literature Review

Literature relating to ecological mine rehabilitation was reviewed to determine the current extent of knowledge on the establishment, maintenance and successful completion of rehabilitation, with a particular focus on recognisability as specific ecological communities and capacity to be self-sustaining. Literature that informed the development of appropriate rehabilitation objectives, completion criteria, performance indicators, monitoring approaches and measures of success was also considered. The outcomes of this literature review are summarised in the following sections.

1.1 Mine Rehabilitation in Australia

The rehabilitation of post-mined land is a legislative requirement in Australia (Commonwealth of Australia 2006). In principle, mine rehabilitation has focussed on the establishment of safe and stable landforms, with secondary goals being the establishment of certain land uses such as (predominantly) agriculture, native forest/woodland or native ecosystems.

The study presented in this report is concerned with the establishment of native ecosystems, therefore the focus of the literature review was on ecological mine rehabilitation. While many aspects are shared with the general mine rehabilitation process, certain initial steps (such as topographic micro-contouring, topsoil utilisation etc.) depart from other traditional approaches, whilst later steps vary significantly due to the very different end purpose to other land uses. Typically, the goal of the post-mining ecological rehabilitation process is to restore either an ecosystem similar in composition, structure and function to the pre-existing ecosystem or a self-sustaining native ecosystem similar to unmined land adjacent to the mine sites (Bell 2001). Approaches to post-mining ecological rehabilitation generally involve the following process as outlined in Bell (2001):

1. modify the topography
2. re-spread topsoil
3. improve soil physical properties
4. establish plants
5. fertilise plants
6. protect new community.

The approach presented above is simplified, but demonstrates the key steps involved in the process. The first step involves re-contouring the area to reduce the slope of steep areas and ensure slopes are stable. Included in this process is the creation of waste rock piles and tailings dams where necessary. Once the final landform design is complete, freshly stripped or stockpiled topsoil is re-spread over the area followed by ripping or ploughing to improve the physical attributes of the topsoil and underlying spoil. Plants can then be established. Often a cover crop, consisting of largely non-native species, is used to help stabilise the soil surface. Native species are then established through direct seeding or tube stock. The species of plants used in rehabilitation often depend on the objectives of the rehabilitation. Methods used to assist in the successful establishment of these plants include fertilisation and watering. Once established, the plants will persist and eventually reproduce and further stabilise the soil surface, leading to nutrient retention, improved carbon and nitrogen cycling and, over time, the development of a more complex and mature ecological community that should eventually become self-sustaining, depending on a range of factors.

Prior to plant establishment, however, and for some time afterwards, the area should be protected from disturbance due to feral animals, unauthorised access and fire until the community can tolerate such events. This general rehabilitation process has been used in a variety of different post-mining settings including coal, sand and bauxite mines (Bell 2001).

The process described above is not without its challenges. A summary of the challenges involved in the post-mine rehabilitation process is provided by Lamb et al. (2015) and includes:

- Unstable landforms and erosion resulting in steep slopes, surface subsidence and vegetation limitations.
- Prolonged topsoil storage limiting plant establishment.
- Failure of plant establishment due to unfavourable soil conditions leading to patchy or unvegetated areas exposed to erosion.
- Plant establishment limited by climatic conditions/water availability.
- Successional trajectory diverted or diversity of plant species declines over time resulting in a plant community different to that proposed in the rehabilitation objectives.
- Invasive exotic species colonise and outcompete native species causing a weed-dominated area.
- Toxic materials in surface and ground water continue to leach from the site leading to downstream contamination and reduced vegetation regeneration.
- Suitable wildlife habitat may take time to recover causing limited wildlife recolonisation.

The former Australian Department of Industry, Innovation and Science (DIIS) (2016) developed a handbook outlining the current recognised leading practices involved in planning, implementing and monitoring mine rehabilitation throughout the life of any given mining operation. Several actions identified in the DIIS handbook, and elsewhere in the literature, have been developed through industry research and application to overcome the challenges (such as those listed above) involved in post-mine rehabilitation. These include, but are not limited to the following:

- Consideration of final landform design to incorporate natural slope features to account for local conditions of rainfall, erodibility, soil type and vegetation cover and using erosion-modelling software to determine long-term stability of various slope designs (Ayres et al. 2006; Nussbaumer et al. 2012).
- Limiting the storage time of topsoil to less than 6 months before application over the landscape to improve the chances of plant establishment (Huxtable et al. 2005; Van Etten et al. 2012; Lamb et al. 2015).
- Testing the soil and growth media conditions to determine any chemical or physical attributes that would inhibit plant or microbial growth and address any potential problems by applying soil ameliorants or microbial inoculations (Kelly 2008; Daynes 2012; Nussbaumer et al. 2012; Kumaresan et al. 2017)
- Application of seed in rehabilitated areas prior to reliable rainfall, either during spring or autumn, or consideration of watering programmes to promote germination and establishment of plants (Read 2002; Nussbaumer et al. 2012)

- Reintroducing plant species that are present in the local area that appear in the target vegetation community and use topsoil from the target community as it contains native seedbank (Nussbaumer et al. 2012).

- Establishing a weed management plan that incorporates appropriate herbicides, mulch or weed mats to control weeds and continually monitor weed occurrence to minimise infestations (Nussbaumer et al. 2012).

- Planting specific fodder and shelter plant species of various structural complexities and floristic diversity to improve fauna re-colonisation and create vegetation corridors to encourage fauna movement (Munro et al. 2007; Nussbaumer et al. 2012). Introduction of augmented habitat such as nest boxes, hollow logs and rock piles to encourage fauna re-colonisation (Nussbaumer et al. 2012; Nichols and Nichols 2003).

Implementing the practices involved in establishing post-mine rehabilitation based on agreed targets should begin early in the life of the operation (DIIS 2016). This allows for progressive rehabilitation and adaptive management for any potential threats that may limit rehabilitation success. A combination of adaptive management outcomes, research and the establishment of targets and objectives all contribute to guiding and achieving rehabilitation success.

1.2 Determining Rehabilitation Success

The Society for Ecological Restoration International Science and Policy Working Group (SER) (2004) developed the International Primer on Ecological Restoration (hereafter termed the SER Primer) that identified nine attributes that provide a basis for successful restoration. While it is anticipated that not all of these attributes can be successfully achieved, it should be demonstrated that they are trending towards the intended goals or reference. These attributes are:

1. The restored ecosystem contains a characteristic assemblage of the species that occur in the reference ecosystem and that provide appropriate community structure.

2. The restored ecosystem consists of indigenous species to the greatest practicable extent. In the restored ecosystems, allowance can be made for exotic domesticated species and for non-invasive ruderal (coloniser) and segetal species (plants that grow intermixed with pasture species) that presumably co-evolved with them.

3. All functional groups necessary for the continued development and/or stability of the restored ecosystem are represented, or if they are not, the missing groups have the potential to colonise by natural means.

4. The physical environment of the restored ecosystem is capable of sustaining reproducing populations of the species necessary for its continued stability or development along the desired trajectory.

5. The restored ecosystem apparently functions normally for its ecological stage of development, and signs of dysfunction are absent.

6. The restored ecosystem is suitably integrated into a larger ecological matrix or landscape, with which it interacts through abiotic and biotic flows and exchanges.

7. Potential threats to the health and integrity of the restored ecosystem from the surrounding landscape have been eliminated or reduced as much as possible.

8. The restored ecosystem is sufficiently resilient to endure the normal periodic stress events in the local environment that serve to maintain the integrity of the ecosystem.

9. The restored ecosystem is self-sustaining to the same degree as its reference ecosystem and has the potential to persist indefinitely under existing environmental conditions. Nevertheless, aspects of its biodiversity, structure and functioning may change as part of normal ecosystem development and may fluctuate in response to normal periodic stress and occasional disturbance events of greater consequence. As in any intact ecosystem, the species composition and other attributes of a restored ecosystem may evolve as environmental conditions change.

Generally, to achieve the aim of ecosystem restoration, considering these nine attributes, a restored ecosystem should demonstrate a trend towards compositional and structural recognisability and effective functionality while also demonstrating evidence of self-sustainability, relative to a reference ecosystem of the same category. A review by Ruiz-Jaen and Aide (2005) concluded that at least two variables within each of the three ecosystem attributes listed in the SER Primer that relate to ecosystem function (diversity, vegetation structure and ecological processes) need to be considered for evaluating restoration success. They go on to highlight that of the nine attributes, those that were considered most important for measuring rehabilitation success include plant diversity (composition), vegetation structure (structure) and ecological processes (function) (Ruiz-Jaen and Aide 2005) and are attributes considered essential for the long-term persistence of an ecosystem (Elmqvist et al. 2003; Dorren et al. 2004). The importance of these attributes is also stated in the National Standards for the Practice of Ecological Restoration in Australia, which were prepared by the Society of Ecological Restoration Australasia (SERA) to guide the practice of restoration and rehabilitation and improve the standards for these practices in Australia (McDonald et al. 2016). This standard highlights the importance of using the composition (species), structure (complexity and configuration) and function (processes and dynamics) as measures for comparing rehabilitated land with comparable reference ecosystems (McDonald et al. 2016).

Methods for measuring these attributes will vary depending on the ecosystem and the rehabilitation objectives, and rehabilitation success will depend on the rehabilitation completion criteria which are set as conditions of approval (Blommerde et al. 2015). Completion criteria are the standards of performance which are used to measure the actions completed for rehabilitation relative to what is required for closure of the site and relinquishment of the mining lease to be achieved (Tiemann et al. 2019; Blommerde et al. 2015). Completion criteria for mine site rehabilitation are typically quantitative and can vary in their level of complexity. Wortley et al. (2013) address the methods by which rehabilitation is likely to be successful, including the assessment of the species composition, plant cover, degree of self-regeneration, extent of colonisation by fauna, etc.

The success of rehabilitation can be measured progressively. Grant (2006) demonstrates a model for assessing rehabilitation as a successional trajectory in meeting the completion criteria for bauxite mining in Jarrah forest ecosystems of Western Australia (WA). Key indicators relating to the desired and deviated state in this study included eucalypt density, species richness, legume density, topsoil cover, vegetation structure, ripping depth and tree health and form (Grant 2006). Similar trajectory tools have been developed that incorporate existing platforms for rehabilitation assessment (e.g. BioCondition scorecard and Ecosystem Dynamics Simulator) to create a verifiable empirical method to identify rehabilitated sites that are on track and provide an estimated timeframe for meeting key benchmarks. These methods also enable the early detection of rehabilitated sites unlikely to reach the benchmark, which then informs timely remedial management intervention (Ngugi et al. 2015). A review of the published literature of bauxite mine rehabilitation in WA revealed that a single measure of ecosystem restoration success, which acts as a surrogate for all others, does not exist (Koch and Hobbs 2007). However, the authors go on to suggest that two attributes, soil organic carbon levels and floristic similarity, would adequately integrate all ecosystem components and could be used to determine the level of ecosystem restoration in the southwestern WA region (Koch and Hobbs 2007).

A recent review of Australian mine relinquishment policy by Tiemann et al. (2019) revealed that the pathway to mine relinquishment, and thus successful rehabilitation, is unclear. Several case studies for achieving relinquishment have been provided as part of the mining industry handbook on mine closure (DIIS 2016) however, such examples of successful relinquished mines in Australia are uncommon, with there being a sizeable proportion of mines being placed into 'care and maintenance' and not relinquished (Tiemann et al. 2019). While much research has been undertaken in rehabilitated ecosystems, there has been no published literature known to the authors that demonstrates successful rehabilitation of a post-open cut coal mining ecosystem in Australia. It is also becoming more common for post-mine rehabilitated ecosystems to be required to meet the diagnostic characteristics of specific vegetation types in order to meet completion criteria, however, there is little published information about rehabilitation achieving a self-sustaining ecosystem that is also considered a recognised vegetation community.

1.2.1 Rehabilitation Monitoring

Rehabilitation progression and success is tracked through ecological monitoring (Loch and Lowe 2008) and its success is measured against completion criteria specific to the mine. Completion criteria for mine site rehabilitation often require the use of a reference ecosystem that represents the desired endpoint of the rehabilitation (Chambers et al. 1994; Herath et al. 2009), however Dey and Schweitzer (2014) note that caution should be employed when using reference sites, as they themselves may be impacted by various forms of disturbance, they may not be suitable examples of what should be used as a target for novel environments and they are not necessarily informative for intermediate stages of ecosystem development. Certain ecological attributes are measured in the reference ecosystem, for example native flora species richness, and these attributes form part of the completion criteria. Within woodland and forest mine rehabilitation there is no accepted method, or suite of methods, regarding the monitoring of ecosystem health and ecological progression. As such, rehabilitation monitoring can be a highly variable practice as shown in the examples provided by LandLine Consulting (2017), AECOM (2018), Umwelt (2018a) and Niche (2017). Common elements of monitoring programmes include the use of reference sites, flora and fauna surveys, and soil analyses (Nichols and Watkins 1984; SER 2004; Grant 2006; Herath et al. 2009).

Bell (2001) proposes the Ecosystem Functions Analysis (EFA) method (Tongway and Hindley 2004; Tongway et al. 1997) for measuring the success of rehabilitated areas. This method is made up of three components: Landscape Function Analysis (LFA), vegetation dynamics, and habitat complexity. EFA is a rapidly-applied, low-cost field assessment that places importance on the use of reference sites and the utilisation of long-term rehabilitation monitoring in order to comprehensively understand if the reconstructed ecosystem is moving toward the reference site condition (Bell 2001). While the LFA method has been widely accepted and used as an indicator for measuring rehabilitation success (Randall 2004), the efficacy of the method has been questioned (Erskine et al. 2013). Similar frameworks for assessing rehabilitation success have been provided by Drake et al. (2010), who advocate for the landscape, function, structure and composition (LFSC) aspects of an ecosystem to be considered when designing a monitoring programme.

1.2.2 Benchmarks

Ecological benchmarks, put simply, are a standard reference value against which features in the environment can be compared. Benchmarks should ideally act as a reference, or control value, in that they are developed with consideration of the range of natural variation that exists (Hawkins et al. 2010; Eyre et al. 2015). Benchmarks are used for monitoring projects to either ensure an intact, healthy ecosystem is remaining healthy, or to track the progression of a restoration project (Hawkins et al. 2010). While the SER (2004) supports the use of benchmarks for achieving and assessing restoration success, the type of benchmark used is widely debated (Wortley et al. 2013).

Care must be taken when selecting which environmental attributes are used as benchmarks. For benchmarks to be meaningful they should be indicators of ecological health and condition (Noss 1990; Oliver et al. 2007; Eyre et al. 2015; Hawkins et al. 2010). When selecting an environmental attribute to act as an indicator, Noss (1990) recommends that the environmental monitor should consider the following:

- The sensitivity of the indicator. The indicator must be sensitive enough that changes in the ecosystem are detected as early as possible.
- How widely distributed the indicator is. To be useful to a wide range of users, the indicator must have a broad geographical distribution.
- If the indicator is sensitive to all environmental stress levels.
- If the indicator needs to reach a certain sample size to give meaningful information, and further to this, the suitability, cost effectiveness, and complexity of the data to be collected should be considered.
- If the assessor is able to differentiate between natural environmental change and changes due to environmental stress.
- If the proposed indicator is ecologically relevant.

Composition, structure and function have been proposed and accepted as three attributes of biodiversity that, when measured together, are able to provide a complete understanding of the biodiversity of an area (Franklin 1988; Noss 1990). It therefore follows reason to use these attributes in the formation of benchmarks upon which to assess the quality of native vegetation. Attributes used to assess biodiversity values in NSW were first standardised in the BioBanking Assessment Method (BBAM) (DECCW 2011). This included the assessment of composition, through total number of native plant species; structure, using percent foliage cover within each stratum; and function, which considered the number of hollow-bearing trees present, length of logs and proportion of tree species with evidence of recruitment present. The Biodiversity Assessment Method (BAM) (OEH 2017), which replaced BBAM as the standard approach to assessing biodiversity value in NSW, was developed using the metrics of its predecessor, but with some modification. The final environmental attributes used to form the Vegetation Integrity attributes as part of the BAM (Oliver et al. 2021) were:

Composition

- Native vascular plant species richness by growth form group.

Structure

- Native vascular plant species foliage cover by growth form group.

Function

- Number of large trees.
- Presence/absence of tree stem size classes.
- Presence/absence of tree regeneration.
- Litter cover.
- Length of logs.

The Vegetation Integrity attributes of the BAM included those which would allow for the development of benchmarks for species richness and cover within growth form groups (Oliver et al. 2021). In NSW the environmental attributes listed above are used to assess native remnant vegetation and calculate a

Vegetation Integrity (VI) score, which provides a quantitative estimate of the value of the vegetation and habitat being assessed (Oliver et al. 2021). The VI score is calculated using benchmark values for each attribute, which have been developed at the vegetation class (Keith 2004) by bioregion (Thackway and Cresswell 1995) level. In the case of biodiversity offset (stewardship) sites, these benchmarks set the goal to be achieved through management actions designed to improve the ecological value of the subject site.

These benchmarks have been generated from data pooled to the vegetation class level (Keith 2004) by IBRA region, due to deficiencies in data at the level of the Plant Community Type (PCT) (Oliver et al. 2019). For this reason, the benchmarks may not be appropriate for all plant communities within the vegetation class. In recognition of this limitation of the BAM in its current form, an option exists for an assessor to develop PCT-level benchmarks using local reference sites or published sources under certain conditions. In consultation with consent authorities local reference sites or published sources can be used in the development of benchmarks when the existing benchmarks have low confidence ratings; when local data better reflects the local environmental conditions, such as drought; or class-level benchmarks are evidently unsuitable for a particular PCT (DPIE 2020a). Using this method, high quality or 'best-on-offer' local vegetation of the target PCT is sampled and the median value for each attribute is used as the benchmark (DPIE 2020a). From a monitoring perspective, 'best-on-offer' reference sites can be used to gain a better understanding of how biodiversity changes over time, as well as contribute to the development of dynamic benchmarks (McNellie et al. 2020).

A similar method of vegetation assessment, referred to as BioCondition, has been developed for Queensland (Eyre et al. 2015). This method also utilises benchmarks to assess vegetation and produce a BioCondition score. Similar to the NSW system, the benchmarks are based on composition, structure, and function, and the resulting BioCondition score is calculated differently depending on whether the vegetation is woodland, shrubland, grassland or a mangrove community (Eyre et al. 2015). This is similar to the approach of the NSW system which uses dynamic weightings to accommodate differences in physiognomy. The environmental attributes used in the BioCondition assessment (Eyre et al. 2015) are:

- Maintenance of plant species diversity:
    - native plant species richness (by form)
    - recruitment of canopy species
    - native perennial 'decreaser' grass species (species that are sensitive to grazing) basal area
    - non-native plant species cover.
- Provision of reliable foraging resources for wildlife (e.g. nectar, leaves, seeds):
    - large trees
    - shrub cover
    - tree canopy cover
    - native perennial grass
    - coarse woody debris
    - organic leaf litter
    - ground cover.
- Provision of reliable sheltering resources and/or breeding sites for wildlife:
    - large trees and/or hollow bearing trees
    - coarse woody debris

- tree canopy cover
  - shrub cover
  - organic litter
  - perennial grass cover.
- Nutrient and water cycling:
  - tree canopy cover
  - organic litter cover
  - coarse woody debris.
- Maintenance of soil condition:
  - organic litter cover
  - native perennial 'decreaser' grass species basal area
  - native perennial non-grass cover
  - coarse woody debris.
- Retention of plant propagules:
  - organic litter
  - coarse woody debris.

The BioCondition method has been applied to mine site rehabilitation ranging from 3 to 20 years post-rehabilitation establishment by Neldner and Ngugi (2014). In this study, previously developed benchmarks, developed from local reference sites (Neldner et al. 2012), were modified to allow for realistic rehabilitation benchmarks (i.e. exclusion of large trees and woody debris) (Neldner and Ngugi 2014). These modified benchmarks were defined as the mean structure and species composition of the amalgam of three regional ecosystems, which were developed from 26 sites in nearby remnant vegetation (Neldner and Ngugi 2014). Results from Neldner and Ngugi (2014) indicated that older rehabilitation was closer to the benchmarks than younger rehabilitation. However, the analysis also identified several considerations when comparing rehabilitation to benchmarks:

- Selecting appropriate benchmarks for rehabilitation is difficult and benchmarks/scores that are used need to consider the age of rehabilitation.
- Due to the unrealistic target of benchmarks from original (remnant) vegetation, the installation of a 'novel' ecosystem may be more practical and appropriate when assessing rehabilitation areas.
- Use of different benchmarks for each age of rehabilitation may be appropriate when trying to assess if rehabilitation has been successful. This may need adjustment to be made to the reference site data (benchmarks) to reflect different ages of rehabilitation.
- The spider web diagrams of the BioCondition score (Eyre et al. 2015) provided a clear illustration of how rehabilitation site scores compare to the benchmark for each attribute.

When rehabilitation was assessed at Meandu Mine (Queensland) against undisturbed remnant woodland sites using the BioCondition assessment method and a tree growth trajectory model, restoration of self-sustaining eucalypt woodland was found to be unachievable during the life of the mine (i.e. 20 to 60 years) (Ngugi and Neldner 2015). None of the sites sampled at Meandu Mine were projected to meet all the BioCondition benchmark values for the considered attributes by 2072 (a 70-year simulation period), but instead, the benchmark attributes were expected to be met at different times (Ngugi and Neldner 2015). These studies highlight the difficulties faced by mine operators and regulatory agencies when rehabilitating post-mined land and subsequently assessing the state of rehabilitation and its progression toward closure.

1.2.3 Completion Criteria and Performance Indicators

In NSW, mining approvals require that proponents prepare rehabilitation objectives and completion criteria in accordance with the *Mining Act 1992,* which in the case of large mines, includes the final landform and rehabilitation plan (NSW Resources Regulator 2021a). Completion criteria act as benchmarks or targets that must be achieved to demonstrate the ultimate success of an attribute and performance indicators describe the specific attribute that can be measured and audited to assess the progress of an aspect of rehabilitation toward the desired completion criterion (NSW Department of Trade and Investment 2013). Rehabilitation requirements, including completion criteria and performance indicators, are determined on a case-by-case basis for individual mining projects, following a rigorous assessment of the mining proposal by the consent authority (NSW Resources Regulator 2019).

Nichols (2005) and Nussbaumer et al. (2012) state that completion criteria should cover all stages of mining from establishment to ecosystem sustainability. Thirteen principles were recommended by Nichols (2005) in his research into the development of rehabilitation completion criteria for native ecosystem establishment at coal mines in the Hunter Valley. These principles consider the large variation that exists between coal mines in various aspects, including surrounding vegetation, land use and degree of disturbance, monitoring that has been undertaken, and remaining life of mine.

Nichols' (2005) 13 principles for developing completion criteria for native ecosystem establishment are as follows:

1. Integration into the overall mine closure plan
2. Stakeholder consultation
3. Completion criteria should reflect what is achievable using cost-effective best practice
4. The company needs to consider the whole lease and other local areas
5. The principles of continuous improvement need to be included in both rehabilitation techniques and completion criteria
6. Completion criteria should be set for all stages of the mining operation
7. For current and future rehabilitation, the development of completion criteria should be an iterative process
8. Integrate relevant components when setting completion criteria, which includes the following:
    a. Setting objectives that can be achieved using cost-effective best practice rehabilitation procedures
    b. Development of rehabilitation monitoring programme
    c. Selection of appropriate indicators
    d. Assessment of long-term sustainability
    e. Development of actual completion criteria, standards and milestones should be linked to the objectives, monitoring programme, indicators and assessment of long-term sustainability
    f. Monitoring and maintenance

9. Treat target standards as ‘trigger’ levels

10. Develop separate objectives and criteria for older rehabilitation

11. Develop specific completion criteria for different domains

12. Regularly review completion criteria

13. Final handover should incur no further liability.

More recently Nussbaumer et al. (2012), who have conducted extensive research at Mt Owen Mine, also located in the Hunter Valley, concluded that completion criteria and rehabilitation objectives should be flexible, rather than precisely defined, to accommodate advances in knowledge and technology over time and changes in mining operations.

Some final land uses, or functions, may take many years to achieve. Nichols (2005) suggests that a specific set of performance indicators be developed to measure the progress toward completion criteria in recognition of this, and if appropriately developed, the indicators should suggest whether ecological processes are trending in the right direction. This allows for early management intervention to be used in the event that positive trends are not observed during monitoring (Nichols 2005). It is also preferable to use performance indicators that are cost-effective and have standard approaches that are simple to employ and produce results that are easily interpreted by different people (Dey and Schweitzer 2014). Regular rehabilitation monitoring, using methods and techniques that are consistent with ascertaining progress towards completion criteria, plays an essential role in the iterative process of incorporating new knowledge to improving outcomes and determining the appropriateness of completion criteria, as well as assessing the progress of rehabilitation at individual monitoring sites. Research also serves a similar role to traditional mine rehabilitation monitoring in assisting with the refinement of rehabilitation methods and completion criteria, as demonstrated by Nussbaumer et al. (2012).

1.3 Recognisability

Determining whether a rehabilitation site is recognised as being similar to a target ecosystem requires local reference site data to create benchmarks for vegetation types which can then be compared with rehabilitation sites (Neldner and Ngugi 2014). These empirical data can then be used to demonstrate that rehabilitated communities have the same, or similar, characteristics as reference sites which represent the target ecosystem, or that the rehabilitation is trending towards these characteristics. The importance of using local reference site data to assess rehabilitated sites has been highlighted in order to provide accurate and meaningful comparisons to rehabilitated sites (Lechner et al. 2018; McDonald et al. 2016) and also create benchmarks (Neldner and Ngugi, 2014). A range of parameters have been investigated during rehabilitation monitoring, throughout all rehabilitation phases, in order to effectively demonstrate recognisability.

Ngugi and Neldner (2015) demonstrated a trajectory of rehabilitation towards benchmark sites using ecosystem dynamics simulator (EDS) modelling for the Meandu mine in Queensland. The EDS model projects long-term growth dynamics of forests by simulating forest succession over time and then analysing the changes in species composition, tree age and tree size structures (Ngugi and Neldner 2015). Similar methods for measuring the success of restored ecosystems include recovery trajectories (Nichols and Nichols 2003), which show changes in variables measured in rehabilitated sites and reference sites over time.

State and transition models have also been used previously as a method for comparing rehabilitation and reference sites (Grant 2006; Koch 2007) to measure rehabilitated land succession towards a target reference ecosystem (Grant 2006).

Some studies have demonstrated that substantial areas of rehabilitated land have met the required completion criteria and have the potential to be managed in an integrated manner with the surrounding unmined ecosystems (Grant 2006; Koch 2007). However, other studies have revealed that assessment of rehabilitated sites against undisturbed remnant woodland sites has demonstrated unachievable outcomes of complete restoration of self-sustaining ecosystems within the life of the mine (typically 20 to 60 years) (Ngugi and Neldner 2015; Grant 2006). Similarly, Humphries' (2016) assessment of native forest rehabilitation success across several mine sites in Australia criticised the adequacy of popular methods in monitoring rehabilitation. Specifically, the use of the soil surface condition-based Landscape/Ecological Functional Analysis approach (Tongway and Ludwig 2006; Lacy et al. 2008; Erskine et al. 2013). More recently the BioCondition method described by Neldner and Ngugi (2014) were viewed as inappropriate as they did not adequately address the key ecosystem characteristics of plant community composition and structural formation (Humphries 2016).

With regard to vegetation communities, recognisability relates to the similarity of a defined area of vegetation to a unit(s) of an existing classification system. Within the scope of this project, which focuses on the vegetation classification systems in NSW, there are two tiers of recognisability for ecological mine rehabilitation, being:

- PCT
- TEC listed under the BC Act or EPBC Act.

The primary attributes of recognisability for ecological communities comprise:

- floristic composition
- vegetation structure
- location (may be explicitly restricted to a location, including geographic (e.g. bioregion, LGA), physiographic (e.g. alluvial plains) or topographic (e.g. elevation).

Secondary attributes that may be important determinants may be considered as part of the recognition of a unit. For example:

- biophysical attributes, such as soil and geology, may be explicitly required for an ecological community to comply with a recognised unit
- formation, class and subclass
- faunal usage of site and habitat features.

Secondary features (typically biophysical) are frequently missing from PCT and TEC descriptions but are useful in the recognition of a vegetation type. Furthermore, these secondary features may be fundamental in the selection and subsequent successful establishment of the target rehabilitation community or communities. In particular, the location of the rehabilitation site must intrinsically inform the selection of the target ecological communities. The BC Act defines an ecological community as '*an assemblage of species occupying a particular area*'. Therefore, selection of the target communities for rehabilitation must be informed by location (the '*particular area*') of the rehabilitation site in order for it to conform to a TEC, especially where such conformation is directed by the mine's completion criteria.

Where specific vegetation communities are the target for rehabilitation, the characteristics of the specific vegetation community, such as the assemblage of species, must be clearly defined. The information contained within the NSW BioNet Vegetation Classification database has been identified in the draft Ancillary Rules for Mine Site Ecological Rehabilitation (DPIE 2021a) as a measure for which both vegetation composition and structure of a rehabilitated site can be compared in order to determine if it is recognisable as a PCT. This database can be used in conjunction with reference sites in assessing whether a rehabilitated site is recognisable as the target PCT.

1.3.1 Floristic Composition

The floristic composition of vegetation communities refers to the flora species present and their relative cover and abundance. Several studies have used floristic species composition when measuring rehabilitation progression (e.g. Gould 2012; Herath et al. 2009; Ngugi et al. 2015) utilising a wide variety of data collection methods that differ between Australian states and territories (refer to Gellie et al. 2018). In NSW, data collected for floristic compositional analysis has been primarily from plot-based samples, which typically comprise a standard 20 m x 20 m plot. The cover abundance of plant taxa within these plots has been, until recently, predominantly collected following the Braun-Blanquet ordinal 6-point scale (Braun-Blanquet 1927, with modifications by Poore 1955) (the modified Braun-Blanquet (MBB) cover abundance scale). More recent sampling techniques have included more precise measurement of species cover and abundance. The recent introduction of the BAM in NSW requires that percentage foliage cover for each species is recorded in a standard 0.04 ha plot (which is later converted to species richness and percentage cover for growth form groups), in addition to the abundance of individuals of each species for species less than or equal to 5% cover (OEH 2017). The collection of data in this format allows for direct conversion of the data to the MBB cover abundance scale, and therefore comparison with historical data, while also providing relatively precise measurements of cover by species and growth form.

Floristic composition is one of the primary attributes used in determining and classifying a vegetation community (based on Beadle and Costin 1952, as modified in Beadle 1981). Similarly, plant diversity and abundance are the most commonly used attributes for measuring restoration success (Ruiz-Jaen and Aide 2005). The SER Primer (2004) includes variations of floristic composition in the nine attributes for determining restoration success. Guidelines for post-mine rehabilitation establishment in the Hunter Valley, NSW, recommend that species composition should be as high as possible in order to promote species redundancy and ecosystem resilience as a result of high biodiversity (Nussbaumer et al. 2012). Often, post-mining rehabilitation aims to re-establish a vegetation community that has similar, but not necessarily identical, vegetation composition to the original ecosystem. Remnant vegetation in proximity to the rehabilitation is often used as a model vegetation community towards which rehabilitated sites are targeted (Nussbaumer et al. 2012). This relies on establishing baseline vegetation surveys from remnant areas and/or utilising classification systems, such as mapped PCTs and formal documents that relate to TECs, in order to develop a species list to inform the flora species suitable for planting in rehabilitation areas (Nussbaumer et al. 2012). The majority of PCT and TEC descriptions, however, lack quantitative measurements of percentage cover, height and/or abundance for each species. Therefore, in comparing rehabilitation floristic data to PCTs or TECs, the use of reference (analogue) site data is typically needed for quantitative floristic composition analysis.

1.3.2 Floristic Structure

Vegetation structure refers to the typical strata, height, cover and growth forms of the flora species within a vegetation community (Hnatiuk et al. 2009). Prior to the introduction of the BioBanking Assessment Method (BBAM) in 2014 and the BAM (OEH 2017) the structure of the vegetation communities in NSW typically included a description of vegetation strata height and density (e.g. emergent, canopy, sub-canopy, mid-stratum, ground stratum), and, typically, the MBB ordinal scale was used to estimate the cover and abundance of each plant species within the standard 0.04 ha plot.

Under BBAM, foliage cover was estimated using a transect-intercept method for each stratum along a 50 m transect in conjunction with recording all flora species present within a standard 0.04 ha plot and their percentage foliage cover.

Under BAM, structure is determined through the allocation of species to growth form groups (tree, shrub, grass and grass-like, forb, fern, other, exotic and high threat exotic) and measuring the foliage cover of each species and therefore through summation, each growth form group.

The BAM (OEH 2017) specifies that:

> *Structure is the assessment of foliage cover for each growth form group within the 20 m x 20 m plot boundary.*
>
> *…*
>
> *Foliage cover for a growth form group is the percentage of cover of all living plant material of all individuals of the species present for that group. This includes leaves, twigs, branchlets and branches as well as canopy overhanging the plot even if the stem is outside the plot.*

The more recent BAM (DPIE 2020a) contains a modified definition, whereby foliage cover is a measure of *'all attached plant material, regardless of whether it appears alive or dead, of all individuals of a species*' present for that group.

Foliage cover must be recorded for each native and exotic species present within the 20 m x 20 m plot as a percentage, with a minimum value of 0.1%, which allows for the percentage foliage cover of each growth form to be calculated by summation.

1.3.3 Threatened Ecological Communities

Related to, but also distinct from, PCT recognisability is TEC recognisability. Although a PCT recognisability assessment might inform the allocation of a TEC, there is no strict relationship between the two, and a TEC can exist independent of any such relationship. Indeed, a TEC can correspond with one or many PCTs, and one PCT may correspond to one or many TECs. A TEC must always be assessed through the direct knowledge of the field situation compared to the TSSC advisory document (Approved Conservation Advice or Final Determination), although in some cases an advisory document (such as a Final Determination under the BC Act) might rely on the characterisation of a TEC through certain mapping units from a particular classification.

Under the Commonwealth EPBC Act, an ecological community is defined as an assemblage of native species that a) inhabits a particular area in nature, and b) meets the additional criteria for listing as threatened specified in the regulation. Under the Act the Minister must establish a list of TECs categorised as either critically endangered, endangered or vulnerable based on the risk of extinction in the wild in the immediate, near or medium-term future. The Commonwealth Threatened Species Scientific Committee (TSSC) publishes descriptions of TECs in documents termed 'Approved Conservation Advice.'

The BC Act defines an ecological community as '*an assemblage of species occupying a particular area*' and although not explicitly mentioned in the BC Act definition, the ecological concept of a community also includes interactions between constituent species (NSW TSSC 2018). Being entities listed under legislation, there is a legal requirement for appropriate descriptions which aid in their identification by both professionals and lay people. For TECs listed under the BC Act, these descriptions are contained within 'Final Determinations' published by the NSW TSSC.

Structurally dominant species are often used as abbreviated descriptors of assemblages, however the occurrence of a few dominant species is not necessarily evidence of the presence of an ecological community (NSW TSSC 2018). Instead of a select group of species (including dominants) being used to describe a community, the NSW TSSC (2018) states that the description and diagnosis of an ecological community should address the overall species composition of the assemblage and include a list of characteristic constituent species. The particular area occupied by an ecological community also needs to be described with reasonable specificity but doesn't need to be highly prescriptive, as evident in NSW where the inclusion of bioregion and/or local government area in the description are considered sufficient by the Land and Environment Court (Preston and Adam 2004a).

Structural features of a TEC, including for example the vertical and horizontal spatial arrangements of species, are often identified as 'supplementary descriptors' to assist in interpretation and field recognition and provide greater certainty to the description. Supplementary descriptors can also include physiognomic features (such as leaf size and shape), relationship to abiotic factors (such as landforms and substrates) and dynamic features (such as disturbance regimes) (NSW TSSC 2018). A deterministic interpretation, where a TEC is regarded as being absent if a site does not match the 'supplementary descriptors' described in the Final Determination, is rarely consistent with the NSW TSSC's intent (NSW TSSC 2018). Stemming from the statutory definition of an ecological community, Preston and Adam (2004b) state that supplementary descriptors '*cannot be used as a substitute for the description of the assemblage of the species and the particular area in which the community is located. Rather they should be seen as a valuable adjunct*'. Consequently, it is important that the wording of legal documents, like 'Final Determinations', provides guidance on when a broad interpretation of supplementary information is intended (NSW TSSC 2018).

There is no standard method for describing ecological communities and descriptions are generally developed with consideration of the specific purpose and intended audience and are limited by the available data, methods, biases and knowledge gaps (Keith 2009; NSW TSSC 2018). Consequently, there is considerable variation in the format and content of ecological community descriptions, however, most contain characteristic species composition, structure and habitat (Keith 2009). Ideally the composition description would include frequently occurring species (though they may not be present through the community's entire distribution) and those whose occurrence may help distinguish the community from other similar communities (i.e. species which exhibit a high fidelity with the community, but which may be less commonly recorded) (NSW TSSC 2018). This information is, however, limited by the amount of systematic sampling undertaken in the target community and the level of analysis undertaken, and it is influenced by spatial and temporal variability. However, even when this information is based on thorough sampling, the application of lists of characteristic species in the diagnosis of threatened ecological communities is difficult, as there are no agreed criteria on the minimum subset of species that is required to confirm their presence (Tozer 2003).

Flexibility is essential in ecological community descriptions to accommodate the natural variability inherent within them (Keith 2009). Keith (2009) states that '*it is therefore important to recognise the uncertainty as an intrinsic characteristic of community descriptions and diagnosis, reduce it where possible, and deal with it explicitly in any decision-making process*'. With the listing of ecological communities as threatened entities under legislation, the need for uncertainty to be addressed in a practical way is imperative. Examples of this are evident in NSW case law, including the statement by Chief Justice Spigelman of the Supreme Court of NSW that '*the use of the word 'assemblage' does not suggest that either the nomination of species or the identification of an area requires a high degree of specificity… The intricacy of all ecological communities means that some indeterminateness is bound to arise from the form of expression used to describe them*' (*VAW (Kurri Kurri) Pty Ltd v. Scientific Committee* (2003)).

A number of limitations exist that should be considered with regard to ecological descriptions. The knowledge of the species composition is limited by the amount of sampling that has been undertaken within it and as composition is only measured using a 'sample', the data is also subject to measurement error and natural variation. Some species are also less detectable than others, which leads to systematic error, meaning that sampling at multiple times and places is required to sample the true variability within the community (Keith 2009). The descriptions may also be influenced by the underlying theory of the community definition subscribed to by the author. The particular species and locations that fall within the definition of a particular community may depend on whether the data is interpreted through the lens of the 'discrete' or 'continuum' model of communities (Keith 2009). Limitations also exist around the language used in the descriptions and linguistic uncertainty that can arise, for example when categorical language is used to describe entities that exist along a continuum, such as wet to dry, or where under-specificity, ambiguity or vagueness exist (Keith 2009).

The scale-dependence of ecological communities, being thematic, spatial and temporal scales, should also be recognised in their description and interpretation (Keith 2009). Thematic scale relates to the classification scale and the level of resemblance used to distinguish the community from others (Keith 2009). The resolution at which a community is mapped refers to the spatial scale and can be quantified using scale ratios, pixel size or minimum polygon size (Keith 2009). Temporal scale relates to the time intervals that distinguish variation within and between communities, which is a particularly important influence in 'successional' stages of a community (Keith 2009). In NSW, the BC Act does not specify any requirement for communities to be defined at a particular scale in order to be eligible for listing as a threatened ecological community (NSW TSSC 2018).

Keith (2009) suggests two methods for dealing with the uncertainty inherent in the interpretation of ecological communities: the reduction in the magnitude of uncertainty, through increased sampling effort; and the explicit incorporation of what is known about the uncertainty into the decision-making process through the use of decision-theory tools or risk assessment methods, in which questions are considered from a probabilistic rather than deterministic perspective, which quantify uncertainty rather than ignoring it.

1.4 Self-sustainability

In order to establish a self-sustaining ecosystem that is resilient to variability in biotic and abiotic factors, it has been identified that increasing ecosystem components and interactions (i.e. complexity) need to be addressed in restoration activities (Drake et al. 2010). Successful rehabilitation of a mine site depends on whole ecosystem rehabilitation. Previous research has broken down the complexity of ecosystems into four components: landscape, function, structure and composition (Elmqvist et al. 2003; Tongway and Hindley 2004; Ruiz-Jaen and Aide 2005). The landscape component includes landform features, water sources, climate and geology of the rehabilitated site which are features that cannot be controlled or adapted to improve the quality of rehabilitated land. However, Gould (2011) highlights certain landscape components as contributors to alter the habitat values of rehabilitated land, including the size of the rehabilitated land patches (Fink et al. 2009) and the area of remnant vegetation in the landscape (Miller and Hobbs 2007; Lindenmayer et al. 2010). The availability of suitable habitat for fauna is also considered an important attribute for measuring the self-sustainability of rehabilitated ecosystems, with features such as ground shelter in the form of logs and rocks, establishment of litter and augmented or artificial hollows promoting faunal recolonisation similar to densities of unmined ecosystems (Nichols and Nichols 2003).

1.4.1 Ecosystem Function

An ecosystem's function has been defined as the ecosystem's dynamic attributes, including interactions between its biotic and abiotic components (SER 2004). This includes nutrient, water, and energy cycling throughout the ecosystem. Ecosystem functions can include pollination, decomposition, predation and plant-fungi interactions (Ruiz-Jaen and Aide 2005). When an ecosystem is functioning well, nutrient and energy cycling occur without major loss from the system while allowing organisms to complete lifecycles (SER 2004; Nussbaumer et al. 2012). Conversely, if an ecosystem is not functioning effectively, there are losses in the form of biomass, energy, nutrients and eventually genetic loss.

Ecosystem functionality is difficult to see and specifically measure in the environment (Eyre et al. 2015) however, there are ecological attributes that can act as indicators of the functionality of an ecosystem.

These include leaf litter cover, woody debris, nitrogen fixing plants (legumes), tree hollows and native species recruitment (Grant 2006 Oliver et al. 2007; Eyre et al. 2015).

It takes many years for the rehabilitated ecosystem to achieve ecosystem function, and associated processes, comparable to the reference ecosystem (Ruiz-Jaen and Aide 2005) and as such, in post mine rehabilitation, aiding the rehabilitating ecosystem's function is a timely and difficult endeavour. The novel ecosystem that is created after the initial landform is established is deficient in all attributes that constitute a functional ecosystem, except where material from the pre-mining landscape has been salvaged and emplaced, such as hollow-bearing trees or stags and coarse woody debris. Of high importance are the nutrient levels in the soil as these will affect the subsequent development of the vegetation; which itself affects the colonisation of fauna (SER 2004; Grant et al. 2007). Mines have used differing methods to try to aid the rehabilitation of the nutrient cycle, including:

- a one-off application of fertiliser or organic ameliorants (i.e. compost made from mixed waste or green waste) (Grant et al. 2007; Nussbaumer et al. 2012)
- establishment of nitrogen fixing plants (Grant et al. 2007)
- the use of topsoil, specifically directly transferred topsoil – this has been shown to preserve the pre-existing soil seed bank and microbial communities which are fundamental to the progression of the rehabilitation (Rokich et al. 2000; Holmes 2001; Nussbaumer et al. 2012).

1.4.2 Ecosystem Resilience

Resilience is an essential component of an ecosystem's ability to be self-sustainable and, by extension, is an essential ecological component of rehabilitation and restoration (SER 2004). Broadly, from an ecological perspective, resilience can be defined as an ecosystem's ability to '*tolerate and recover from a disturbance*' (Newton 2016). However, ecosystem resilience has been defined and redefined in the literature with differing concepts of resilience proposed (SER 2004; Hollnagel 2010; Lake 2013; Newton 2016). For example, engineering resilience and ecosystem resilience are two of the most used definitions of resilience. Engineering resilience is defined as the system's ability to adjust its functioning before, during, and after a disturbance in order to resume its normal functions; a system's ability to return to its regular state after a disturbance (Hollnagel 2010; Lake 2013). Ecological resilience defines an ecosystem as having multiple stable states. Under this definition, the ecosystem, after a disturbance event, may shift to a different stable state and continue to function healthily (SER 2004; Lake 2013; Newton 2016; Quinlan et al. 2016). Due to the ambiguity surrounding the definition of resilience there are inherent difficulties when trying to understand and measure what processes contribute to an ecosystem's resilience (Bennett et al. 2005).

Very few studies have been conducted with the specific aim to measure resilience, and even fewer examining resilience in rehabilitated areas. This is because, by definition, resilience can only be adequately assessed post-disturbance event, for example post-fire resilience (Bennett et al. 2005; Quinlan et al. 2016). Studies have been completed examining mine rehabilitation response to fire disturbance with varying results, two of which examined sites of comparable ages (Grant and Loneragan 1999; Grant and Loneragan 2001; Herath et al. 2009). One study observed an increase in species richness after the rehabilitation area had been burnt (Grant and Loneragan 1999), whereas another observed a significant decrease in species richness (Herath et al. 2009). It has been proposed that the differences in results could be due to differences in rainfall patterns; reproductive maturity of lignotubers and seedbanks; interactions between multiple disturbances (e.g. drought); and difference in vegetation resilience (Herath et al. 2009). While these studies do not provide much insight into what creates a resilient ecosystem, they do demonstrate the great complexity that exists in measuring ecosystem resilience and methods to ensure rehabilitated sites demonstrate resilience to disturbance events.

1.4.3 Faunal Use

Fauna colonisation of rehabilitated areas on mine sites has been assessed and monitored in a variety of ways and the literature indicates that mine rehabilitation can, with appropriate time, support a diversity of fauna species (Ruiz-Jaen and Aide 2005; Cristescu et al. 2012). When considering fauna as a whole group, the methods used to rehabilitate the area (i.e. specifically using fresh topsoil and using seeds, or a combination of seeds and seedlings) were shown to have the strongest effect on fauna richness and density in a review conducted by Cristescu et al. (2012). This review also identified the age of the rehabilitation area as having a small positive effect on fauna richness, and this finding is supported by Munro et al. (2007). Despite these findings, different taxa appear to have different environmental requirements when recolonising a rehabilitated area (Munro et al. 2007; Cristescu et al. 2012).

Rehabilitation areas in proximity to remnant vegetation have been shown to benefit from bird recolonisation (Hobbs et al. 2003; Munro et al. 2007). Mammals, having less mobility, are slower to recolonise rehabilitation areas (Munro et al. 2007) due to the absence of habitat features such as tree hollows and habitat logs, upon which they would rely for site occupation. Studies on the colonisation of ants and other invertebrates (collembola, arachnids, crustacea) in rehabilitated areas have had variable results. For example, ants have had the most success in rehabilitated areas, with studies demonstrating the diversity, richness, and density values recorded in rehabilitation areas are often higher than those in undisturbed areas. Conversely, the assemblage of ant species and functional groups found in rehabilitated areas were not comparable to those in undisturbed areas (Cristescu et al. 2012). These results demonstrate the complexities that are faced when attempting to encourage the recolonisation of post-mined lands by faunal groups.

When compared to other ecological restoration types (e.g. restoration of land previously utilised for agriculture), mine site rehabilitation appears to be recolonised by multiple taxa in a shorter period. In bauxite mine rehabilitation, birds, reptiles, and invertebrates achieved species richness scores comparable with unmined reference sites within seven years (Nichols and Watkins 1984; Nichols and Bamford 1985; Nichols and Muir 1989; Munro et al. 2007).

2.0 Legislation, Policy and Guidelines

Relevant legislation, policies and guidelines were reviewed for their applicability to this project, particularly those that relate to NSW and Queensland. Summaries of these reviews are provided in the following sections.

2.1 Commonwealth

***Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)**

The EPBC Act provides the framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places, which are defined as matters of national environmental significance. The EPBC Act provides for the identification and listing of species and ecological communities as threatened (vulnerable, endangered or critically endangered categories) and the development of conservation advice and recovery plans for listed species and ecological communities. In the case of ecological communities, the conservation advice provides the information necessary to confirm their presence, or otherwise. The Act provides for the establishment of a Threatened Species Scientific Committee responsible for listing of these entities, however the Minister for the Environment retains approval over the final listing.

EPBC Act Environmental Offset Policy (October 2012)

This policy aims to ensure that biodiversity offsets under the EPBC Act meet a set of clearly stated requirements. There is no mention in the policy of the ability to use, or otherwise, ecological mine rehabilitation as an offset, however a recently approved mining project in NSW has been permitted to use 'rehabilitation offsets' to partially compensate for the impact on a critically endangered ecological community.

The policy provides the overarching offset requirements under the EPBC Act, which state that offsets must meet the following:

- deliver an overall conservation outcome that improves or maintains the viability of the aspect of the environment that is protected by national environment law and affected by the proposed action
- be built around direct offsets but may include other compensatory measures
- be in proportion to the level of statutory protection that applies to the protected matter
- be of a size and scale proportionate to the residual impacts on the protected matter
- effectively account for and manage the risks of the offset not succeeding
- be additional to what is already required, determined by law or planning regulations or agreed to under other schemes or programmes (this does not preclude the recognition of state or territory offsets that may be suitable as offsets under the EPBC Act for the same action)
- be efficient, effective, timely, transparent, scientifically robust and reasonable
- have transparent governance arrangements including being able to be readily measured, monitored, audited and enforced.

The policy also states that in assessing the suitability of an offset, government decision-making will be:

- informed by scientifically robust information and incorporate the precautionary principle in the absence of scientific certainty
- conducted in a consistent and transparent manner.

2.2 New South Wales

Biodiversity Conservation Act 2016 **(BC Act)**

The purpose of the BC Act is to maintain a healthy, productive and resilient environment for the greatest well-being of the community, now and into the future, consistent with the principles of ecologically sustainable development. This Act provides for the listing of species and ecological communities native to NSW as threatened (vulnerable, endangered or critically endangered categories) and provides for the establishment of an independent Threatened Species Scientific Committee responsible for listing of these entities.

The BC Act establishes the framework for the assessment of biodiversity on development and offset sites through the Biodiversity Assessment Method (BAM) and the Biodiversity Offset Scheme (BOS). The Biodiversity Conservation Trust (BCT) is a body corporate established under the BC Act to implement the BOS.

Upon its commencement on 20 August 2017, the BC Act replaced the *Threatened Species Conservation Act 1995* (TSC Act), and all relevant listed ecological communities, species, populations and key threatening processes were transferred to the new legislation.

Biodiversity Conservation Regulation 2017

This Regulation was established under the BC Act. It makes provision for matters that are required or authorised to be prescribed by the Regulations as a consequence of the enactment of the BC Act, such as the BOS which provides the framework to avoid, minimise and offset impacts on biodiversity values from development, the listing criteria for threatened species and ecological communities and biodiversity assessments and approvals under the *Environmental Planning and Assessment Act 1979* (EP&A Act).

Mine Site Ecological Rehabilitation under the Biodiversity Offsets Scheme – Proposed Ancillary Rules

The draft of the Mine Site Ecological Rehabilitation Under the Biodiversity Offsets Scheme (DPIE 2021a) contains Ancillary Rules to be published under clause 6.5 of the Biodiversity Conservation Regulation 2017 (BC Regulation), permitting the use of mine site ecological rehabilitation as an offset. The Bilateral Agreement between the Commonwealth and NSW governments (Bilateral agreement made under section 45 of the EPBC Act) ensures that the Commonwealth can permit ecological mine rehabilitation in mine development approvals.

This document contains the standards and information required for mine site rehabilitation that is proposed to be used as a biodiversity offset to meet a credit obligation under the BOS, which is applied as part of the development consent process. It contains two sections: Part A being Background Information and Part B being the Ancillary Rules.

The following rules apply to the use of ecological mine rehabilitation to meet an offset requirement:

- the proposed development must be a state significant mining project that is under a mining lease

- it must be used to offset the development seeking approval
- it must be established on the site of the proposed development.

The draft Ancillary Rules (Part B) set out the following:

1. Definition of ecological rehabilitation applicable to the ancillary rules, being rehabilitation that is "*recognisable and self-sustaining native plant community types and habitat that supports self-sustaining threatened species population (where threatened species or their habitat have been identified previously as likely to be present*" (DPIE 2021a)
2. Using ecological rehabilitation to contribute to meeting an offset obligation, including requirements to meet an offset obligation (general and requirements for the Environmental Impact Statement (EIS))
3. information that must be provided to the consent authority when seeking approval for the mining development (in an Environmental Impact Statement (EIS))
4. the targeted type of biodiversity to be recreated in the rehabilitation, depending on the biodiversity to be impacted (i.e. like-for-like rehabilitation or ecological rehabilitation for species credits)
5. monitoring and assessment of ecological rehabilitation under the ancillary rules
6. objectives, performance indicators and completion criteria that must be met
7. a method to calculate the biodiversity value (in credits) of the rehabilitation obligation.

A number of general requirements are stipulated in the document, as well as specific requirements depending on whether the rehabilitation is intended to meet an offset obligation in ecosystem or species credits. Guidance is also provided on the types of information which could be provided to demonstrate that the proposed rehabilitation is feasible and likely to succeed.

In the case where a credit obligation is generated for impacts to a vegetation community that is consistent with more than one TEC, for example a TEC listed under both the BC Act and the EPBC Act, and that credit obligation is to be met using ecological mine rehabilitation, the rehabilitation objectives must be for the creation of a PCT associated with both TECs.

The draft Ancillary Rules state the rehabilitation objectives that must be contained within the EIS for a proposed mining development where ecological mine rehabilitation is proposed to be used as an offset. The rehabilitation objectives set the standard that must be met for the rehabilitation to be considered successful and they are also included in the conditions of consent for the mining development. The draft Ancillary Rules state that it is expected that the rehabilitation objectives can generally be achieved within 20 years. If they are not met within this timeframe the timeframe may be extended for a period of up to 5 years if the NSW Resources Regulator and the consent authority consider that the objectives are likely to be met within that time, based on trends in the monitoring data, or the consent authority may require that the obligation is met through one of the other options in clause 6.2 of the BC Regulation (payment into the Biodiversity Conservation Fund for example).

The method used to calculate the biodiversity credit value of mine site ecological rehabilitation is described in the draft Ancillary Rules, which includes changes to section 11 of the BAM (DPIE 2020a) using modified interpretations of key terms when applying the Ancillary Rules, such as 'biodiversity stewardship site' meaning the proposed ecological rehabilitation.

Guidelines for the Ecological Rehabilitation of Recognisable and Self-sustaining Plant Community Types: Guidance for the Upper Hunter Strategic Assessment

These guidelines (Office of Environment and Heritage and Department of Industry 2016) were developed to set the standard that proponents must commit to in order to use rehabilitation to contribute to meeting an offset requirement under the Upper Hunter Strategic Assessment (UHSA), an assessment of the potential impacts of coal mining in the Upper Hunter Valley on nationally protected matters and threatened species, populations and ecological communities. They provide guidance on the development of appropriate rehabilitation objectives, performance indicators and performance targets/completion criteria for ecological rehabilitation. They also provide clarification of key risks to successful ecological rehabilitation and provide guidance on risk mitigation at each stage in the mining process through to lease relinquishment. The UHSA has not been formally approved by NSW or Commonwealth governments, and as such these guidelines are not active or enforceable.

Standard Rehabilitation Conditions on Mining Leases

An amendment to the Regulation for mine rehabilitation in NSW under the *Mining Act 1992* came into effect on 2 July 2021 (NSW Resources Regulator 2021b). The Mining Amendment (Standard Conditions of Mining Leases—Rehabilitation) Regulation 2021 prescribes new mining lease conditions to set clear and enforceable requirements for mine rehabilitation which is applicable to all mining leases in NSW. The NSW Resources Regulator (2021b) has also developed a series of 'form and way' documents and supporting guidelines to specify how mining operations must prepare the required documentation to satisfy the requirements of the Regulation.

Under the Regulation, mining operations are required to prepare and implement Rehabilitation Management Plans to define Rehabilitation Objectives, Completion Criteria and identify and address risks to rehabilitation. Annual Rehabilitation Reports and forward programs must also be prepared, detailing mining and rehabilitation activities planned over the next three years. These requirements replace existing Mining Operations Plans (MOPs), which have a 12-month transition period starting from the date the Regulation commenced for large mines, and a 24-month transition period for small mines (NSW Resources Regulator 2021b).

2.3 Queensland

Environmental Offsets Act 2014

The *Environmental Offsets Act 2014* (EO Act) provides for the use of environmental offsets to counterbalance the significant residual impacts of activities on environmental matters. This is achieved through the establishment of a framework for environmental offsets; recognition of the level of protection given to prescribed environmental matters under other legislation; provision for national, state and local matters of environmental significance to be prescribed environmental matters for the purpose of the Act; and co-ordination of the implementation of the framework in conjunction with other legislation.

The use of rehabilitated lands as an offset is not specifically mentioned in the EO Act, however, it is mentioned in the Queensland Environmental Offsets Policy (State of Queensland 2017) which supports this Act. The EO Act is currently under review.

Environmental Offsets Regulation 2014

The Environmental Offsets Regulation supports and provides detail on elements of the EO Act, including the activities and environmental matters to which the EO Act applies. There is no mention of the use of rehabilitated lands as an offset in this document.

Environmental Offsets Policy 2017

The Environmental Offsets Policy (State of Queensland 2017) was developed to assist in the interpretation and implementation of the Queensland environmental offsets framework and is not a statutory document.

The Environmental Offsets Policy states that land that has been rehabilitated as a result of an authority requirement for one project can be used as an offset for a different project, once the rehabilitation works have been completed to the satisfaction of the authority condition. The rehabilitation must also meet the requirements of the offset framework in delivering a conservation outcome for the impacted matters.

Vegetation Management Act 1999

The purpose of the *Vegetation Management Act 1999* (VM Act) is to regulate clearing of vegetation in a way that:

a) conserves remnant vegetation that is an 'endangered', 'of concern' or 'least concern' regional ecosystem

b) conserves vegetation in declared areas

c) ensures clearing does not cause land degradation

d) prevents the loss of biodiversity

e) maintains ecological processes

f) manages the environmental effects of the clearing to achieve the matters mentioned in a) to e)

g) reduces greenhouse gas emissions

h) allows for sustainable land use.

This purpose is achieved through providing for assessment of relevant developments under the *Planning Act 2016*; enforcement of planning provisions; declared areas; a framework for decision making; and the regulation of particular regrowth vegetation.

2.4 General Guidance

Integrated Mine Closure, Good Practice Guide, 2nd Edition

The Integrated Mine Closure, Good Practice Guide, 2nd Edition (International Council on Mining and Metals (ICMM) 2019) provides guidance to the mining industry on integrated mine closure that takes into account environmental, social and economic considerations, with the overarching purpose of the document being to promote comprehensive closure planning in the early stages of mine development. The document describes the following as being integral to the mine closure process:

- Early definition of the closure plan, principles, and objectives.
- Implementation of closure activities both progressively and at the time of closure. The closure activities are to be specific to achieving the mine closure objectives, require criteria to determine success of each, and should be monitored to ensure success.
- Adequate planning and preparation for social transition.
- Consideration of the costs of closure and understanding alternative options for closure.

- Continued adaptation of the mine closure plan and periodic assessment of 'what-if' scenarios, such as sudden mine closure, to help minimise disruption caused by unplanned events.
- Planning for land relinquishment post closure.

3.0 Purpose of the Study

3.1 Knowledge Gap and Significance

There is strong view that for policy to be effective it must be based on, or influenced by, scientific evidence (Gulbrandsen 2008; Argyrous 2012). Indeed, this science-policy interface is crucial to the development of beneficial policy in the environmental management and decision-making sphere (Gulbrandsen 2008), for environmental issues can only be adequately managed, on a large scale, through interaction and knowledge sharing between researchers and policy makers (Gulbrandsen 2008). The recent progression in environmental legislation, along with accompanying policy and guidelines, is evidence that there is a push within the NSW, Queensland and Commonwealth governments, and likely elsewhere, to allow the use of mine rehabilitation as a biodiversity offset (BC Act 2016; State of Queensland 2017; DPIE 2021a). These policy changes have the potential to result in positive environmental outcomes, for example the production of higher quality mine rehabilitation which provides potential conservation outcomes. However, there remains a knowledge deficit surrounding the ability for mine rehabilitation to perform in such a way and appropriate methods to adequately manage these ecosystems.

For this legislative initiative to have beneficial ecological outcomes it is first necessary to comprehensively understand whether mine rehabilitation has the potential to achieve a recognisable vegetation community that is able to sustain itself in the long-term. In addition to this fundamental need, mine operators, and those monitoring rehabilitation condition and performance, must also have guidance on how best to monitor rehabilitation progression and assess rehabilitation success. Without the enactment of scientifically verified, ecologically sound management programmes and objectives, there emerges the risk of sub-optimal management strategies which may subsequently result in negative ecological outcomes (Stefano 2004). To this end, targeted research is required in this field.

3.2 Aims and Objectives

This research project aimed to understand whether specific ecological communities can be established in mine rehabilitation to not only meet mining project approval requirements, but also potentially satisfy a biodiversity offset requirement due to their potential contribution to conservation outcomes in a locality and through their long-term persistence.

The following objectives were set to achieve this aim:

1. Determine whether mine rehabilitation can support recognisable and self-sustaining ecological communities in Australian temperate woodland environments.
2. Determine whether mine rehabilitation can support a recognisable and self-sustaining ecological community that meets the EPBC Act Approved Conservation Advice for the *Central Hunter Valley Eucalypt Forest and Woodland CEEC* and also relevant BC Act listed TECs.
3. Determine whether mine rehabilitation can support habitat for a range of threatened fauna species, including birds and mammals.
4. Develop a set of principles to inform the establishment of appropriate rehabilitation objectives, performance indicators and completion criteria for the establishment of recognisable and self-sustaining ecological communities (focusing on temperate woodlands).

5. Provide guidance to industry to inform the establishment of benchmark successional stage criteria and a monitoring programme to guide progressive ecological rehabilitation success or adaptive management.

Investigations that relate to Objectives 1, 2 and 3 are discussed in **Part Two** of this report. Objectives 4 and 5, which were informed by the outcomes of investigations undertaken in **Part Two**, are addressed in **Part Three** of this report.

Part Two – Data Collection, Analysis and Results

This section addresses Objectives 1, 2 and 3 of the project and focuses on the collation of existing information, the collection of field-based data, and analyses to determine whether mine rehabilitation can support recognisable and self-sustaining ecological communities, including TECs, in temperate Australian environments as well as habitat for a range of threatened fauna species.

As part of these investigations, desktop assessments of existing information pertaining to individual mine sites were collated, including flora and fauna monitoring data, to review the progress of rehabilitation at various mining operations and compile records of threatened fauna species observed within rehabilitated areas.

A comprehensive field survey programme was undertaken across five mine sites in the Hunter Valley, NSW, to collect information relating to recognisability and self-sustainability. Field surveys were undertaken in collaboration with DPIE staff, who focused on the collection of function data, excluding LFA data. A standalone report was prepared by DPIE (Oliver and Dorrough 2019), which is provided in **Appendix 1**, with key methods and results summarised and presented in the main report.

4.0 Background Information

The investigations relating to Objectives 1, 2 and 3 of this project required a thorough review and understanding of the vegetation classification system used in NSW, namely the classification of PCTs, and the documents that describe the target TECs under the NSW and Commonwealth legislation. This information is summarised below.

4.1 PCT Classification in NSW

The timing of this project coincided with a foreshadowed transition from one PCT classification system to another in NSW. Prior to field surveys, an analysis of PCTs that were currently in use in NSW, and that underpin the BAM, was undertaken with the aim of selecting candidate PCTs that have a strong relationship to the three Central Hunter TECs listed under the BC Act and the *Central Hunter Valley Eucalypt Forest and Woodland CEEC* listed under the EPBC Act. The floristic composition and distribution information provided on the BioNet Vegetation Classification website (DPIE 2021b) for a refined list of PCTs known to occur in the central Hunter Valley was used to determine which PCTs were most likely to conform to the target TECs. This analysis resulted in the selection of five PCTs, as shown in **Table 4.1**.

Table 4.1 PCTs from Current and Proposed Eastern NSW PCT Classifications and Relevant TEC

Original PCT (Current PCT Classification)	PCT (Eastern NSW PCT Classification)	Relevant TEC (BC Act)	Relevant TEC (EPBC Act)
PCT1601 – Spotted Gum – Narrow-leaved Ironbark – Red Ironbark shrub-grass open forest	PCT3315 – Central Hunter Ironbark-Spotted Gum Forest	Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC	Central Hunter Valley Eucalypt Forest and Woodland CEEC
PCT1604 – Narrow-leaved Ironbark – Grey Box – Spotted Gum shrub-grass woodland			
PCT1603 – Narrow-leaved Ironbark – Bull Oak – Grey Box shrub-grass open forest	PCT3431 – Central Hunter Ironbark Grassy Woodland	Central Hunter Grey Box – Ironbark Woodland EEC	
PCT1691 – Narrow-leaved Ironbark – Grey Box grassy woodland			
PCT1655 – Grey Box – Slaty Box shrub-grass woodland	PCT3485 – Central Hunter Slaty Gum Grassy Forest	Hunter Valley Footslopes Slaty Gum Woodland VEC	

An additional PCT, *PCT1176 – Slaty Box – Grey Gum shrubby woodland on the footslopes of the upper Hunter Valley, Sydney Basin Bioregion*, was considered for inclusion however information received from DPIE stated that recent analyses indicated that PCT1176 should be unassigned from the Hunter in favour of PCT1655 and that for this project we should view sites containing slaty box (*Eucalyptus dawsonii*) as being part of PCT1655 (Charles Huxtable pers. comm. 16 May 2019).

Following completion of field surveys, correspondence with the Vegetation Ecology and Classification team of DPIE identified that the Eastern NSW (ENSW) PCT Classification Revision was largely complete and that access to this draft classification could be provided to Umwelt for the purposes of this project. Consequently, additional analyses were undertaken, using the draft PCT Assignment Tool developed by

DPIE in conjunction with the revised ENSW PCT classification, to allocate sites sampled as part of the project to this new classification (refer to **Section 4.1.1**). This analysis identified three target PCTs that broadly correspond with target PCTs from the current classification and the target TECs, as shown in **Table 4.1**.

4.1.1 ENSW PCT Classification Revision

The following description of the proposed ENSW PCT Classification is based on a working draft of methods and results provided by DPIE (2019b) for inclusion in this study.

The ENSW PCT Classification was developed with the aim of providing revised PCTs identified through analysis of standard plot-based data at a consistent classification scale with floristic composition, distribution and environmental domains defined by explicit plot assignments stored in accessible databases. It is envisaged by DPIE that this approach, combined with diagnostic tools, will allow for transparent and objective assignment of new standard flora plots to the revised PCTs.

The study area for the project consisted of seven bioregions of eastern NSW and the ACT comprising the Australian Alps, New England Tableland, NSW North Coast, South East Corner, South Eastern Highlands, South-East Queensland and the Sydney Basin bioregions. Flora survey plot data was sourced from the Systematic Flora Survey module within the NSW BioNet database. Surveys conducted in highly modified vegetation were excluded, as were plots characterised by a high proportion or cover of exotic species. A total of approximately 49,000 plots were considered suitable for inclusion in analysis for the study, which included approximately 41,000 standard 400 m^2 floristic plots collected using a method that could reliably be converted to MBB 6-point scale. The study also utilised spatial layers (in raster format) for 54 environmental variables considered to have potential value as predictors of patterns of vegetation composition.

The dataset was initially partitioned using broad-scale environmental gradients through modelling species composition and environmental variables which resulted in 'Regions of Common Probability Profile' (RCPs). Analysis of the RCPs resulted in 10 RCP subsets, to which clustering was applied. Many clusters within each RCP were identified, which were then reviewed against legacy classification units, environmental domains and survey method/observer. Groups that formed around disturbed plots or observer effects were removed and their plots were reassigned to other groups.

A comprehensive review of all groups was undertaken using a variety of means including ordinations, group environment analyses and alternative clustering strategies using multiple statistical packages. The review considered group metrics, relationship to legacy classification units, census-based information and independent environmental data, as well as spatial distribution, floristic summaries and a tabulation of the 10 closest distance to group centroid values. The decision to retain groups was related to high floristic and environmental homogeneity, high fidelity to legacy classification units, low floristic overlap and/or coherent environmental relationships. Groups that did not have these attributes were retired.

Plot membership of retained groups was determined by the application of a standard distance-based measure. Plots were categorised as 'primary' members of a group where their distance to a group centroid was below a threshold value of 0.695. This threshold value represented the 95^{th} percentile of distances for all groups containing 20 or more plots. For small groups containing less than five plots with distinct floristic and environmental character, the 'placeholder' status was assigned. Plots were categorised as a 'secondary' member if the plot had plausible floristic and environmental relationships to a group but its distance to group centroid was above the 0.695 threshold value and the data indicated low species richness, atypical cover scores or potential disturbance effects. Plots were assigned to the 'unresolved' category where no satisfactory choices were available, and a small number of plots were 'excluded' where the data was considered to have an irredeemable problem.

Multiple rounds of review were undertaken, each time incorporating additional plots that had been withheld in previous rounds due to potential 'noise' or the use of different scoring systems, including presence/absence data. On completion of each round of review, the revised primary plot assignments were used to update group definitions and distance to group centroid values for all plots. Each round was completed by applying a final set of group review processes.

Following the completion of four rounds of review, groups were evaluated against four environmental covariates to identify consistency of environmental definitions and to identify potential environmental outliers. Elevation, mean annual rainfall, mean annual temperature and seasonal radiation were selected as the useful variables in explaining within-RCP-group variations and all except radiation had consistently high values for discriminating among groups within RCPs.

Draft revised PCTs were determined following round four of review and the plot membership of each group was used to define the floristic and environmental attributes for each draft PCT. Short descriptive labels were given and included salient features such as regional descriptors or locality information and relevant combinations relating to topography, substrate, characteristic species and vegetation structure that were suitable to distinguish PCTs.

The relationship to existing classifications was also undertaken as part of the study. This included relationships to legacy classifications, existing PCTs, threatened ecological communities listed under the BC Act and/or the EPBC Act and NSW Class and Formation Classes (Keith 2004).

In conjunction with the revised ENSW PCT Classification, DPIE have developed a web-based tool to assist in the assignment of new unclassified plots. This draft PCT Assignment Tool provides information about the degree to which a plot aligns with revised PCTs using three criteria:

1. comparing plot *distance to centroid* for all revised PCTs
2. percentage of each PCT's *characteristic species* recorded in the plot (under development)
3. whether the plot is located within the known *spatial and environmental range* of the closest matching PCTs, based on elevation, mean annual rainfall and mean annual temperature.

4.2 Threatened Ecological Communities

In the NSW Hunter Valley, two endangered ecological communities (EECs) and one vulnerable ecological community (VEC) listed under the BC Act significantly overlap with one CEEC listed under the Commonwealth EPBC Act. Key and ancillary features vary between TECs, which are described in the Approved Conservation Advices (for EPBC Act listed units) and the Final Determinations (for BC Act listed units). The key diagnostic or characteristic attributes for each TEC vary according to the legislation that they relate to, with TECs listed under the EPBC Act typically having more prescriptive or diagnostic criteria that must be satisfied compared to TECs listed under the BC Act, which can be more open to interpretation and less deterministic.

Approved Conservation Advice for TECs listed under the EPBC Act typically contain information relating to the identification of EPBC Act-listed TECs in the form of 'Diagnostic Features and Condition Thresholds'. They also contain extensive information including a comprehensive description of the community and its biophysical determinants, structural and taxonomic composition, threats, listing eligibility details, priority conservation actions and a range of other supporting information. However, it is the diagnostic criteria and condition thresholds that are critical in determining the presence or absence of the threatened ecological community.

Modern Final Determinations describing TECs listed under the BC Act generally contain the following:

- Parts 1 & 2: Section 1.6 of the BC Act defines an ecological community as '*an assemblage of species occupying a particular area*'. These features of an ecological community are described in Parts 1 and 2 of the Final Determination, respectively.
- Part 3: Part 3 of the Final Determination describes the eligibility for listing of the ecological community in Schedule 2 of the BC Act according to criteria as prescribed by the Biodiversity Conservation Regulation 2017.
- Part 4: Part 4 of the Final Determination provides additional information intended to aid recognition of the community in the field. Rather than being diagnostic, information in Part 4 is a guide to assist recognition as, given natural variability, along with disturbance history, the ecological community may sometimes occur outside the typical range of variation in the features described in Part 4.

Older Final Determinations do not necessarily adhere to the approach described above, but generally they include the following:

- characteristic assemblage of flora species, including dominant species
- vegetation structure
- locational features (geographic and landscape)
- biophysical features
- relationship to other vegetation types and/or TECs.

As discussed in **Section 1.3.3**, there are no agreed and accepted approaches to applying the list of characteristic species (as opposed to diagnostic species) contained in Final Determinations in the identification of TECs listed under the BC Act. Tozer (2003) developed an approach to identifying vegetation map unit types in the Cumberland Plain based on the total number of native species present in a standard 400 m^2 plot and the minimum number of diagnostic species. The classification of species as 'diagnostic' however, requires statistical analysis to determine which species have positive fidelity to a specific community (those that occur more frequently in a target group than in all other sites within the classification), as opposed to species which are classified as 'constant' (those that occur frequently in the target group and other groups) which are more 'characteristic' than 'diagnostic' (Tozer 2003). As the Final Determinations contain only characteristic species, rather than diagnostic, this approach is not appropriate for use in this study.

The TECs which are the focus of this study are those that occur predominantly on the coal measures of the NSW Hunter Valley. The Hunter Valley contains a convenient overlap of one EPBC Act and three BC Act listed TECs within the coal mining district, as identified in **Table 4.1** above, being:

- Central Hunter Valley Eucalypt Forest and Woodland CEEC (EPBC Act)
- Central Hunter Grey Box – Ironbark Woodland EEC (BC Act)
- Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC (BC Act)
- Hunter Valley Footslopes Slaty Gum Woodland VEC (BC Act).

Areas under the management of coal mining companies in the Hunter Valley often contain at least one, but often several, of the abovementioned TECs. Areas of these TECs occur in varying condition depending on the nature, duration and intensity of previous land uses. Many of these areas have been previously cleared for agricultural activities, particularly for stock grazing, and many remnants are highly fragmented and fringed by areas of derived native grassland (Peake 2006). Areas of regeneration of the TECs are also present where grazing and clearing pressure has been removed, particularly in mining buffer areas or areas established as a land-based biodiversity offset for mining activities.

Previous investigation by Umwelt (2017a) indicates that some areas of mine rehabilitation in the Hunter Valley were meeting, or were trending towards, the *Central Hunter Valley Eucalypt Forest and Woodland CEEC* listed under the EPBC Act despite there being no planning, design or requirement to achieve such. It is therefore also feasible and likely that these areas could also align with one of the TECs listed under the BC Act.

4.2.1 Central Hunter Valley Eucalypt Forest and Woodland CEEC

The *Central Hunter Valley Eucalypt Forest and Woodland CEEC* was listed under the EPBC Act in 2015 and is located in the central Hunter Valley of NSW, generally on soils derived from Permian-aged sedimentary rock found on valley floors, lower hillslopes and low ridges (DoE 2015). The diagnostic characteristics of this CEEC are provided in **Table 4.2**.

Table 4.2 Diagnostic Characteristics of Central Hunter Valley Eucalypt Forest and Woodland CEEC

Component	Central Hunter Valley Eucalypt Forest and Woodland CEEC
Geology/geomorphology	Typically* occurs on lower hillslopes and low ridges, or valley floors in undulating country; on soils derived from Permian sedimentary rocks (DoE 2015).
Composition	The canopy of this community is dominated by one or more of the following species: narrow-leaved ironbark (*Eucalyptus crebra*), spotted gum (*Corymbia maculata*), slaty gum (*Eucalyptus dawsonii*), and grey box (*Eucalyptus moluccana*). The CEEC typically has a shrubby midstorey and the ground layer typically contains native ferns, forbs, grasses and rushes. The list of characteristic flora species is contained in Table B1 of the Conservation Advice (DoE 2015). Several contra-indicative species are listed in the Approved Conservation Advice (2015) as being largely absent, however isolated occurrences may occur. These include forest oak (*Allocasuarina torulosa*), white mahogany (*Eucalyptus acmenoides*) and red ironbark (*Eucalyptus fibrosa*).
Structure	The CEEC comprises woodlands and open forests, typically with a shrub layer of variable density and/or a grassy ground layer (DoE 2015).
Location	The CEEC occurs in the Hunter Valley region, primarily the Central Hunter in the Sydney Basin Bioregion, and to the north east in the NSW North Coast IBRA bioregion (DoE 2015). Within the Sydney Basin Bioregion, the CEEC occurs mainly within the Hunter Valley IBRA subregion. It also occurs in adjacent subregions including the Kerrabee IBRA subregion (Goulburn Valley) and in the Upper Hunter IBRA subregion (Hunter Thrust Zone) (DoE 2015).
Other information	The list of key diagnostic characteristics of the CEEC are listed in Section 1.5.1 of the Conservation Advice (DoE 2015) which specify location, geomorphology, soil type, canopy cover and floristic composition. Condition thresholds which must be met for the CEEC to be present are contained in Section 1.5.3 of the Conservation Advice (DoE 2015). The condition thresholds require vegetation patches to be of a certain sized zone with at least 50 % of perennial understorey vegetative cover comprising native species.

Note: *The term 'typically' is interpreted here as applying to the whole sentence rather than the first phrase only, that is, "typically occurs on lower hillslopes and low ridges, or valley floors in undulating country"; and typically "on soils derived from Permian sedimentary rocks" meaning that, apart from soils derived from geological strata specifically excluded from the Advice (Triassic, aeolian and Quaternary alluvium) the CEEC may occur on soils types other than those derived from Permian strata.

4.2.2 Central Hunter Grey Box – Ironbark Woodland EEC

The *Central Hunter Grey Box – Ironbark Woodland EEC* was listed under the former TSC Act in 2010. It occurs on slopes and undulating hills in the central Hunter Valley (NSW Scientific Committee 2010a). The key characteristics of this EEC are provided in **Table 4.3**.

Table 4.3 Characteristics of Central Hunter Grey Box – Ironbark Woodland EEC

Component	Central Hunter Grey Box – Ironbark Woodland EEC
Geology/geomorphology	The EEC occurs on Permian sediments in the Hunter Valley.
Composition	The EEC is characterised by the assemblage of 38 species listed in Paragraph 2 of the Final Determination (NSW Scientific Committee 2010a). It is noted that the total list of species that comprise the community is considerably larger than that provided in Paragraph 2 and the species present will be influenced by the size of the site, rainfall, drought conditions and disturbance history. The community also includes micro-organisms, fungi, cryptogams and vertebrate and invertebrate fauna, which are all poorly documented.
Structure	The EEC typically forms a woodland to open forest (NSW Scientific Committee 2010a).
Location	The EEC has been recorded from Cessnock, Singleton and Muswellbrook local government areas but may occur elsewhere in the Sydney Basin Bioregion (NSW Scientific Committee 2010a).
Other information	It is noted that the EEC shares characteristic species with, but is not part of, the Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC (NSW Scientific Committee 2010a).

4.2.3 Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC

The *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* was listed under the former TSC Act in 2010. It generally occurs on Permian sediments in the central Hunter Valley (NSW Scientific Committee 2010b). The key characteristics of this EEC are provided in **Table 4.4**.

Table 4.4 Characteristics of Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC

Component	Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC
Geology/geomorphology	The EEC occurs on Permian sediments in the Hunter Valley (NSW Scientific Committee, 2010b).
Composition	The EEC is characterised by the assemblage of 44 species listed in Paragraph 2 of the Final Determination (NSW Scientific Committee 2010b). It is noted that the total list of species that comprise the community is considerably larger than that provided in Paragraph 2 and the species present will be influenced by the size of the site, rainfall, drought conditions and disturbance history. The community also includes micro-organisms, fungi, cryptogams and vertebrate and invertebrate fauna, which are all poorly documented.
Structure	The EEC typically forms an open forest to woodland (NSW Scientific Committee 2010b).

Component	Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC
Location	The EEC has been recorded from Cessnock, Singleton and Muswellbrook local government areas but may occur elsewhere in the Sydney Basin Bioregion (NSW Scientific Committee 2010b).
Other information	It is noted that the EEC shares characteristic species with, but is not part of, the Central Hunter Grey Box – Ironbark Woodland EEC (NSW Scientific Committee 2010b).

4.2.4 Hunter Valley Footslopes Slaty Gum Woodland VEC

The *Hunter Valley Footslopes Slaty Gum Woodland VEC* was listed under the former TSC Act in 2010. It generally occurs at the interface of Narrabeen Sandstone and Permian sediments in the Hunter Valley (NSW Scientific Committee 2010c). The key characteristics of this VEC are provided in **Table 4.5**.

Table 4.5 Characteristics of Hunter Valley Footslopes Slaty Gum Woodland VEC

Component	Hunter Valley Footslopes Slaty Gum Woodland VEC
Geology/geomorphology	The VEC generally occurs on colluvial soils on exposed footslopes at the interface of Narrabeen Sandstone and Permian sediments in the Hunter Valley (NSW Scientific Committee 2010c).
Composition	The VEC is characterised by the assemblage of 29 species listed in Paragraph 2 of the Final Determination (NSW Scientific Committee 2010c). It is noted that the total list of species that comprise the community is considerably larger than that provided in Paragraph 2 and the species present will be influenced by the size of the site, rainfall, drought conditions and disturbance history. The community also includes micro-organisms, fungi, cryptogams and vertebrate and invertebrate fauna, which are all poorly documented.
Structure	The VEC forms a woodland structure, or occasionally forest, with a sparse to moderately dense tree stratum, occasional low tree stratum, and moderately dense to dense shrub stratum. The groundcover is typically sparse to very sparse and is relatively species poor (NSW Scientific Committee 2010c).
Location	The VEC has been recorded from Singleton and Muswellbrook local government areas but may occur elsewhere in the Sydney Basin Bioregion (NSW Scientific Committee 2010c).

5.0 Methods

5.1 Evidence of Recognisable and Self-sustaining Rehabilitation from NSW and Queensland Mines

A desktop analysis was undertaken to collect information on various mines in NSW, focussing on the Hunter Valley in NSW and the Bowen Basin in Queensland. Documents such as MOPs, management plans and monitoring reports from each of the target coal mines (Mangoola Coal, Mount Thorley Warkworth, Mount Owen Mine, Bulga Coal, United Collieries, Boggabri Coal, Wilpinjong Coal Mine, Burton Coal Mine and Rolleston Mine) were used to collate existing data. The data were then used to determine whether there is any evidence that these mine sites have been able to achieve, or are on a trajectory toward achieving, recognisable and self-sustainable ecological communities in their rehabilitation areas. Raw data were not available for this project for every mine site, consequently the reviews presented in **Section 6.1** were generally based on interpretations of the data provided within the monitoring reports.

5.2 Threatened Fauna Use of Rehabilitation Sites

A desktop analysis was undertaken to collect information on fauna habitat use in rehabilitation areas. Threatened species records contained in fauna monitoring reports from Mangoola Coal, Mount Owen Mine, Bulga Coal and United Collieries were collated. For some mine sites, only the most recent monitoring report was reviewed as historical monitoring results were referred to within them. The monitoring reports reviewed in this task were:

- Bulga Coal Complex Annual Fauna Monitoring Report (RPS 2017 and 2020)
- United Collieries 2018 Ecological Monitoring Report (Umwelt 2019b)
- Mangoola Open Cut 2020 Ecological Monitoring Report (Umwelt 2021)
- Mangoola Open Cut 2018 Ecological Monitoring Report (Umwelt 2019c)
- Mangoola Open Cut 2016 Ecological Monitoring Report (Umwelt 2017b)
- Mangoola Coal Project Ecological Monitoring 2015 (Forest Fauna Surveys and Eastcoast Flora Surveys 2016)
- Mt Owen Glendell Operations (MGO) Fauna Monitoring 2019 Annual Report (Forest Fauna Surveys 2020)
- Mt Owen Complex Fauna Monitoring 2004-2019 Annual Reports (Forest Fauna Surveys 2004-2020).

5.3 Sample Size Analysis

To determine the number of sites to sample for each vegetation type, preliminary multivariate sample sufficiency tests were conducted to determine the number of sample replicates required in order to achieve robust analysis for comparing vegetation composition with reasonable precision for subsequent dissimilarity-based multivariate analysis. Tests were conducted using a multSE method developed by Anderson and Santana-Garcon (2015), which assesses sample-size adequacy with the aim of determining when additional sampling has no improvement in describing whole communities with reasonable precision for subsequent dissimilarity-based multivariate analysis. It should be noted that the multSE method is used here as a heuristic diagnostic tool rather than prescriptive analyses.

Tests were conducted using existing floristic abundance data collected from a previous monitoring programme at Mangoola Mine. These data were collected from both reference and rehabilitation sites in similar vegetation types to be sampled for this study. The vegetation communities used are consistent with those identified in the 2016 Mangoola monitoring report (Umwelt 2017b), being Slaty Box Woodland, Ironbark Woodland, Grey Box Woodland and Spotted Gum Forest communities, while treatments referred to whether the area consisted of post-mine rehabilitated lands, revegetated areas, or reference sites in areas of remnant vegetation. These data were log+1 transformed before being analysed using the multSE method to derive errors for estimates so that significant changes in precision, as a function of sample size, could be tested. Permutations of 10,000 iterations were used to arrive at a mean for each sample size and bootstrapped to derive 95% confidence intervals around these means. Subsequent determination of overlap in confidence intervals allowed the identification of significant precision changes from one sample size to another.

5.4 Field Sampling

Field surveys in the NSW Hunter Valley were conducted between March and May 2019. Rehabilitation data were collected at five open cut coal mines, and reference site sampling was undertaken in remnant vegetation situated on land managed by these and one other mine, and one conservation area (**Table 5.1**). The field team consisted of two Umwelt ecologists, two DPIE scientists and one contractor to DPIE. Umwelt focused on collecting data for the recognisability component of the study while DPIE focused on the self-sustainability component. As such, this report will focus on the recognisability methods, results, and discussion while only reporting the overall findings of the self-sustainability component. The full DPIE report can be viewed in **Appendix 1**.

Table 5.1 Field Sampling Dates and Locations

Location	Survey Dates
Mangoola Mine	4-8 March 2019 11-15 March 2019
Mt Thorley Warkworth (MTW) (including reference sites at Wambo Mine, Belford National Park and properties at Jerrys Plains owned by Peabody and Glencore)	25-29 March 2019 1-4 April 2019
United Mine	5 April 2019
Mount Owen Mine (MTO)	6-9 May 2019
Bulga Mine	13-16 May 2019

5.4.1 Climatic Conditions

At the time of survey commencement, the Hunter Valley was classified as ‘drought watch’ and ‘drought onset’ according to the Department of Primary Industry website (DPI 2019). By the completion of surveys, some areas had been upgraded to ‘drought’ level, whilst the remaining areas were mapped as either ‘drought onset’ or ‘drought watch’ (DPI 2019). Refer to **Appendix 2** for the rainfall data for each mine site for the twelve months preceding the survey and the long-term average rainfall for the nearest weather station.

5.4.2 Site Selection

The selection of specific mines to be included in field sampling for this project was undertaken in conjunction with the desktop analysis discussed in **Section 5.1**. Mines were selected if they met the following criteria:

- the mine is located in the central Hunter Valley, NSW
- there is a requirement for the mine to rehabilitate specific vegetation communities, as specified in their project approval/s
- the rehabilitation is a minimum of three years old
- the results of monitoring indicate that the rehabilitation may resemble one of the target communities
- to a lesser extent, the methods used in the monitoring programme allow for a longitudinal analysis of data.

A review of monitoring reports from the selected mines was undertaken to assess the extent and likely applicability of individual monitoring sites to the project. Existing rehabilitation and reference monitoring sites were identified as suitable for the project where they were assessed as likely to contain the target PCT (existing PCT classification), based on floristic composition. The sampling of existing monitoring sites was considered a higher priority than the establishment of new sites, as their inclusion might allow for previous monitoring data to be considered in longitudinal analyses, or at least provide some insight into previous management and response.

Where new reference sites were required to complement the existing monitoring sites and achieve the target number of replicates per group, target areas for sampling were identified using the Greater Hunter Native Vegetation Mapping (DPIE 2012) and ground-truthed vegetation mapping undertaken for specific development projects (Umwelt 2006 and 2019a) and conservation agreements (Mangoola Coal Operations 2018a, 2018b, 2018c, 2018d, 2018e). The selection of target areas aimed to provide spatial coverage of buffer areas and/or accessible areas under the ownership or management of the target mine sites, preferably in older remnants that had not been subject to recent disturbance. The actual site location was confirmed following field reconnaissance and confirmation that the target area:

- contained the target PCT
- supported vegetation which was representative of that present in the locality
- had not been subject to significant disturbances
- was not ecotonal in nature.

New rehabilitation sites were selected in a similar fashion to new reference sites but relied upon recording of the rehabilitation age and likely target vegetation community by the relevant mine site. The actual location of rehabilitation sites was selected in the field following confirmation of the presence of vegetation consistent with the target community, where all strata (canopy, mid and ground layers) and characteristic canopy species were present. In some cases, the target vegetation communities of rehabilitation units were not clear and field reconnaissance was required to ascertain the likely target community.

The sites selected for inclusion in the study were not subject to a thorough assessment of the 'best fit' PCT prior to survey. Rather, the selection of the most likely PCT was largely based on existing vegetation mapping and the location of the site in relation to the location of BioNet sites and their assigned PCT (current PCT classification). In the case of monitoring sites, the species composition was also considered.

Based on the results of the sample size analysis and availability of representative sites at each mine site a total of 45 rehabilitation sites and 48 reference sites were surveyed as part of this study (**Figure 5.1**), including 14 pre-existing rehabilitation monitoring sites and 21 pre-existing reference monitoring sites, as shown in **Table 5.2**.

Table 5.2 Sites Sampled and Target PCT

PCT	Rehabilitation			Reference		
	Existing	New	Total	Existing	New	Total
PCT1601 – Spotted Gum – Narrow-leaved Ironbark – Red Ironbark shrub-grass open forest	7	1	**8**	7	1	**8**
PCT1604 – Narrow-leaved Ironbark – Grey Box – Spotted Gum shrub-grass woodland	5	5	**10**	7	2	**9**
PCT1603 – Narrow-leaved Ironbark – Bull Oak – Grey Box shrub-grass open forest	1	7	**8**	6	4	**10**
PCT1691 – Narrow-leaved Ironbark – Grey Box grassy woodland	1	8	**9**	0	10	**10**
PCT1655 – Grey Box – Slaty Box shrub-grass woodland	0	10	**10**	1	10	**11**
Total number of sites	**14**	**31**	**45**	**21**	**27**	**48**

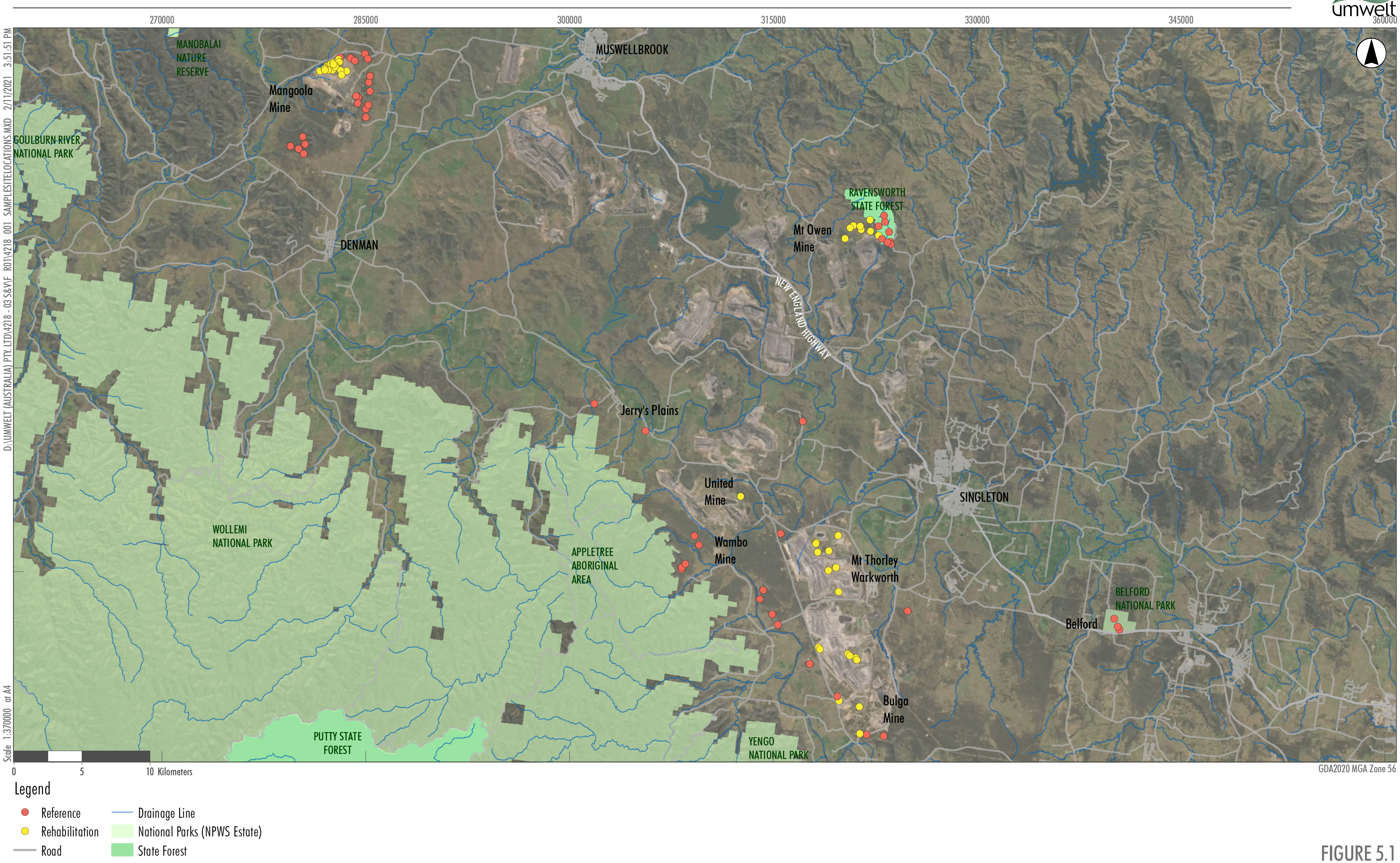


FIGURE 5.1
Sample Site Locations

Image Source: ESRI Basemap (2021) Data source: NSW DSFI (2021), NPWS Estate (2019)

5.4.3 Floristic, BAM and BBAM Sampling

Data on the composition, structure, and function of vegetation at each site were collected in accordance with the BAM (OEH 2017). This involved setting out 20 x 50 m, 20 x 20 m and 1 x 1m plots.

At each plot, data were collected in accordance with Table 2 of the BAM (OEH 2017) and approximately 60 minutes was spent searching for all vascular flora species present within the 20 x 20 m plot. Searches of each 20 x 20 m plot were generally undertaken using parallel transects from one side of the plot to another, with most effort spent on examining the groundcover, which usually supported the majority of species present, however the composition of any shrub, mid-storey, canopy and emergent layers were also thoroughly examined, and visual searches for epiphytes and mistletoes were conducted. The percentage foliage cover of each species was recorded, as well as an estimate of its abundance. Whilst not a BAM requirement, the presence of flowering or fruiting material for each vascular plant species was noted. Voucher specimens were collected where species could not be confidently identified in the field. A small proportion of eucalypts could not be confidently identified during the sampling of rehabilitation sites due to their young age and lack of distinguishing features, such as reproductive material. In this situation eucalypts were assigned to the species that was considered the most likely, based on professional opinion and with reference to, but not restricted to, the list of species included in the seed mix. All vascular plants recorded or collected by Umwelt were identified using keys and nomenclature consistent with Harden (1992, 1993, 2000 and 2002), with updates provided on the PlantNET website (Botanic Gardens Trust 2019). Keys for grass species contained in Wheeler et al. (2002) were also used as a supplementary resource.

In addition to the floristic composition, the following information was collected at each site, as per the BAM (OEH 2017), except where noted:

- percentage cover of litter (within five 1 x 1 m plots) (bare soil, cryptogam and rock cover were also recorded)
- number of tree stems within size classes (DBH <5 cm, 5-9 cm, 10-19 cm, 20-29 cm, 30-49cm, 50-79 cm and ≥80 cm) for eucalypts and non-eucalypts when ≤10 individuals within a size class are present, and estimates used for >10 individuals (within 20 x 50 m plot) (this is a variation of BAM method, which requires the collection of presence/absence of the stated stem size classes)
- length of fallen logs (within 20 x 50 m plot)
- number of trees with hollows (within 20 x 50 m plot).

BBAM data which was not covered by the BAM attributes described above, as documented in the Operational Manual (DECC 2008a), was collected at each site as BBAM was included in recent mine rehabilitation monitoring programs and could potentially provide a means of data comparison. BBAM data included:

- at 10 points along the 50 metre transect, the following were assessed:
  - percentage native overstorey cover
  - percentage native mid-storey cover
- at 50 points along the 50 metre transect, the following were assessed:
  - percentage native groundcover (grass)
  - percentage native groundcover (shrubs)

- percentage native groundcover (other)
- percentage exotic plant cover.

5.4.4 Landscape Function Analysis (LFA)

LFA (Tongway and Hindley 2004) data were collected at each rehabilitation and reference site. The 50 m transect which ran through the centre of the 20 m x 50 m BAM vegetation sampling transect (refer to **Section 5.4.3**) was utilised for the collection of LFA data. When establishing each site, the 50 m transect was positioned to run downslope from the starting point. The transect orientation was modified at some previously established monitoring sites. Where this occurred the LFA data were collected in a manner that was consistent with previous years' monitoring events.

In accordance with Tongway and Hindley (2004), three broad steps were used to assess landscape function, being:

- generating an overall description of the geographic location
- characterising the landscape organisation (along a 50 m transect) by recording the length and width of the patch zones (resource accumulation) and the length of the interpatch zones (resource loss)
- conducting Soil Surface Assessments (SSAs) on each of the patch and interpatch types, with five replicates of each, where possible.

The SSA is a semi-quantitative assessment method that measures the following 11 soil condition features:

- rain splash protection
- perennial vegetation cover
- litter cover, origin and degree of decomposition
- biological crust cover
- physical crust brokenness
- erosion features
- deposited materials
- micro topography
- surface resistance to erosion
- soil texture
- slaking characteristics.

The data collected were then entered into a spreadsheet, developed by CSIRO Sustainable Ecosystems and previously provided to Umwelt as part of LFA training by Tongway. This spreadsheet calculates index values for stability, infiltration and nutrient cycling, as well as a Landscape Organisation Index score. This study focused on the three index values of stability, infiltration, and nutrient cycling.

5.4.5 Self-sustainability Assessments

Field sampling investigating the function, or self-sustaining capacity, of reference and rehabilitation sites discussed in **Section 5.4.2** was undertaken by DPIE (Oliver and Dorrough 2019). Refer to **Appendix 1** for a full description of the methods used.

Sampling included the collection of soil and litter at the base of trees and where tree canopy cover was lowest. Leaf samples were collected from the three most abundant shrub and/or tree species at each site.

The following laboratory analyses were undertaken:

- Litter:
  - litter mass by size category
  - weight and source of animal dung
  - abundance of major groups of invertebrates
- Soil microbiology:
  - microbial enzyme activity
  - microbial respiration
  - Phospholipid Fatty Acids (PLFA)
  - microbial community composition
- Soil chemistry:
  - extractable phosphorus
  - pH
  - electrical conductivity
  - total nitrogen
  - total organic carbon
  - particulate organic carbon
  - humic organic carbon
  - resistant organic carbon
- Leaf sampling
  - leaf area
  - leaf nutrient concentrations (total N, total C, B, Na, Mg, P, K, Ca43, Ca44, Mn, Fe, Cu, Zn66, Zn67, Sr, Mo, Pb).

5.5 Data Analysis

5.5.1 Allocation of Sites to PCT

5.5.1.1 Data Preparation and Standardisation

Data were prepared for analysis in accordance with a data standardisation approach recommended by DPIE to ensure consistency with data compiled for the proposed ENSW PCT Classification. This included standardisation of nomenclature to follow Harden (1992, 1993, 2000 and 2002) with updates to reflect currently accepted botanical revisions using the PlantNET website (Botanic Gardens Trust 2019). Additional standardisation was conducted to remove exotic species and species identified to genus level only and to combine some subspecies, varieties or forms into a single entity. Percent cover and abundance data collected in accordance with Table 2 of the BAM (OEH 2017) were converted to a MBB ordinal 6-point scale (Braun-Blanquet 1927; Poore, 1955) as shown in **Table 5.3**.

Table 5.3 Modified Braun-Blanquet Crown Cover-Abundance Scale

Modified Braun-Blanquet 6-point scale	% cover	Abundance
1	< 5%	< 5 individuals
2	< 5%	≥ 5 individuals
3	≥ 5% and < 20%	N/A
4	≥ 20% and < 50%	N/A
5	≥ 50% and < 75%	N/A
6	≥ 75%	N/A

Note: Modified Braun-Blanquet scale (Braun-Blanquet 1927; Poore 1955).

Elevation, rainfall and temperature information for each site, as determined by site location, was also required for analysis within the draft PCT Assignment Tool. DPIE assisted with populating these abiotic data fields following the supply of the site coordinates.

5.5.1.2 PCT Assignment

The online draft PCT Assignment Tool developed by DPIE in conjunction with the revised ENSW PCT Classification was the primary method for allocating sites to PCT. At the time of provision by DPIE, the PCT Assignment Tool was in draft format using plot assignments developed in April 2019. It was acknowledged that the data contained within the draft PCT Assignment Tool were not the most current, as some movement of primary sites between PCTs had occurred following further review. A summary of changes that occurred within the target PCTs between April and October 2019, when the Tool was utilised for the project, is provided in **Table 5.4**.

Table 5.4 Summary of Changes to Target PCTs

ENSW PCT	Number of assigned plots at April 2019*	Number of assigned plots at October 2019*	% change
PCT3315	209	178	-14.8%
PCT3438	52	51	-1.9%
PCT3757	12	13	8.3%
PCT3485	28	28	0.0%
PCT3490	30	25	-16.7%
PCT3431	165	162	-1.9%
PCT3314	97	100	3.1%

Source: (Tim Hager pers. comm. 8 October 2019)
* refers to ‘primary’ plots used in the ENSW classification

The draft PCT Assignment Tool (DPIE 2019c) contained two outputs which were utilised for this study as shown in **Figure 5.2**. A conceptual representation of the measurement of *distance to centroid* from the target site to all PCTs is shown in **Figure 5.3**.

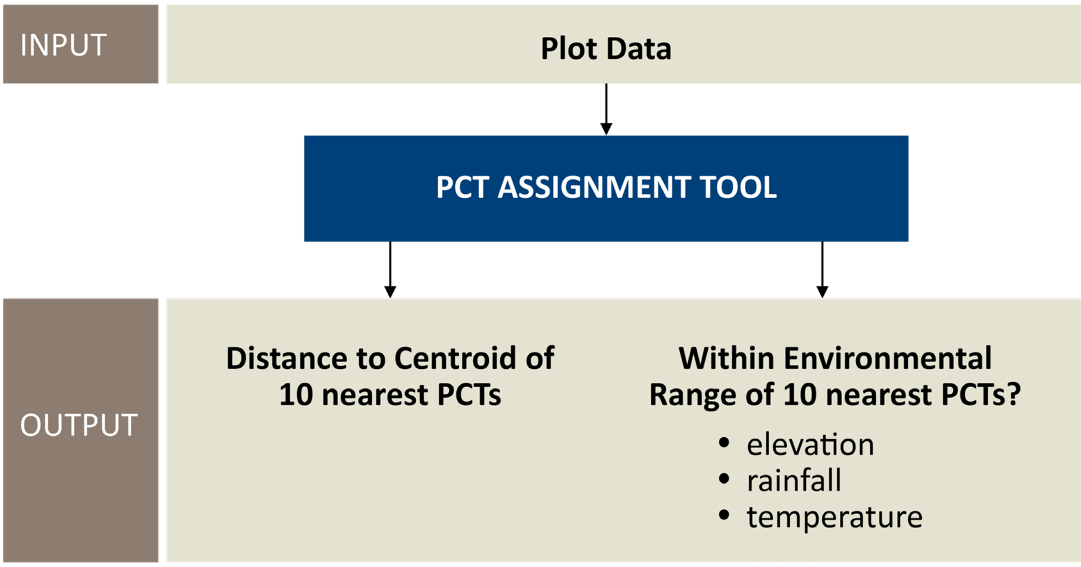


Figure 5.2 Input and outputs of draft PCT Assignment Tool (DPIE, 2019c)

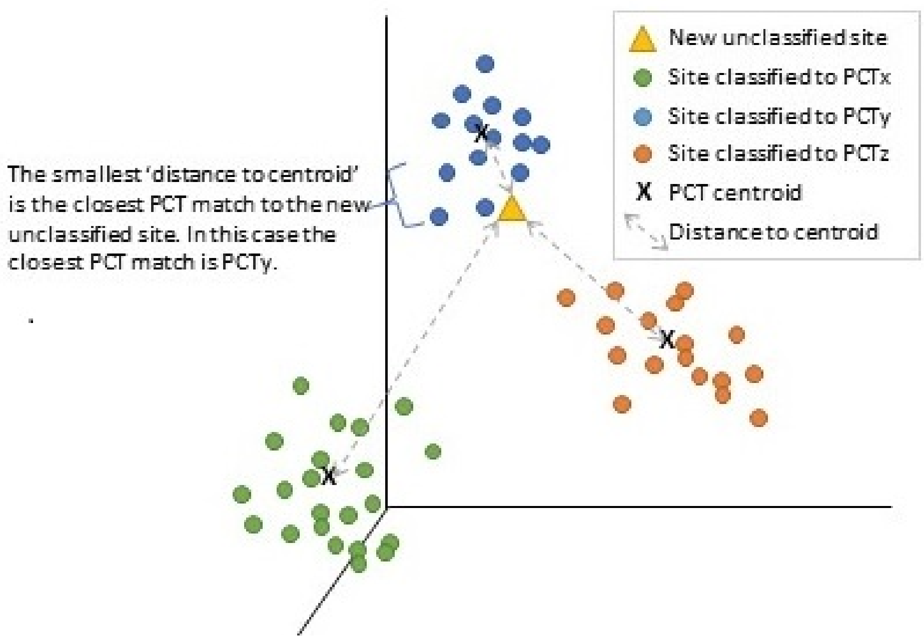


Figure 5.3 Conceptual Representation of Distance to Centroid Analysis

Source: DPIE (2019c)

A third analysis, which measures the percentage of each PCT's characteristic species found within the target site, was considered but was not found to be useful for this project due to the draft format of the PCT Assignment Tool. It is understood that this component of the draft PCT Assignment Tool was still under development at the time of use.

Sites were generally allocated to the PCT with the lowest distance to centroid and where the site was located within the environmental range (elevation, rainfall and temperature) for that PCT. DPIE (2019b) states that the draft PCT Assignment Tool is not designed to be an exact matching tool, but rather a guide to assist sensible choices, and therefore interpretation of the outputs is required. In addition to the distance to centroid and the environmental range analyses, the following were considered:

- Draft ENSW PCT profiles embedded in the draft PCT Assignment Tool (DPIE 2019c) containing a list of species with their median cover score and group frequency.
- The mapping function within the draft PCT Assignment Tool (DPIE 2019c) was also used to view nearby BioNet sites and consider the PCT allocations for sites located in a similar landscape position.

The PCT allocation was undertaken in the absence of diagnostic soil and geology information for each PCT, however the location of assigned BioNet sites and the information contained within the PCT name that indicated or implied location, landscape position and/or substrate, were used to further refine the possible PCTs encountered during sampling.

All rehabilitation sites were allocated to one of the three target Central Hunter PCTs that occur on Permian substrates, as all rehabilitation sampled was established with the intention of reinstating vegetation similar to that present prior to mining (although in no cases were the precise target PCTs envisaged). For the purposes of this project it was assumed that all rehabilitation was located on soils derived from Permian-aged strata, as all mining in the Central Hunter is undertaken within Permian-aged coal measures, and therefore PCTs that do not occur on Permian substrates were excluded. Allocation of rehabilitation sites to PCTs using the draft PCT Assignment Tool was influenced by the target vegetation community, the remnant vegetation adjacent to the mine site and/or previously present within the mining footprint and from which topsoil may have been sourced, in addition to the species composition of the rehabilitation. In the event that the target vegetation community for a rehabilitation site was not identified in the ten closest PCT distance to centroid values, the site was allocated to the next 'best fit'.

5.5.2 Compositional Recognisability

There are several ways that compositional recognisability can be assessed, and the following sections focus on recognisability at the level of PCT. Refer to **Section 5.5.5** for methods investigating recognisability at the level of TEC.

5.5.2.1 Distance to PCT Centroid

If a rehabilitation site recorded a distance to PCT centroid value below the 0.695 threshold value, it was deemed as having a clear alignment to the PCT and was therefore considered recognisable as that PCT with respect to floristic composition.

To develop a secondary threshold of recognisability, the distance to PCT centroid for BioNet plots categorised as 'secondary' in the ENSW PCT Classification (DPIE 2019b) were analysed, using data provided by DPIE which was equivalent to the PCT Assignment Tool outputs described in **Section 5.5.1.2**. The dataset included the assigned PCT for each 'secondary' plot and the distance to the centroid of the ten closest PCTs. As discussed in **Section 4.1.1**, plots were classified as 'secondary' if the plot had plausible floristic and environmental relationships to a group but its distance to group centroid was above the 0.695 threshold value and the data indicated lower species richness, atypical cover scores or potential disturbance effects (DPIE 2019b). By analysing these sites using the ENSW PCT Classification Tool the variability in distance to centroid values for disturbed sites, which are considered to represent the assigned PCT in a condition that is not 'moderate to good', could be determined. Sites were excluded from analysis if they recorded a distance to their assigned PCT of equal to or less than 0.695 or if a distance to centroid measure to the assigned PCT was not contained in the dataset (i.e. the assigned PCT was not within the ten closest PCTs), which resulted in the removal of 2337 plots. A total of 4153 'secondary' sites assigned to 744 PCTs were considered in the subsequent analysis.

Using the distance to centroid measures for the remaining 'secondary' sites, recognisability thresholds were created using the mean distance to the assigned PCT centroid value and standard deviation, as summarised in **Table 5.5**.

Table 5.5 Level of PCT Recognisability based on Distance to Centroid Value

Level of Recognisability	Distance to Centroid Value
Very Strong	≤0.695
Strong	>0.695 but ≤ mean distance to PCT centroid of all secondary plots
Moderate	> mean distance to centroid of all secondary PCT to their target PCT but ≤ 1 standard deviation from the mean distance to PCT centroid of secondary plots
Weak	> 1 standard deviation from the mean distance to PCT centroid of secondary plots

5.5.2.2 Comparison to PCT Profiles

The draft ENSW PCT profiles for the target PCTs were obtained from the draft PCT Assignment Tool (DPIE 2019c). These draft profiles contain details of frequently encountered species listed by growth form and listed 58 species for PCT3315, 61 species for PCT3485 and 60 species for PCT3431 (mean = 59.7). The number of species recorded at rehabilitation and reference sites which were listed in the draft profile for the allocated PCT was calculated. Pearson correlation was calculated to determine whether the two variables had a clear linear relationship, and they were considered to be strongly correlated where the correlation coefficient (r) was >±0.7.

5.5.2.3 Comparison to Reference Sites

An analysis was undertaken to determine the number of species recorded at a rehabilitation site which were also recorded on at least one occasion at the pool of reference sites allocated to the same PCT. Pearson correlation was calculated to determine whether there was a clear linear relationship between this number and the distance to PCT centroid. These variables were considered to be strongly correlated where the correlation coefficient (r) was >±0.7.

5.5.2.4 Comparison to Benchmarks

BAM data collected from reference sites allocated to PCT3315, PCT3485 and PCT3431 were used to develop PCT-level benchmarks following the approach described in the updated BAM manual (DPIE 2020a) for the collection of benchmark data from local reference sites. In accordance with these guidelines (DPIE 2020a), local benchmarks for PCTs 3315, 3485 and 3431 were derived through calculating the median for each attribute for which class level benchmarks exist. This included richness and cover per growth form, number of large trees (the definition of 'large trees' varies according to the vegetation class), litter cover and length of fallen logs. A total of 12 sites were used to calculate benchmarks for PCT3315 and PCT3485 and data from 16 sites were used to calculate PCT3431 benchmarks. One reference site (Site 70, PCT3315) was excluded as this site included trees planted in a derived native grassland.

PCT-level local benchmarks were compared with BAM benchmarks for the Vegetation (Keith) Class to which the PCT has been allocated by DPIE and according to the IBRA region in which the plots are located (Sydney Basin). The average rainfall class-level benchmarks used were obtained from BioNet Vegetation Classification website (DPIE 2021b). The *dry* benchmarks, which are applicable to a BAM assessment when rainfall over the 12 months prior to assessment falls below the 20th percentile of the annual totals in long-term rainfall records (DPIE 2020b), were obtained from DPIE (DPIE 2021c).

Based on information provided by DPIE, PCT3315 belongs to Class Coastal Valley Grassy Woodlands; PCT3431 belongs to Class Hunter-Macleay Dry Sclerophyll Forests; and PCT3485 belongs to Class Western Slopes Grassy Woodlands.

5.5.3 Structural Recognisability

In order to determine if the rehabilitation sites were structurally recognisable as the PCT, the structural components of the rehabilitation sites were compared to those of the reference sites. To do this, for each attribute assessed, individual rehabilitation sites were assessed using the 10^{th}, 25^{th}, 75^{th} and 90^{th} percentiles and the minimum and maximum values of reference sites within each allocated PCT group. This approach is consistent with Oliver et al. (unpublished manuscript) for assessing the "acceptable range of variation" for assessing restoration success. This approach finds rehabilitation site values that fall within the inter-quartile range (between 25^{th} and 75^{th} percentiles) as being most recognisable to reference sites for that attribute, and values that fall outside of the observed range of reference sites, being the least recognisable. The 10^{th}, 25^{th}, 75^{th} and 90^{th} percentiles were calculated following the method from Hyndman and Fan (2007), which uses the 'quantile' function from the stats package in R (R Core Team, 2021). The approach for determining the four levels of structural recognisability of rehabilitation sites for this study is provided in **Table 5.6**.

Table 5.6 Assessment of Level of Structural Recognisability Based on Reference Site Data

Level of Recognisability	Definition
Very Strong	Rehabilitation site value for an attribute falls within the inter-quartile range (IQR) (between 25^{th} and 75^{th} percentiles) of all reference site values for the given PCT
Strong	Rehabilitation site value for an attribute falls between the 10^{th} and 90^{th} percentiles of reference site values for the given PCT, but outside of the IQR
Moderate	Rehabilitation site falls below the 10^{th} percentile or above the 90^{th} percentile, but is within the observed range of reference site values for the given PCT
Weak	Rehabilitation site falls below the minimum or above the maximum observed reference site values for the given PCT

The data collected for this study were supplemented by floristic plot data from BioNet where it contained percentage foliage cover data and where it had been attributed to PCTs 3315, 3431 or 3485. Replicate plots were omitted from data analyses, as were survey datasets which utilised 1% cover as the minimum foliage cover value, as this value is 10 times greater than the minimum value used in the BAM. Further interrogation of the BioNet dataset revealed that crown cover had been used in some instances, evident by values greater than 50% (and up to 80%) for tree species, which was confirmed by one of the data collectors (Steve Lewer, personal communication). For survey datasets which contained crown cover values, species allocated to the tree (TG) growth form were excluded from further analysis. The BioNet data used in analyses included all growth forms from Eastcoast Flora Vegetation Surveys (five plots allocated to PCT3315); and all growth forms excluding trees (TG) from FloraSearch Vegetation Surveys (four plots allocated to PCT3431, and three plots allocated to PCT3485) and MER_HCR Vegetation Surveys (nine plots allocated to PCT3315, two plots allocated to PCT3431, and four plots allocated to PCT3485). Structural recognisability analyses, excluding tree (TG) foliage cover, utilised data from 27 plots for PCT3315, 22 plots for PCT3431, and 19 plots for PCT3485 (**Table 5.7**). Analysis of tree (TG) cover used data from 18 plots for PCT3315, 16 plots for PCT3431 and 12 plots for PCT3485 (**Table 5.7**).

Table 5.7 Number of reference floristic plots used in structural recognisability analysis

Dataset	Growth Forms	Number of floristic plots per PCT		
		3315	3431	3485
Umwelt (current study)	TG, SG, GG, FG	13	16	12
Eastcoast Flora Survey	TG, SG, GG, FG	5	0	0
FloraSearch Vegetation Survey	SG, GG, FG	0	4	3
MER_HCR Vegetation Survey	SG, GG, FG	9	2	4
Total		27	22	19

The attributes used in these analyses were foliage cover of growth forms used for the BAM (including trees (TG), shrubs (SG), grass and grass-like (GG) and forbs (FG)) and tree abundance by stem class. The stem classes used were the four smallest DBH size classes in accordance with the BAM: being <5 cm DBH, 5-9 cm DBH, 10-19 cm DBH and 20-29 cm DBH. No trees with >30 cm DBH were recorded at rehabilitation sites and therefore were not considered in analyses.

The BAM structure score was obtained by entering the vegetation integrity data into the BAM-calculator (BAM-C) (State of NSW 2021). As the revised ENSW Classification had not been released at the time of writing, the target PCTs 3315, 3431 and 3485 could not be entered into the BAM-C. Alternative PCTs of the same vegetation class as the target PCTs were entered into the BAM-C for the appropriate weighting of growth forms to be applied. The structural recognisability of each rehabilitation site was assessed using the BAM structure condition score applying the same approach as that used for individual growth forms (**Table 5.6**). The recognisability of rehabilitation sites based on each of the three dominant growth forms and the BAM structure condition score were qualitatively compared to assess the similarity of results using the two approaches.

5.5.4 Compositional and Structural Change of Rehabilitation Over Time

To understand the progress of rehabilitation at specific points in time, the project aimed to undertake a longitudinal analysis of floristic composition and structure at individual rehabilitation sites. In seeking to do this it was anticipated that previous rehabilitation monitoring data from the same mine sites visited for the current study could be utilised. Previous monitoring data and corresponding reports sourced from Mangoola, Mt Owen, Mt Thorley Warkworth, Bulga and United were compiled and an assessment of the consistency of methods with those used for the current study was undertaken. Where an inconsistency of methods used to collect floristic or structural data was identified, the historical data were excluded from further consideration. Insufficient data were gathered through this process to complete a longitudinal analysis.

An alternative approach to investigating performance of rehabilitation over time was to compare differences between age cohorts of rehabilitation with data collected for the current study within the same allocated PCT. In order to determine whether observed differences between age cohorts could be attributed to age or establishment conditions, an analysis of the influence of age and mine site was undertaken in a space-for-time substitution analysis.

All analyses were performed using R statistical software (version 6.4.1). Five mine sites were the subject of this research project. Between these mine sites the rehabilitation areas ranged from 3-27 years post-initial vegetation establishment.

A list of *a priori* candidate models were identified to test the influence of mine site and age on rehabilitation. Depending on the distribution of the data, a Gaussian or Poisson General Linear Model (GLM) was used. Overdispersion was tested and where present, quasi-Poisson GLMs were used (Zuur et al. 2009). Poisson distributions were used for variables that did not have overdispersion in their datasets, and quasi-Poisson distributions were used for variables that required correction for overdispersion to fit the model.

5.5.5 Threatened Ecological Community Analysis

5.5.5.1 Nationally-listed TECs

The Approved Conservation Advice (TSSC 2015) contains a detailed description of the *Central Hunter Valley Eucalypt Forest and Woodland CEEC* and the 'key diagnostic characteristics and condition thresholds' that an ecological community must satisfy for it to be identified as the CEEC (refer to **Section 4.2.1** for further information). This study aimed to apply the information contained within the Approved Conservation Advice (TSSC 2015) to confidently identify sites containing vegetation that is consistent with the CEEC. To achieve this the 'key diagnostic characteristics and condition thresholds' and supporting CEEC identification information contained within the Approved Conservation Advice that were deemed the most useful in identifying the CEEC were reviewed, and an assessment was made as to whether each criterion was diagnostic or indicative; the former being more determinative and the latter being more open to interpretation. The criteria that were assessed as being diagnostic were applied to each site sampled for the project (refer to **Section 5.4** for data collection methods) in the manner described in **Table 5.8**. Those sites that satisfied all nine diagnostic criteria were assessed as supporting vegetation consistent with the CEEC and therefore recognisable as such.

Table 5.8 Central Hunter Valley Eucalypt Forest and Woodland CEEC Assessment Criteria

No.	Criterion description	Approved Conservation Advice Section	Diagnostic Value	Application
1	It occurs in the Hunter River catchment (typically called the Hunter Valley region)	1.5.1	Diagnostic	No assessment required. All sampling was conducted in the Hunter Valley.
2	It typically occurs on lower hillslopes and low ridges, or valley floors in undulating country; on soils derived from Permian sedimentary rocks	1.5.1	Diagnostic	The term 'typically' is interpreted here as applying to the entire sentence, that is, "typically occurs on lower hillslopes and low ridges, or valley floors in undulating country"; and typically "on soils derived from Permian sedimentary rocks". Location of sites was overlaid with the Hunter Coalfield Regional 1:100,000 Geology Map (Glen and Beckett 1993) in GIS to identify the parent geology material at each location. Rehabilitation substrates are derived from overburden from mined areas targeting Permian coal seams, however some Triassic, Jurassic, Carboniferous, Tertiary or Quaternary aged substrates may also be present. For the purposes of this assessment, it has been assumed that all sampled rehabilitation sites are located on substrates derived from predominantly Permian geology.
3	It does not occur on alluvial flats, river terraces, Aeolian sands, Triassic sediments or escarpments	1.5.1	Diagnostic	The absence of Triassic substrates was identified in Criterion 2. Field observations were used to identify the presence or absence of alluvial flats, river terraces, Aeolian sands and escarpments.
4	It is woodland or forest, with a projected canopy cover (assumes solid canopy) of trees of 10 % or more; or with a native tree density of at least 10 native tree stems per 0.5 ha (at least 20 native tree stems/ha) that are at 1 m in height	1.5.1	Diagnostic	Stem count estimates collected in the 20 x 50 m plot in accordance with the BAM were converted to stems per hectare. There was no requirement to convert foliage cover collected in accordance with the BAM to projected canopy cover as no sites recorded less than 20 native tree stems/ha.

No.	Criterion description	Approved Conservation Advice Section	Diagnostic Value	Application
5	The canopy of the ecological community is dominated by one or more of the following four eucalypt species: *Eucalyptus crebra* (narrow-leaved ironbark), *Corymbia maculata* (syn. *E. maculata*) (spotted gum), *E. dawsonii* (slaty gum) and *E. moluccana* (grey box); OR A fifth species, *Allocasuarina luehmannii* (bulloak, buloke) dominates in combination with one or more of the above four eucalypt species, in sites previously dominated by one or more of the above four eucalypt species.	1.5.1	Diagnostic	The proportion of characteristic species within the canopy stratum was calculated and sites that recorded 50% or less dominance by one or more of the four eucalypt species were assessed as not comprising the CEEC, unless bulloak occurred as a co-dominant canopy species.
6	*Allocasuarina torulosa* (forest oak/she-oak, rose she-oak/oak), *Eucalyptus acmenoides* (white mahogany) and *Eucalyptus fibrosa* (red/broad-leaved ironbark) are largely absent from the canopy of a patch. Largely absent is defined as no more than two trees per hectare, on average, across a patch.	1.5.1	Diagnostic	Two trees per hectare is equivalent to 0.08 trees within the 20 x 20 m plot. For the purposes of this assessment, sites containing any contra-indicative species within the 20 x 20 m plot were assessed as not comprising the CEEC. The plot was representative of the presence or absence of contra-indicative species in the patch.
7	A ground layer is present (although it may vary in development and composition), as a sparse to thick layer of native grasses and other native herbs and/or native shrubs.	1.5.1	Diagnostic	At least one native grass was recorded in the 20 x 20 m plot, as well as a minimum of one native herb and/or one native shrub.
8	The ecological community predominantly occurs in the Sydney Basin and the NSW North Coast IBRA bioregions in NSW.	1.5.2	Diagnostic	All sampling was conducted in the Hunter Valley within the Sydney Basin IBRA bioregion.
9	The patch* is ≥ 0.5 ha in size AND ≥ 50% of perennial understorey vegetative cover# is native AND contains at least 12 native understorey species; OR The patch* is ≥ 2 ha in size AND ≥ 50% of perennial understorey vegetative cover# is native AND the patch is contiguous with another patch of native woody vegetation ≥ 1 ha in area OR the patch has at least one large locally indigenous tree (≥ 60 cm DBH), at or least one tree with hollows OR the patch is ≥ 3 ha in size.	1.5.3	Diagnostic	The location of each site was viewed with recent aerial imagery in GIS. Where sites were located in smaller patches estimated to be less than 0.5 ha, a polygon was drawn around the patch to measure its size. For the purposes of this assessment, the vegetation present at the site was considered to be representative of the patch.

No.	Criterion description	Approved Conservation Advice Section	Diagnostic Value	Application
10	The ecological community corresponds, in large part, to the three NSW listed ecological communities: • Central Hunter Grey Box – Ironbark woodland in the NSW North Coast and Sydney Basin Bioregions EEC; • Central Hunter Ironbark – Spotted Gum – Grey Box Forest in the NSW North Coast and Sydney Basin Bioregions EEC; and • Hunter Valley Footslopes Slaty Gum Woodland in the Sydney Basin Bioregion VEC. The ecological community includes some outliers in the Lower Hunter Valley region recognised as Lower Hunter Spotted Gum – Ironbark Forest in the Sydney Basin Bioregion EEC, however much of this EEC does not meet the diagnostic criteria and is therefore excluded.	1.6.1	Indicative	Indicative only. Not utilised for this assessment.
11	Characterised by the list of vascular plant species provided in the Approved Conservation Advice.	App B	Indicative	Indicative only. Not utilised for this assessment.
12	The ecological community corresponds to a number of vegetation units identified through mapping projects and surveys, however the correspondence is not exact.	App D	Indicative	Indicative only. Approved Conservation Advice indicates broad correspondence (entirely or in part). Not utilised for this assessment.

Notes:

* A 'patch' is defined in the Approved Conservation Advice (TSSC 2015) as 'a discrete and mostly continuous area of the ecological community'. A patch may include some small-scale variations and disturbances which do not significantly alter the overall functionality of the ecological community and separate patches are present where there is a break in native vegetation cover of 30 m or more between the edge of the tree canopies (TSSC 2015).

[#] 'Perennial understorey vegetation cover' includes vascular plant species of the ground layer and the mid/shrub layer (i.e. below the tree canopy).

5.5.5.2 State-listed TECs

Detailed descriptions of the target TECs listed under the BC Act, Central Hunter Grey Box – Ironbark Woodland EEC, Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC and Hunter Valley Footslopes Slaty Gum Woodland VEC, are found within the corresponding Final Determinations (NSW Scientific Committee 2010a, 2010b and 2010c). These Final Determinations were reviewed and information that could be used to identify the TECs and distinguish them from other ecological communities was located. The identified characteristic features were then classified as indicative or diagnostic for the purposes of determining whether vegetation at a site is consistent with the target TEC, as shown in **Table 5.9** for Central Hunter Grey Box – Ironbark Woodland EEC, **Table 5.10** for Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC and **Table 5.11** for Hunter Valley Footslopes Slaty Gum Woodland VEC. The information contained within the Final Determinations, and summarised in **Table 5.9** to **Table 5.11**, was used as the basis for the development of appropriate analyses to determine the presence of the TECs at each sampled site using a standardised approach.

Table 5.9 Characteristics of Central Hunter Grey Box – Ironbark Woodland EEC

Characteristic	Final Determination Section	Diagnostic Value
Occurs in NSW North Coast and Sydney Basin Bioregions.	1	**Explicitly diagnostic**
Generally occurs on Permian Sediments.	1	Indicative
Typically forms a woodland to open forest on slopes and undulating hills.	1	Indicative
Characterised by the listed 38 species.	2	**Diagnostic**, however, application of this information to plot-based floristic data is not straightforward
Typically forms a woodland dominated by *Eucalyptus crebra*, *Brachychiton populneus* subsp. *populneus* and *Eucalyptus moluccana*. Other tree species may be present and occasionally co-dominate and include *Angophora floribunda* and *Callitris endlicheri*.	4	Indicative
A shrub layer may be present and common shrub species include *Notelaea microcarpa* var. *microcarpa*, *Breynia oblongifolia*, *Bursaria spinosa* subsp. *spinosa*, *Cassinia quinquefaria* and *Dodonaea viscosa.*	4	Indicative
Subshrubs may also be common and include *Solanum cinereum*, *Phyllanthus virgatus* and *Maireana microphylla*.	4	Indicative
Ground cover can be moderately dense to dense, and consist of numerous forbs and grass species, and a small number of ferns, sedges and twiners. Common 21 species of grasses, forbs, ferns, rushes and sedges are listed which are attributed to Peake (2006).	4	Indicative

Characteristic	Final Determination Section	Diagnostic Value
EEC has been described by Peake (2006) as Central Hunter Box – Ironbark Woodland (Map Unit 10). It has also been described by Thomas (1998) as part of *Eucalyptus crebra – Eucalyptus moluccana – Eucalyptus glaucina/tereticornis* woodland (Map Unit 4.4) and by Fallding et al. (1999) as Ironbark Forest on Alluvium (Map Unit Q2).	5	**Diagnostic**, where there is a clear relationship between previous map units and the EEC (i.e. Peake (2006))
It shares some characteristics with, but is not part of, a community described by Peake (2006) as Central Hunter Spotted Gum – Ironbark – Grey Box Forest and by Bell (2005) as Goulburn Valley Ironbark Woodland. It also shares some characteristics with, but is not part of, the Central Hunter Ironbark – Spotted Gum – Grey Box Forest in the NSW North Coast and Sydney Basin Bioregions EEC (NSW Scientific Committee, 2010b).	5	Indicative
Known from three LGAs but may occur elsewhere within the Sydney Basin Bioregion.	6	Indicative

Table 5.10 Characteristics of Central Hunter Ironbark – Spotted Gum - Grey Box Forest EEC

Characteristic	Final Determination Section	Diagnostic Value
Occurs in NSW North Coast and Sydney Basin Bioregions.	1	**Explicitly diagnostic**
Generally occurs on Permian Sediments.	1	Indicative
Typically forms an open forest to woodland.	1	Indicative
Characterised by the listed 44 species.	2	**Diagnostic**, however, application of this information to plot-based floristic data is not straightforward
Typically forms a woodland dominated by *Eucalyptus crebra*, *Corymbia maculata* and *Eucalyptus moluccana*. Other tree species may be present and occasionally dominate or co-dominate and include *Eucalyptus fibrosa* and *Eucalyptus tereticornis*.	4	Indicative
A sparse layer of small trees may be present in some areas, typically including *Allocasuarina luehmannii* or *Acacia parvipinnula*.	4	Indicative
A shrub layer is typically sparse or absent in some cases, through to moderately dense. Common shrub species include *Daviesia ulicifolia* subsp. *ulicifolia*, *Pultenaea spinosa*, *Breynia oblongifolia*, *Hakea sericea* and *Bursaria spinosa* subsp. *spinosa.*	4	Indicative

Characteristic	Final Determination Section	Diagnostic Value
Ground cover can be sparse to moderately dense, and consist of numerous forbs, a few grass species and a limited number of ferns, sedges and other herbs. Common 23 species of grasses, forbs, ferns and rushes are listed which are attributed to Peake (2006).	4	Indicative
EEC has been described by Peake (2006) as Central Hunter Ironbark – Spotted Gum – Grey Box Forest (Map Unit 27) and as Map Unit 18 (NSW NPWS 2000; DECC 2008b). It includes part of a community described by Thomas (1998) as *Eucalyptus crebra – Eucalyptus moluccana – Eucalyptus glaucina/tereticornis* woodland.	5	**Diagnostic**, where there is a clear relationship between previous map units and the EEC (i.e. Peake (2006), NSW NPWS (2000) and DECC 2008b))
It shares some characteristics with, but is not part of, a community described by Bell (2005) as Narrabeen Residual Spotted Gum Forest from a small area near Bulga. It shares some characteristics with, but is not part of, a community described by Peake (2006) as Central Hunter Grey Box – Ironbark Woodland, and it also shares some characteristics with, but is not part of, the EEC Central Grey Box – Ironbark Woodland in the NSW North Coast and Sydney Basin Bioregions EEC (NSW Scientific Committee 2010a).	5	Indicative
Known from three LGAs but may occur elsewhere within the NSW North Coast and Sydney Basin Bioregions.	6	Indicative
It has been mapped as being recorded in the Bellfield National Park and in the Singleton Military Area.	8	Indicative

Table 5.11 Characteristics of Hunter Valley Footslopes Slaty Gum Woodland VEC

Characteristic	Final Determination Section	Diagnostic Value
Occurs in Sydney Basin Bioregion.	1	**Explicitly diagnostic**
Generally occurs at the interface of Narrabeen Sandstone and Permian sediments in the Hunter Valley.	1	Indicative
Typically forms a low to mid-high woodland.	1	Indicative
Characterised by the listed 29 species.	2	**Diagnostic**, however, application of this information to plot-based floristic data is not straightforward.
Typically forms a woodland, or occasionally forest, comprising a sparse to moderately dense tree stratum, occasional low tree stratum, and moderately dense to dense shrub stratum.	4	Indicative
The tree canopy is typically dominated by *Eucalyptus dawsonii* and/or *Eucalyptus moluccana*.	4	Indicative

Characteristic	Final Determination Section	Diagnostic Value
Acacia salicina and *Allocasuarina luehmannii* may form a low tree stratum or may be part of the upper-most canopy. Other trees which may be present include *Brachychiton populneus* subsp. *populneus*, *Callitris endlicheri*, *Eucalyptus crebra* and *Eucalyptus punctata*.	4	Indicative
The shrub layer may include *Olearia elliptica*, *Acacia cultriformis*, *Canthium odoratum*, *Notelaea microcarpa* subsp. *microcarpa*, *Dodonaea viscosa* subsp. *cuneata*, *Acacia decora*, *Bursaria spinosa* subsp. *spinosa, Myoporum montanum* and *Solanum brownii.*	4	Indicative
The groundcover is typically sparse to very sparse and is relatively species poor. It may include 9 listed species of grasses, forbs and rushes which are attributed to Peake (2006).	4	Indicative
Typically occurs in colluvial soils on exposed footslopes associated with the interface of Triassic Narrabeen sandstone and Permian sediments.	5	Indicative
VEC has been described by Peake (2006) as Narrabeen Footslopes Slaty Box Woodland (Map Unit 7). It is also included in vegetation types described by Fallding et al. (1999) as Dawson's Box Woodland on Permian Sediments (Map Unit P1), by Bell (1998) as Permian Widden Talus Woodland (Map Unit W23), by Hill (1999) as Slaty Gum Open Forest (Map Unit OF8) and by McRae and Cooper (1985) as Woodland in Sandstone Gullies (Map Unit 4).	5	**Diagnostic**, where there is a clear relationship between previous map units and the EEC (i.e. Peake 2006))
It shares some characteristics with, but is not part of, a community in the Western Blue Mountains called Capertee Slopes Slaty Gum – Grey Gum – Mugga – Callitris Open Forest (DECC 2006), nor is it part of the Narrabeen Grey Box Forests of Wollemi National Park (Bell 2005).	5	Indicative
Recorded from two LGAs but may occur elsewhere within the Sydney Basin Bioregion.	6	Indicative

Canonical Analysis of Principal Coordinates

The constrained ordination technique *canonical analysis of principal coordinates* (CAP) (Anderson and Willis 2003) uses multivariate data to discriminate among *a priori* groups and to find axes through the multivariate cloud of points that have the strongest correlation with another set of variables (Clarke and Gorley 2015). In short, this allows the floristic composition of field data collected from the rehabilitated and reference sites to be compared with floristic sites used in the determination of three TECs listed under NSW legislation.

The dataset for this analysis included 402 plant taxa from 75 plots used in the specific vegetation classifications identified in the Final Determinations of the three TECs (refer to **Table 5.9**, **Table 5.10** and **Table 5.11**) and are therefore representative of their respective TECs. The plots available for analysis were limited to those that could be readily exported from BioNet, which was not the complete set of plots used in the identified classifications (Peake 2006; NSW NPWS 2000).

A total of 38 plots representing *Central Hunter Grey Box – Ironbark Woodland EEC* were included in the analysis, along with 33 plots for *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* and four for *Hunter Valley Footslopes Slaty Gum Woodland VEC*. Prior to analysis, Bray-Curtis distance similarities (Bray and Curtis 1957) were calculated between every pair of observations to produce a resemblance matrix. The data comprised MBB ordinal 6-point scale (Braun-Blanquet 1927; Poore 1955) and therefore did not require any transformation.

An initial CAP of the data was performed using the automatically generated number of principal coordinate analysis (PCoA) axes set by the software. The number of PCoA axes (*m*) to include in the refined CAP was chosen by plotting the proportion of correct allocations obtained with increases in the number of axes included in the analysis, following Anderson and Willis (2003). Tests of the multivariate null hypotheses of no differences among *a priori* defined groups were examined using the CAP classification success rate. CAP ordination, CAP classification success rates and CAP trace$_{Q_m0\ HQ_m}$ statistics were examined in combination to draw conclusions about separation of *a priori* groups in relation to the pre-defined TECs. The CAP classification rate, calculated as the ratio between source (known affiliation) and successfully classified (predicted affiliation) data in the CAP model, provides a quantitative estimate of the degree of discrimination among the groups achieved by the canonical axes (Anderson and Willis 2003). Data were analysed in Primer 7.

Firstly, the CAP (Anderson and Willis 2003) was used to visualise multivariate differences in floristic composition among sites, and to determine how accurately sites could be allocated to pre-defined TECs. The CAP was re-run to improve the fit of the groups, by adding a dummy variable. The addition of a dummy variable is used to minimise the effect of zero inflation of the data by forcing two samples with no content to be 100% similar and two samples with a single real individual species to have some similarity, whether that species is shared (100%) or not (50%) (Clarke and Gorley 2015). Lastly, CAP was repeated with the addition of the field data collected from rehabilitation and reference sites and analysed following the CAP routine, with and without a dummy variable. The dataset included 242 plant taxa from 86 sites (reference sites allocated to non-target PCTs were excluded) and were treated in the same manner as the Peake (2006) and NSW NPWS (2000) data prior to analysis. The CAP was used to measure the degree of compositional membership of the Umwelt sites to the TECs in a manner that assumes a site has varying degrees of membership simultaneously to the TEC groups. Each sample is then allocated to the group whose centroid is the closest to it in the canonical space based on the output of the CAP which provides the proximity of each site, as the distance to centroid, to its allocated TEC. The distance to centroid values for each site were used to generate a heat map that categorises the proximity of the sites to their allocated TEC.

Characteristic Species Analysis

The Final Determination for each State-listed TEC identifies the 'assemblage of species' which characterises the community, as identified in **Table 5.9**, **Table 5.10** and **Table 5.11**. The number of species recorded at each Umwelt site, as well as Peake (2006) and NSW NPWS (2000) sites, which are identified in the Final Determinations, were calculated, as was the proportion of the list which was recorded at each site.

Similarity to PCTs

The species listed in the Final Determinations (NSW Scientific Committee 2010a, 2010b, and 2010c) as characteristic of the TECs were compared with the list of species contained in the corresponding draft PCT profile and the number of species shared between them was calculated. For the purposes of this assessment, the lists contained within the Final Determinations were standardised to species level, with subspecies and varieties removed, to achieve consistency with current plant taxonomy used in the draft PCT profiles.

5.5.6 Self-sustainability Assessments

The data analyses undertaken by DPIE in their self-sustainability assessments (Oliver and Dorrough 2019) are summarised below. Refer to **Appendix 1** for the full report.

Data used in analyses included those collected by DPIE, as listed in **Section 5.4.5**, as well as floristics, BAM, BBAM and LFA data collected by Umwelt (see **Section 5.4.3** and **Section 5.4.4)**.

A total of 23 datasets, including 84 variables collected by DPIE and Umwelt, were considered in analyses. The following analyses were undertaken:

- conversion of patch-scale data to site-scale data
- data reduction
- box plots for displaying range of variation at reference sites
- estimating variable importance
- visualising self-sustainability among priority variables
- benefits and costs of indicator collection, processing and data preparation
- probabilistic determination of self-sustainability.

Refer to **Appendix 1** for a full description of the data analyses completed.

Umwelt used the dataset of Oliver and Dorrough (2019) to calculate the 10th, 25th, 75th and 90th percentiles of reference site values for function attributes to assess the level of function of rehabilitation sites (**Table 5.12**), consistent with the approach of Oliver et al. (unpublished manuscript). Sites that fall between the 10th and 90th percentiles for an attribute are considered to show evidence of restoration success for that indicator (Oliver et al. unpublished manuscript). For the purposes of this study the sites that fall within this range are further divided in two categories, being 'very strong' for sites that fall within the IQR and 'strong' for those outside the IQR, to maintain consistency with the approach to assessing structural recognisability (**Section 5.5.3**).

Table 5.12 Assessment of Rehabilitation Function Based on Reference Site Data

Level of Function	Definition
Very Strong	Rehabilitation site value for an attribute falls within the inter-quartile range (IQR) (between 25th and 75th percentiles) of all reference site values for the given PCT
Strong	Rehabilitation site value for an attribute falls between the 10th and 90th percentiles of reference site values for the given PCT, but outside of the IQR
Moderate	Rehabilitation site falls below the 10th percentile or above the 90th percentile, but is within the observed range of reference site values for the given PCT
Weak	Rehabilitation site falls below the minimum or above the maximum observed reference site values for the given PCT

5.6 Stakeholder Consultation

A workshop with nine mining industry representatives from Glencore, Yancoal, Peabody and the NSW Minerals Council was undertaken on 27 February 2020. The purpose of the workshop was to present the proposed rehabilitation objectives, completion criteria and performance indicators for ecological mine rehabilitation and gather feedback on their adequacy and relevance.

For the purposes of this workshop, the rehabilitation objectives stated in the draft Ancillary Rules (DPIE 2019a and 2021a) were utilised and focus was on the performance indicators and completion criteria that relate to the establishment of rehabilitation intended to be recognisable as a specific PCT.

Correspondence with these and other mining and government agency representatives (MACH Energy, DPIE, Commonwealth Department of Agriculture, Water and the Environment and the QLD Department of Environment and Science (DES)) was also undertaken at various points during the project timeframe.

Further stakeholder consultation was undertaken during Stage 2 of the project following invitation to a DPIE workshop on the draft NSW BC Act Ancillary Rules for ecological mine rehabilitation (DPIE 2021a). The draft findings and conclusions of this project were tested with representatives from DPIE and the NSW Resources Regulator and their feedback was utilised, where appropriate.

6.0 Results

6.1 Existing Evidence of Recognisable and Self-sustaining Rehabilitation from New South Wales and Queensland Mines

6.1.1 Mangoola Coal, NSW

Mangoola Coal (Mangoola), located in the Hunter Valley of NSW, has been progressively rehabilitating its post-mined lands since 2007 (Umwelt 2018a). Under its conditions of consent, Mangoola is required to rehabilitate the following vegetation communities (DPE 2017a) to meet final land use obligations:

- Native Grassland
- Ironbark Woodland Complex
- Bulloak Woodland
- Paperbark Woodland
- Slaty Box Woodland
- Forest Red Gum Riparian Woodland
- Rough Barked Apple Woodland
- Swamp Oak Riparian Forest
- Weeping Myall Woodland.

Mangoola has used similar rehabilitation methods throughout its rehabilitated areas. Broadly, these methods involve the application of topsoil and gypsum and incorporating them through mechanical ripping. The area being rehabilitated is then seeded via direct seeding; infill planting has occurred where deficiencies in certain species were detected. Refer to **Appendix 3** for specific information relating to rehabilitation establishment, management and monitoring.

Mangoola's rehabilitation has been established and monitored since 2011. As of 2019, when the desktop and field assessment were undertaken, the rehabilitation was a maximum of eight years old and rehabilitation was ongoing. Review of the rehabilitation monitoring reports indicates that, despite the drought conditions experienced throughout NSW, the rehabilitated areas are progressing toward their reference sites with native species richness generally increasing between each monitoring event (Umwelt 2018a). Rehabilitation sites had, on average, 23 native plant species and 8.5 non-native species within a standard 400 m^2 plot. The rehabilitation sites shared an average of 11 native plant species with reference sites. As could be expected, due to its young age, the rehabilitation areas lacked the level of habitat complexity (that is, presence of logs, tree hollows, and diversity in the structure of the vegetation) present in the reference areas, however over time it is likely that the rehabilitated areas will develop more complex habitat. The presence and abundance of weed species was cited as the major deterrent to the success of vegetation establishment in rehabilitation areas (Umwelt 2018a). This desktop review indicates that, based on the monitoring previously undertaken, the rehabilitation at Mangoola could be developing towards a recognisable plant community.

6.1.2 Mount Thorley Warkworth, NSW

Mount Thorley Warkworth (MTW), located in the central Hunter Valley of NSW, has been progressively rehabilitating its post-mined lands since 2000 (Niche 2017). As of 2019, when the desktop and field assessment were undertaken, the rehabilitation was a maximum of 19 years old and rehabilitation was ongoing. Due to the approval of recent mining leases the mine is operating under multiple development consents. The historic development consent requires post-mined areas be rehabilitated to non-specific woodland while the current consent requires post-mined areas to be rehabilitated to conform to the *Central Hunter Grey Box – Ironbark Woodland EEC* (Niche 2017). As such, the rehabilitation reviewed for the mine comprises the rehabilitation established under the current consent.

Appendix 3 contains specific information relating to rehabilitation establishment, management and monitoring. Briefly, MTW has trialled different methods for rehabilitation establishment, which include:

- topsoil with native seed broadcast
- compost with spoil, native seeds drilled
- topsoil with native seeds hydroseeded
- compost with topsoil, native seeds drilled.

Rehabilitation monitoring has been conducted at MTW since 2014, the year the rehabilitation works began for the mining approval requiring floristically recognisable rehabilitation. It is understood that monitoring of native vegetation rehabilitation was not undertaken prior to 2014. Since monitoring commenced there have been changes to the specific methods used to monitor the rehabilitation as well as changes to the organisations and personnel conducting the monitoring. Changes to monitoring methods create challenges in comparing datasets and as such it is difficult to analyse how the individual rehabilitation monitoring plots are trending over time. However, review of the monitoring reports indicates the rehabilitation areas intended for the establishment of *Central Hunter Grey Box – Ironbark Woodland EEC* are developing into woodland communities. Fourteen rehabilitation monitoring sites intended for EEC establishment, and which were documented in monitoring reports (Niche 2016, 2018) as having native species included in the rehabilitation (through seed broadcast, hydroseeding or drilling), recorded an average of 16.1 native plant species within a standard 400 m^2 plot. The monitoring reports indicate a lack of habitat complexity due to the young age of the rehabilitation areas (Niche 2017). Cover of non-native plant species appears to be the main limiting factor to the establishment of native plant species, and more importantly native groundcover species, with an average weed cover of 35% (and range of 2-80%) of the groundcover in the rehabilitation areas (Niche 2016). A second potential limiting factor in achieving rehabilitation of the *Central Hunter Grey Box – Ironbark Woodland EEC* is the presence of spotted gum (*Corymbia maculata*), which does not typically occur in this EEC, throughout much of the rehabilitated areas. After a desktop review of the monitoring documents it was determined that MTW's rehabilitation was of a standard that would potentially be recognised as a native plant community.

6.1.3 Mount Owen Mine, NSW

Mount Owen Mine (MTO), located in the NSW central Hunter Valley, is required to rehabilitate their post-mined lands to be consistent with the *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* (SLR Consulting Australia 2017) as part of the development consent conditions. MTO has been progressively rehabilitating post-mined areas since 1998 using a variety of rehabilitation methods; refer to **Appendix 3** for full detail on these methods, management practices and monitoring methods. As of 2019, when the desktop and field assessment were undertaken, the rehabilitation was a maximum of 21 years old and rehabilitation was ongoing. In summary MTO has used direct and indirect transfer of forest and pasture topsoil as well as subsoil over mine spoil, with varying seed mixes that were applied via direct seeding. Golden wreath wattle (*Acacia saligna*), a species endemic to Western Australia which has become naturalised in parts of NSW, was used in the planting mix for much of the older (1998-1999) rehabilitation areas (SLR Consulting Australia 2017).

Ecological monitoring has been conducted at MTO since early 2001, with research projects examining many of the different facets that contribute to the functioning of a rehabilitated ecosystem (Nussbaumer et al. 2015). The research has included:

- examining the competition and control of golden wreath wattle (*Acacia saligna*)
- a long-term analysis of native understorey regeneration
- methods for shrub and herbaceous species establishment and dispersal
- long-term monitoring of rehabilitation areas.

The ecological monitoring indicates that most of the areas where forest topsoil was used in the rehabilitation establishment phase show promising signs of developing a diverse vegetation community and an abundance of essential soil microbes responsible for nutrient cycling (Nussbaumer et al. 2015). Canopy species appear to be successfully colonising in rehabilitation areas (with some areas supporting second-generation tree species), where golden wreath wattle (*Acacia saligna*) is not present. However, it has been observed that understorey and groundcover species have not been successful in establishment post-seeding. It is not fully understood why this situation has occurred; however, it is suggested that the timing of seeding (i.e. inadequate climatic conditions), the amount of seeding or predation by ants could be contributing factors (Nussbaumer et al. 2015). Based on this desktop review, the age and quality of MTO rehabilitation together indicate that the rehabilitation has a strong potential to achieve a recognisable plant community.

6.1.4 Bulga Coal, NSW

Bulga Coal (Bulga), located in the central Hunter Valley, NSW, is required under development consent conditions to rehabilitate a matrix of *Central Hunter Grey Box – Ironbark Woodland EEC*, *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* and Central Hunter Swamp Oak Forest (DPE 2017b). Bulga has been progressively rehabilitating their post-mined lands since 2007 (Emergent Ecology 2018). As of 2019, when the desktop and field assessment were undertaken, the rehabilitation was a maximum of 12 years old and rehabilitation was ongoing.

Details of the rehabilitation methods, management actions, and monitoring methods used at Bulga are contained in **Appendix 3**. In summary, Bulga rip the area to be rehabilitated, apply topsoil and compost, then apply a seed mix via direct seeding (T. Scott pers. comm. 2019).

Bulga has conducted ecological monitoring in their rehabilitation areas since 2012 (Emergent Ecology 2018). Monitoring data indicated that while the rehabilitation sites are showing progress in terms of developing into a woodland vegetation community, advances in vegetation structure and a decrease in weed cover are required before the rehabilitation resembles a woodland community. Rehabilitation sites supported an average of 17.8 native plant species, with an average of 11.4 non-native plant species within a standard 400 m^2 plot (Emergent Ecology 2018). There remains a combination of ecological factors that are potentially impeding the development of the rehabilitation areas, including a high density of tree species resulting in low groundcover (forbs, grasses, ferns and others), and an increasing level of weed cover, including a high diversity of weed species classified as 'High Threat Exotic' under the BAM (Emergent Ecology 2018). Based on this desktop review of the monitoring reports, Bulga's rehabilitation, although young, could develop into a recognised plant community.

6.1.5 United Mine, NSW

United Collieries (United), located in the central Hunter Valley NSW, commenced rehabilitation activities in the early 1990s, however exact dates could not be determined. Since this time there has been substantial development in the requirements of the regulatory agencies, both in terms of the ecological community to rehabilitate, and the amount of data to collect and document. United was required to rehabilitate their post-mined areas to a native woodland and this was undertaken using topsoil, where available, during the rehabilitation process (S. Pigott pers. comm. 2019).

Ecological monitoring has been conducted at United since 2005 (Umwelt 2018b). United's rehabilitation is currently resembling a native woodland, with an average of 24.6 native plant species and 14.6 non-native plant species recorded within a standard 400 m^2 plot (Umwelt 2018b). Ecological monitoring has recorded the presence of second-generation canopy species and nesting and reproducing woodland avifauna (Umwelt 2018b). The foremost threats to the rehabilitation areas include erosion, non-native plant species invasion, overly dense areas of sugar gum (*Eucalyptus cladocalyx*), native to South Australia, and low native plant species diversity (Umwelt 2018b). This desktop reviews suggests that, despite the presence of sugar gum, the wider species composition and age of the rehabilitation indicate that United's rehabilitation could be considered as conforming to a recognised plant community.

6.1.6 Boggabri Coal, NSW

Boggabri Coal (Boggabri), located in the Gunnedah Basin, NSW, is required under development consent conditions to rehabilitate post-mined lands to a vegetation community consistent with *White Box – Yellow Box – Blakeley's Red Gum Grassy Woodland CEEC* (Box-Gum Woodland CEEC) listed under the EPBC Act (DPE 2012). Boggabri has been progressively rehabilitating their lands since 2008 (WSP Parsons Brinckerhoff 2017), therefore as of 2019, when the desktop assessment was undertaken, the rehabilitation was a maximum of 11 years old and rehabilitation was ongoing.

Rehabilitation methods include:

- tube stock planting
- watering where required
- tube stock fertilised with 100 g of diammonium phosphate
- weed control
- planting in spring or autumn (Boggabri Coal 2015).

Ecological monitoring has been conducted since 2012 (WSP Parsons Brinckerhoff 2013). Native species richness appears to have increased as the rehabilitation areas have aged, however the data is collected along two randomly placed 100 m transects at each site and therefore the data does not allow for direct comparison of native species richness over time. As of 2016 the rehabilitation areas had an average of 40.8 native plant species, compared to an average of 17.8 in 2013; 27.9 in 2014; and 30 in 2015. Ecological monitoring indicates the rehabilitation areas were trending toward, and in some instances had already reached the BioBanking Benchmark values for BC Act-listed equivalent to Box-Gum Woodland CEEC. The sites had experienced the negative impacts of non-native plant species, particularly Rhodes grass (*Chloris gayana*), however it was noted that as the canopy foliage cover has developed, the Rhodes grass is becoming shaded out and decreasing in abundance (WSP Parsons Brinckerhoff 2017). After desktop reviews of the monitoring documents it was determined that Boggabri's rehabilitation was of a standard that would potentially conform to a recognised plant community.

6.1.7 Wilpinjong Coal Mine, NSW

Wilpinjong Coal Mine (Wilpinjong), located in the western coalfields near Mudgee, NSW, is operating under multiple development consents/project approvals that require different vegetation communities to be rehabilitated. Of interest is the Project Approval of 2008 that requires Wilpinjong to rehabilitate vegetation communities consistent with *Fuzzy Box Woodland on alluvial brown loam soils mainly in the NSW South Western Slopes Bioregion* (HU547); *Rough-barked Apple grassy tall woodlands of the Brigalow Belt South* (HU981); and *White Box-Black Cypress Pine shrubby woodland of the Western Slopes* (HU824) (DPE 2017c). Of these HU547 aligns with *Fuzzy Box Woodland on alluvial soils of the South Western Slopes, Darling Riverine Plains and Brigalow Belt South Bioregions EEC*. As of 2019, when the desktop assessment was undertaken, the rehabilitation at Wilpinjong was a maximum of 11 years old and rehabilitation was ongoing.

The woodland rehabilitation areas recorded an average of 13 native plant species providing moderate foraging resources to fauna within a standard 400 m^2 plot (Eco Logical Australia 2018). Rehabilitation areas met the BioBanking Benchmark values for native species richness (with the exception of one site) and native overstorey cover (Eco Logical Australia 2018). The rehabilitation sites were assessed as beginning progress toward achieving the Benchmark scores for native ground cover and exotic weed cover however most sites had not yet achieved these scores (Eco Logical Australia 2018). High non-native plant species cover was cited as the dominant threat for the rehabilitation areas (Eco Logical Australia 2018). Based on this desktop review, with adequate management of exotic plant species Wilpinjong's rehabilitation areas have the potential to meet the requirements of their consent conditions.

6.1.8 Burton Mine, QLD

Burton Mine (Burton), located in the Bowen Basin, QLD, is required to progressively rehabilitate post-mined lands (Peabody 2018). Burton is rehabilitating pasture vegetation and non-specific native woodland (AECOM 2018). Where available, Burton uses topsoil (stored for as little time as possible) when establishing their rehabilitation areas (Peabody 2018).

Burton has been progressively rehabilitating post-mined lands since 2009 and has been monitoring the rehabilitation since 2011 (AECOM 2018). As of 2019, when the desktop assessment was undertaken, the rehabilitation was a maximum of 12 years old and rehabilitation was ongoing. On average the rehabilitation areas supported 28.7 species per assessed area, the precise dimensions of which could not be determined. In all vegetated rehabilitation sites the groundcover was dominated by non-native pasture species however some rehabilitated areas were developing a shrub and tree layer and in these areas the exotic pasture species occurred in lower densities (AECOM 2018). The monitoring reports indicated a high cover of pasture grass species and a general lack of establishment of both native groundcover and mid-storey species. Based on this desktop review, it is unlikely that the rehabilitation will achieve a recognised plant community without intervention, however there is currently no requirement for a recognised native plant community to be established at this site.

6.1.9 Rolleston Mine, QLD

Rolleston Open Cut Mine (Rolleston), located in the Bowen Basin, QLD, is required to progressively rehabilitate post-mined lands (DES 2018). Rolleston is rehabilitating grazing land and Semi-evergreen Vine Thicket (SEVT) vegetation (Land Line Consulting 2017), which is listed as an EEC under the EPBC Act in the Brigalow Belt (North and South) and Nandewar bioregions. In Queensland, several regional ecosystems listed under the *Vegetation Management Act 1999* (VM Act) are analogous with SEVT, including RE11.9.4 which is listed as 'Of Concern' under the VM Act and is known to occur in the region of Rolleston.

Rehabilitation has been progressively occurring since 2012 and monitored since 2013 (Land Line Consulting 2017). As of 2019, when the desktop assessment was undertaken, the rehabilitation was a maximum of 7 years old and rehabilitation was ongoing. The SEVT rehabilitation areas were dominated by both native and non-native grasses, with some *Acacia* spp. and *Brachychiton* spp. present (Land Line Consulting 2017). The desktop review indicates that the rehabilitation, based its assessed condition by Land Line Consulting (2017), is unlikely to achieve a recognised plant community without intervention, due to a lack of target species establishment and the high cover of pasture grass species.

6.1.10 Threatened Fauna Habitat Use

The results of the desktop analysis show that a range of threatened fauna species have utilised mine rehabilitation on the selected Hunter Valley mine sites. A total of 21 threatened fauna species were recorded in mine rehabilitation across four mine sites (refer to **Table 6.1**) comprising nine species of bird and 12 species of mammal.

Table 6.1 Threatened Fauna Species Records on Mine Rehabilitation

Common Name	Scientific Name	Conservation Status*		Mt Owen														Mangoola				Bulga				United								
		BC Act	EPBC Act	2002/2003	2004/2005	2005/2006	2006/2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2019	2015	2016	2018	2020	2015	2016	2017	2019	2008	2009	2010	2011	2013	2014	2015	2016	2018
Diamond Firetail	*Stagonopleura guttata*	V							✓																									
Dusky Woodswallow	*Artamus cyanopterus*	V														✓																		
Grey Crowned Babbler	*Pomatostomus temporalis*	V										✓			✓					✓	✓			✓		✓		✓	✓		✓	✓	✓	✓
Hooded Robin	*Melanodryas cucullata cucullata*	V							✓			✓			✓																			
Little Lorikeet	*Glossopsitta pusilla*	V														✓						✓												
Masked Owl	*Tyto novaehollandiae*	V																✓																
Scarlet Robin	*Petroica boodang*	V																												✓				

Common Name	Scientific Name	Conservation Status*		Mt Owen														Mangoola				Bulga				United								
		BC Act	EPBC Act	2002/2003	2004/2005	2005/2006	2006/2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2019	2015	2016	2018	2020	2015	2016	2017	2019	2008	2009	2010	2011	2013	2014	2015	2016	2018
Speckled Warbler	*Chthonicola sagittata*	V			✓	✓		✓	✓	✓				✓	✓	✓	✓		✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
White-bellied sea-eagle	*Haliaeetus leucogaster*	V															✓																	
Brush-tailed Phascogale	*Phascogale tapoatafa*	V															✓																	
East Coast Free-tail Bat	*Micronomus norfolkensis* (syn. *Mormopterus norfolkensis*)	V		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓				✓				✓				✓		✓
Eastern Bentwing-bat	*Miniopterus orianae oceanensis*	V			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										✓			✓		✓	✓
Eastern Cave Bat	*Vespadelus troughtoni*	V																										✓		✓		✓	✓	✓
Greater Broad-nosed Bat	*Scoteanax rueppellii*	V						✓	✓	✓																		✓						
Grey-headed Flying-fox	*Pteropus poliocephalus*	V	V													✓																		
Large-eared Pied Bat	*Chalinolobus dwyeri*	V	V					✓										✓		✓	✓												✓	✓
Little Bentwing-bat	*Miniopterus australis*	V						✓																										

Common Name	Scientific Name	Conservation Status*		Mt Owen														Mangoola				Bulga				United								
		BC Act	EPBC Act	2002/2003	2004/2005	2005/2006	2006/2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2019	2015	2016	2018	2020	2015	2016	2017	2019	2008	2009	2010	2011	2013	2014	2015	2016	2018
New Holland Mouse	*Pseudomys novaehollandiae*		V			✓																												
Southern Myotis	*Myotis macropus*	V																											✓					
Spotted-tailed Quoll	*Dasyurus maculatus*	V	E								✓	✓	✓																					
Yellow-Bellied Sheath-Tailed Bat	*Saccolaimus flaviventris*	V							✓	✓		✓	✓							✓								✓						

Notes:

E - endangered

V - Vulnerable

6.2 Sample Size Analysis

The sample size analysis was undertaken prior to field surveys using existing monitoring data from Mangoola Mine to determine the number of sample replicates required for statistical analysis of compositional data. By examining **Figure 6.1** and **Figure 6.2** below, it is apparent that heterogeneity in the multSE values occurs across the four different vegetation community types and the three different treatments (rehabilitation, revegetation and remnant vegetation) at Mangoola Mine. A double resampling scheme was used to generate means for each sample size using 10,000 permutations and error bars as bias-adjusted 2.5 and 97.5 percentiles from 10,000 bootstrap resamples.

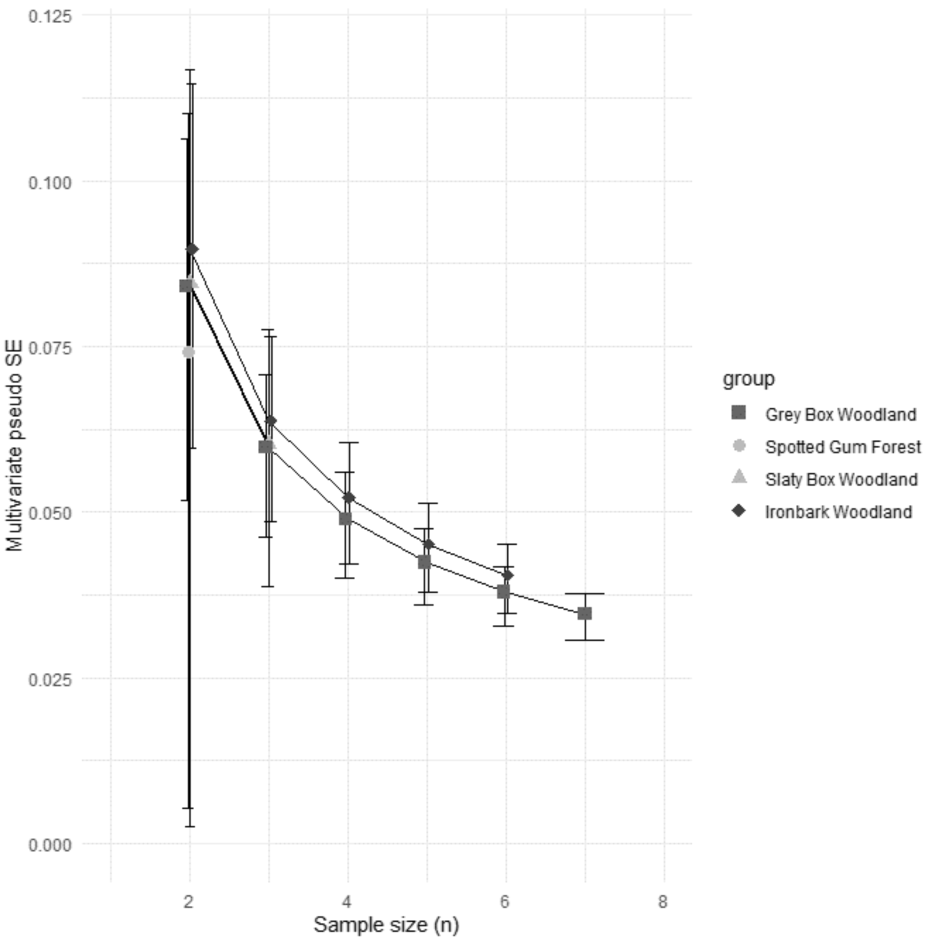


Figure 6.1 Multivariate pseudo standard error (MultSE) analysis for four vegetation community types

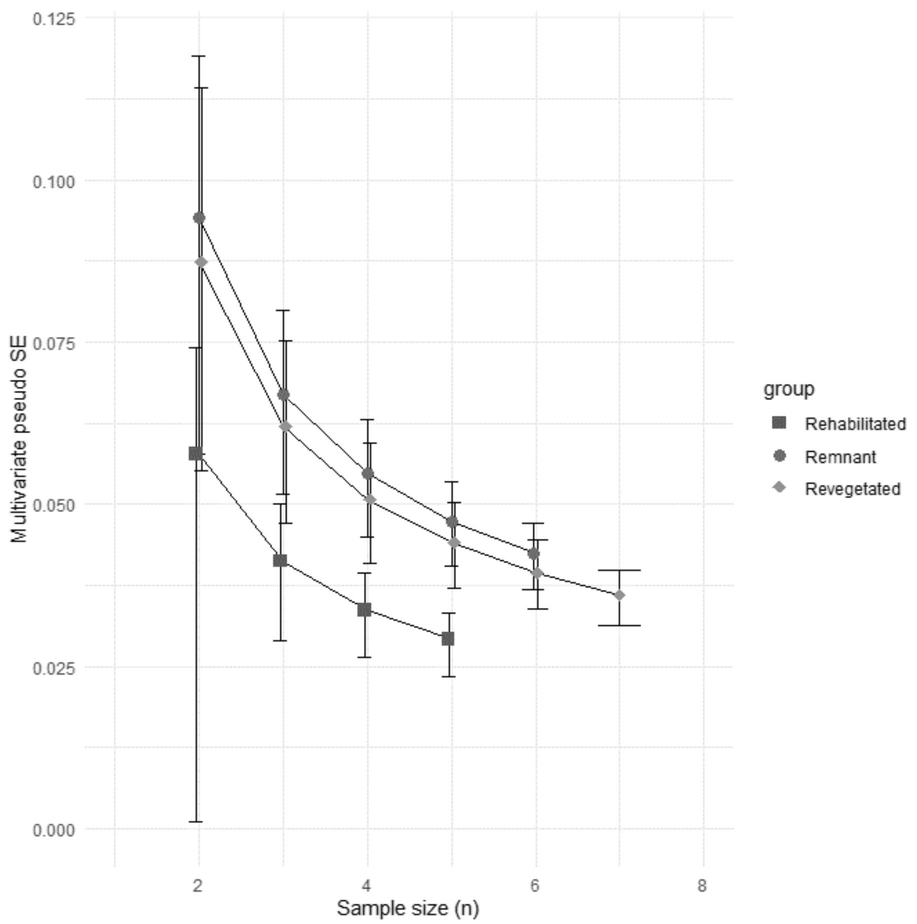


Figure 6.2 Multivariate pseudo standard error (MultSE) analysis for three vegetation community treatments

Figure 6.1 and **Figure 6.2** shows the dissimilarity of log10 abundance of flora species per vegetation community type and treatment with decreasing variability occurring as sample size increases. By considering values of multSE with increasing samples, reductions in variance stabilise at about *n* = 5 sampling units.

6.3 Allocation of Sites to PCT

Analysis using the draft PCT Assignment Tool (DPIE 2019c) and informed interpretation of the 'best fit' results utilising the range of environmental attributes (elevation, rainfall and temperature), showed that 45 of the 48 reference sites and 15 of the 45 rehabilitation sites recorded a distance to centroid value below the 0.695 threshold for the allocated PCT.

The majority of reference sites were allocated to three PCTs, being 3431, 3315 and 3485 (refer to **Table 6.2**). Seven plots were allocated to an additional three PCTs, being 3438, 3757 and 3314 which are located on, or near to, Hunter Valley footslopes or escarpments and are influenced by soils derived from Triassic-aged sandstone strata. Consequently, the latter three PCTs, which do not represent the target PCTs for this study, and the seven plots allocated to these PCTs, were excluded from further analyses. The results presented hereafter in this report focus on the sites allocated to the target PCTs (**Table 6.2**).

Table 6.2 PCT Allocations

PCT	Number of Sites		
	Reference	Rehabilitation	Total
3314 Central Hunter Slopes Grey Box Forest	1	0	1
3315 Central Hunter Ironbark-Spotted Gum Forest	13	7	20
3431 Central Hunter Ironbark Grassy Woodland	16	28	44
3438 Hunter Escarpment Footslopes Ironbark Forest	4	0	4
3485 Central Hunter Slaty Gum Grassy Forest	12	10	22
3757 Hunter Escarpment Ironbark Scrubby Low Forest	2	0	2
Total number of sites	**48**	**45**	**93**

Note: non-target PCTs are shaded grey

Rehabilitation sites were allocated to the PCT considered the 'best fit' of the three target PCTs (3315, 3485 and 3431) based on the target vegetation community of the rehabilitation; or where the target PCT was not clear, the sites were allocated to the PCT with the lowest distance to centroid value. For the 15 rehabilitation sites that recorded a distance to centroid value of <0.695, one site was not allocated to the target PCT. However, for this particular site, the distance to centroid to the target PCT was also <0.695 and the decision regarding which PCT to allocate the site to was based on maximising the number of sites allocated to PCT3485. For one rehabilitation site with lower recognisability, the target PCT (3315) was not identified in the ten nearest matches, which prevented access to the distance to centroid measure to this PCT and consequently the site was allocated to the next 'best fit' being 3431. A total of 28 rehabilitation sites were allocated to 3431, 10 were allocated to 3485 and 7 were allocated to PCT3315.

For most reference sites, the target PCT with the lowest distance to centroid value was the most appropriate allocation based on floristic composition. The target PCTs were also the 'best fit' with regard to the environmental attributes (elevation, rainfall and temperature), as the sites were located within their known geographic range. A total of 39 (of 48, or 81%) reference sites and 25 (of 45, or 56%) rehabilitation sites were allocated to the PCT with the closest distance to centroid (**Table 6.3**). Six reference sites were allocated to the second closest match and three were allocated to the third closest match, due to the elevation, rainfall and/or temperature range of the sampling location being inconsistent with the known range for the PCT with the lowest distance to centroid value. Rehabilitation sites were allocated to a higher number of PCT matches, ranging from the first to the ninth closest match and, in a small number of cases, the anticipated PCT, based on the target vegetation community, was not identified in the ten closest matches (which, as in the example above, prevented access to the actual centroid distance measurement for that PCT). The outputs from the draft PCT Assignment Tool are provided in **Appendix 4**.

Table 6.3 Number and Proportion of Sites from Each Treatment Allocated to PCT match number 1 to 9

PCT/Type	Number (proportion) of sites allocated to closest match[1]								
	1	2	3	4	5	6	7	8	9
3315 Rehabilitation	4 (57.1)	1 (14.3)	0	0	0	0	2 (28.6)	0	0
3431 Rehabilitation	13 (46.4)	8 (28.6)	3 (10.7)	2 (7.1)	1 (3.6)	0	0	0	1 (3.6)

PCT/Type	Number (proportion) of sites allocated to closest match[1]								
	1	2	3	4	5	6	7	8	9
3485 Rehabilitation	8 (80)	2 (20)	0	0	0	0	0	0	0
3315 Reference	12 (92.3)	1 (7.7)	0	0	0	0	0	0	0
3431 Reference	13 (81.3)	2 (12.5)	1 (6.3)	0	0	0	0	0	0
3485 Reference	9 (75)	3 (25)	0	0	0	0	0	0	0
3314/3438/3757 Reference[2]	5 (71.4)	0	2 (28.6)	0	0	0	0	0	0

[1] As indicated by the Draft PCT Assignment Tool, which provides the ten nearest PCT matches for each floristic plot (i.e. the ten PCTs with the lowest distance to centroid value). Match number 10 is not displayed, as no sites were allocated to the tenth nearest PCT match.

[2] Non-target PCTs

The results of the draft PCT Assignment Tool confirmed that there is a strong negative correlation (r = -0.748) between native species richness and distance to centroid value to the allocated PCT, with distance to centroid value decreasing as native species richness increases (**Figure 6.3**). As shown in **Figure 6.3**, reference sites typically recorded higher native species richness combined with lower distance to PCT centroid values, whereas rehabilitation sites generally recorded lower native species richness and higher distance to PCT centroid values.

A total of 45 of the 48 reference sites recorded a distance to centroid value below the 0.695 threshold. Although two reference sites scored the lowest native species richness (22 species) they still recorded a distance to threshold value below the 0.695 threshold. However, three other reference sites which also recorded the lowest native species richness count (22 species), recorded a distance to centroid value above the threshold, which indicates that other factors, such as the identity of the species recorded and their foliage cover within the plot, contributes to the distance to centroid value and not native species richness alone. A similar trend was observed with rehabilitation sites, such that those sites which recorded the highest native species richness also recorded the lowest distances to centroid values, whilst the sites with the lowest native species richness recorded the highest distance to centroid values; however, there were mixed results in between the upper and lower ranges.

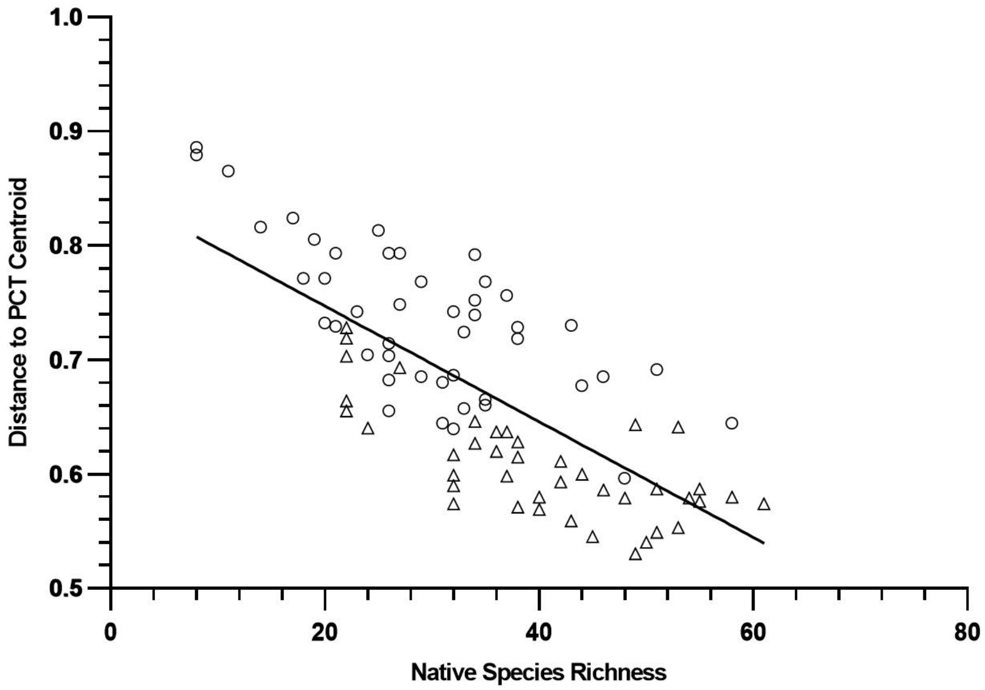


Figure 6.3 Relationship between distance to centroid of allocated PCT and native species richness for all rehabilitation sites (represented by circles) and reference sites (represented by triangles)

Plate 6.1 Representative image of PCT3315 Central Hunter Ironbark-Spotted Gum Forest Reference Site

Plate 6.2 Representative image of PCT3315 Central Hunter Ironbark-Spotted Gum Forest Rehabilitation Site (21 years old)

Plate 6.3 Representative image of PCT3485 Central Hunter Slaty Gum Grassy Forest Reference Site

Plate 6.4 Representative image of PCT3485 Central Hunter Slaty Gum Grassy Forest Rehabilitation Site (6 years old)

Plate 6.5 Representative image of PCT3431 Central Hunter Ironbark Grassy Woodland Reference Site

Plate 6.6 Representative image of PCT3431 Central Hunter Ironbark Grassy Woodland Rehabilitation Site (6 years old)

6.4 Compositional Recognisability

The following sections focus on recognisability at the level of PCT. Refer to **Section 6.8** for the results of TEC recognisability investigations.

6.4.1 Degree of Compositional Recognisability Using Distance to PCT Centroid

Following the analysis of the distance to PCT centroid of BioNet plots categorised as 'secondary' in the ENSW PCT Classification (DPIE 2019b), thresholds of PCT recognisability were developed (**Table 6.4**). The threshold values were determined using the mean and standard deviation of 4153 plots allocated to 744 PCTs. The mean distance to PCT centroid was 0.736 and the standard deviation was 0.032. The development of these threshold values assumes that the PCT Assignment Tool required to determine distance to PCT centroid will be publicly available in the near future (expected early 2022).

Table 6.4 PCT Recognisability Thresholds

Level of recognisability	Distance to PCT centroid threshold value
Very Strong	≤0.695
Strong	>0.695 and ≤0.736
Moderate	>0.736 and ≤0.768
Weak	>0.768

The thresholds described in **Table 6.4** were applied to rehabilitation sites sampled for the project, using the distance to centroid values for the allocated PCT. The results are shown in **Table 6.5**.

Table 6.5 Level of PCT Recognisability of Rehabilitation Sites as Target PCTs

PCT	Level of PCT Recognisability				Total
	Very Strong	Strong	Moderate	Weak	
3315	6	1	0	0	7
3431	6	6	6	10	28
3485	3	2	2	3	10
Total	**15**	**9**	**8**	**13**	**45**

The highest level of recognisability recorded for young rehabilitation sites less than five years old was 'strong'. The three older rehabilitation sites greater than 20 years of age all recorded a 'very strong' level of recognisability. The intermediate aged rehabilitation sites recorded variation in the level of recognisability and overall, there was found to be no clear correlation between distance to PCT centroid and the age of rehabilitation (r = -0.338). The level of recognisability of rehabilitation sites by age is shown in **Table 6.6**.

Table 6.6 Level of PCT Recognisability of Rehabilitation Sites by Age Class

Age of rehabilitation (years)	Level of PCT Recognisability				Total
	Very Strong	Strong	Moderate	Weak	
<5	0	2	2	2	6
5 - 9	9	5	6	10	30
10 - 14	3	2	0	1	6
>20	3	0	0	0	3
Total	**15**	**9**	**8**	**13**	**45**

All mine sites where rehabilitation data were collected exhibited variation in the level of PCT recognisability recorded, excluding United Mine where a single site was sampled (**Table 6.7**).

Table 6.7 Level of PCT Recognisability Recorded in Rehabilitation at Mine Sites

Mine Site	Level of PCT Recognisability in Rehabilitation			
	Very Strong	Strong	Moderate	Weak
Bulga	0	2	0	7
Mangoola	7	4	4	4
Mt Owen	6	2	0	0
Mount Thorley Warkworth	1	1	4	2
United	1	0	0	0

Mine Site	Level of PCT Recognisability in Rehabilitation			
	Very Strong	Strong	Moderate	Weak
Total	**15**	**9**	**8**	**13**

6.4.2 Comparison to PCT Profiles

A strong negative correlation (r = -0.939) was identified between the number of species recorded at sampled sites that are listed in the draft PCT profile for the corresponding PCT and the distance to centroid measure obtained through the draft PCT Assignment Tool (**Figure 6.4**). A similar trend was observed for each of the individual PCTs; 3315 (r = -0.869); 3431 (r = -0.950); and 3485 (r = -0.940) (**Figure 6.4**). The minimum number of species recorded from the draft PCT profile that achieved ‘very strong’ compositional recognisability was 17, and of sites that achieved ‘strong’ recognisability, between 12 to 18 species from the draft PCT profile were recorded.

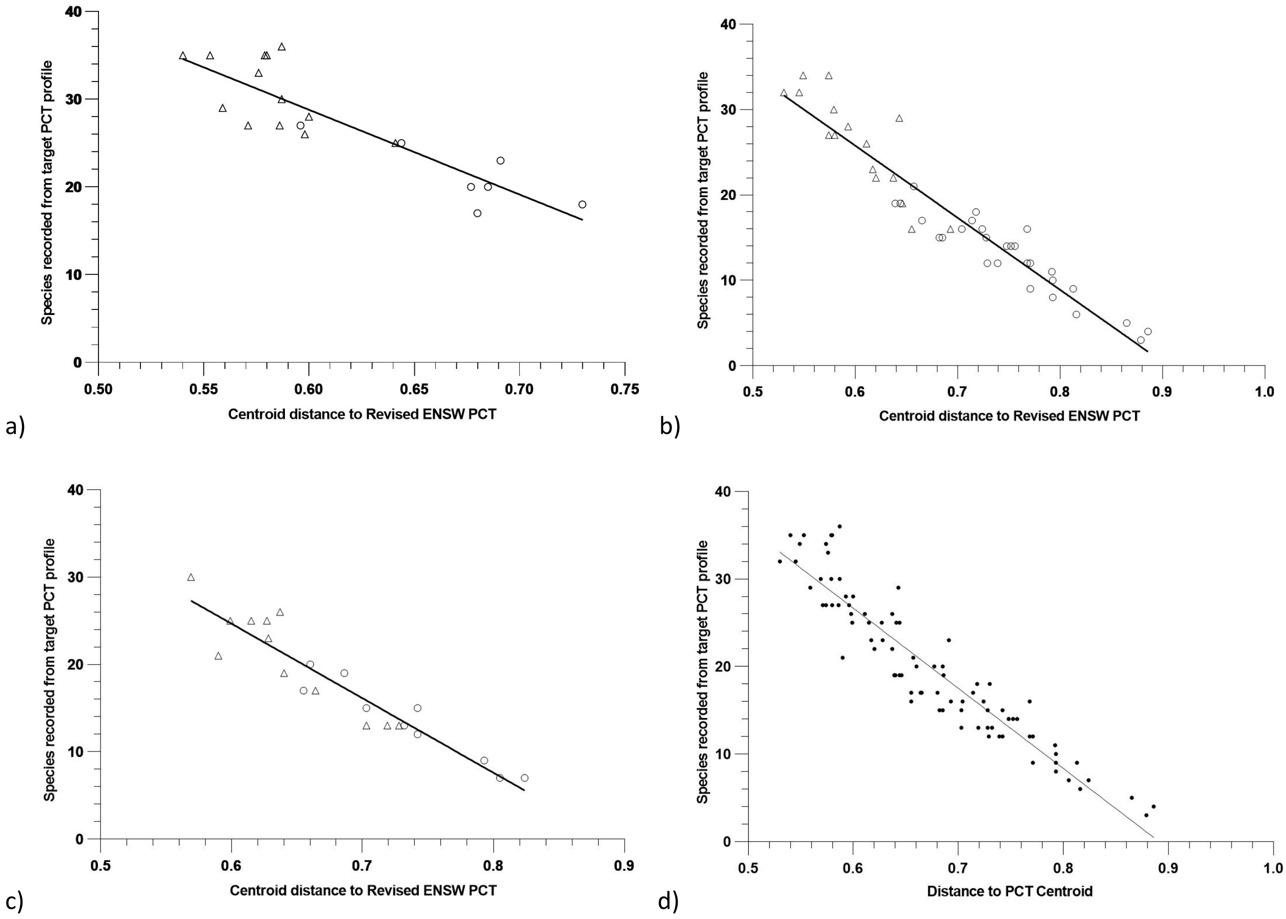


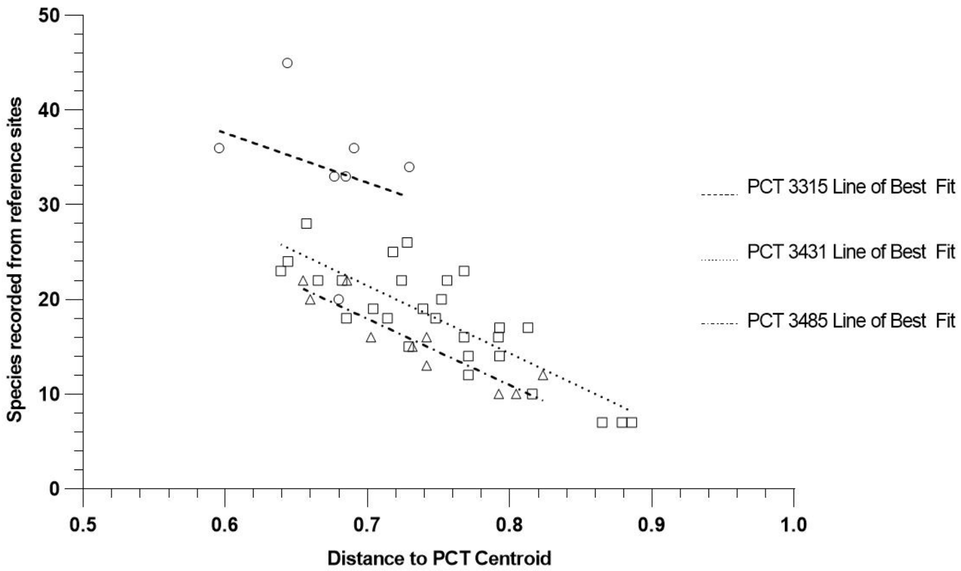
Figure 6.4 Relationship between distance to PCT centroid and the number of species recorded from the corresponding draft PCT profile for reference sites (represented by triangles) and rehabilitation sites (represented by circles) allocated to PCT3315 (a); PCT3431 (b); PCT3485 (c); and all rehabilitation and reference sites from the three target PCTs (d).

6.4.3 Comparison of Rehabilitation to Reference Sites

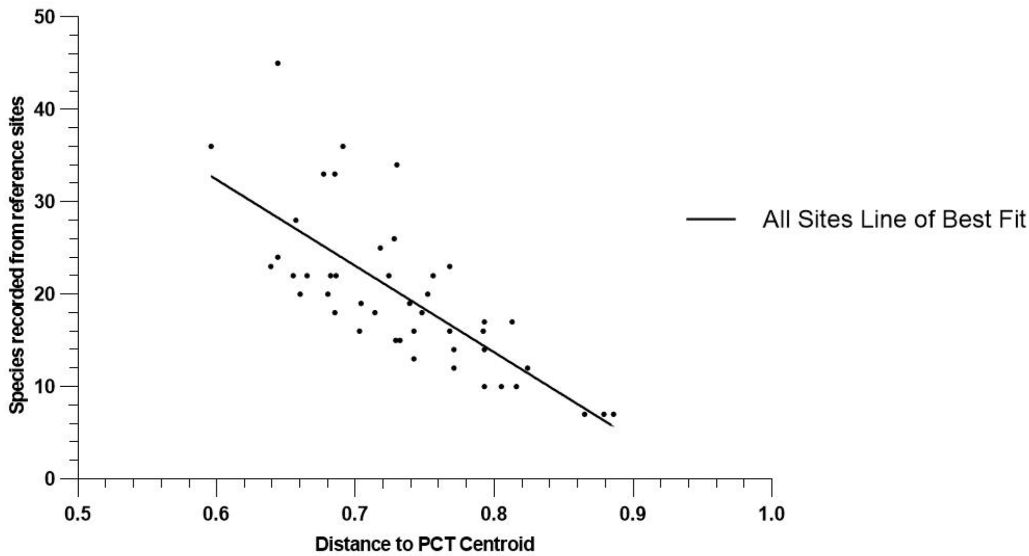
Most reference sites were found to have a distance to PCT centroid below the 0.695 threshold of the draft PCT Assignment Tool and are therefore very strongly aligned with that PCT. A strong negative correlation ($r = -0.745$) was found between the number of native species recorded at rehabilitation sites that were also recorded at the pool of reference sites allocated to the same PCT and the distance to PCT centroid, however the strength of the correlation varied by PCT (**Figure 6.5**). PCTs 3431 and 3485 recorded strong correlations between these attributes ($r = -0.825$ and $r = -0.917$, respectively), whilst PCT3315 recorded a correlation of $r = -0.297$, which is not significant (**Figure 6.5**).

A total of 123 native flora species were recorded at PCT3315 reference sites (n=13), 65 were recorded at PCT3485 reference sites (n=12) and 107 were recorded at PCT3431 reference sites (n=16). Of rehabilitation sites allocated to PCT3315 with 'very strong' recognisability, the minimum number of native species in common with reference sites was 20, however the PCT3315 rehabilitation sites which achieved 'strong' recognisability had 34 native species in common with reference sites. A similar trend was observed for PCT3431, where rehabilitation sites with 'very strong' recognisability recorded a minimum of 18 native species recorded at reference sites, and rehabilitation sites with 'strong' recognisability recorded between 15 and 26 native species from PCT3431 reference sites. PCT3485 rehabilitation sites which achieved recognisability of 'very strong' recorded between 20 and 22 native species in common with PCT3485 reference sites, and sites assessed as having 'strong' recognisability contained 15 or 16 native species also recorded at PCT3485 reference sites.

umwelt



a)



b)

Figure 6.5 Relationship between distance to PCT centroid and the number of species recorded at rehabilitation sites that also occur at reference sites of the same PCT for PCTs 3315 (represented by circles), 3431 (represented by squares), and 3485 (represented by triangles) (a), and all rehabilitation sites combined (b).

6.5 Structural Recognisability

To determine which rehabilitation sites could be considered to be structurally recognisable, a comparison was made between the individual rehabilitation sites and the range of reference site data for each structural attribute. Rehabilitation sites were considered *very strongly* recognisable if they fell within the IQR of the allocated PCT reference site data and *strongly* recognisable if they fell between the 10th and 90th percentile of reference site values. Rehabilitation sites within the range of reference sites were considered to be *moderately* recognisable to the reference sites and the sites that fell outside of this were considered to be *weakly* recognisable.

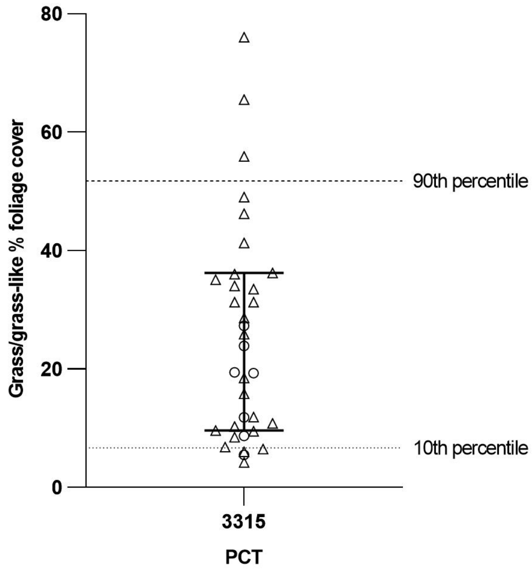
The structural attributes that were assessed included the foliage cover of native species allocated to tree, shrub, forb, and grass and grass-like growth forms, as defined by the BAM, to assess the dominant growth forms across the three target PCTs (refer to **Section 6.6**). Tree abundance by DBH size class was also assessed for the four smallest size classes.

6.5.1 Native Grass Cover

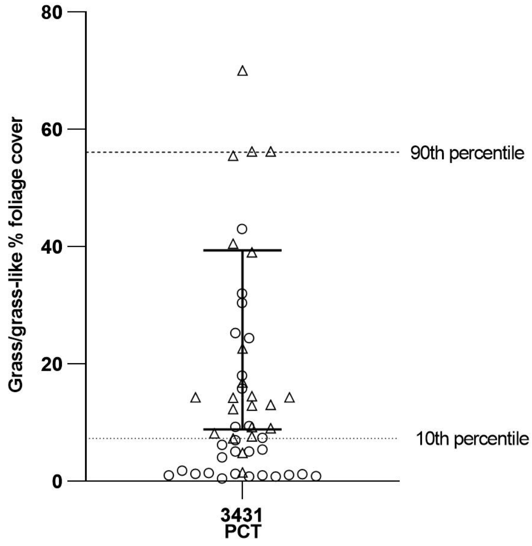
The rehabilitation sites, across all PCTs, were largely within range for foliage cover of native species assigned to the grass and grass-like growth form, however a substantial number of values collected from PCTs 3431 and 3485 fall below the 10^{th} percentile of reference sites. A total of 15 of the 45 rehabilitation sites were considered very strongly recognisable, 4 strongly recognisable, 12 moderately recognisable and 14 weakly recognisable (refer to **Appendix 5** for site-specific results). **Figure 6.6** displays the results of this comparison and the threshold values are shown in **Table 6.8**.

Table 6.8 Reference Site % Foliage Cover Values for Grass and Grass-like (GG) Growth Form

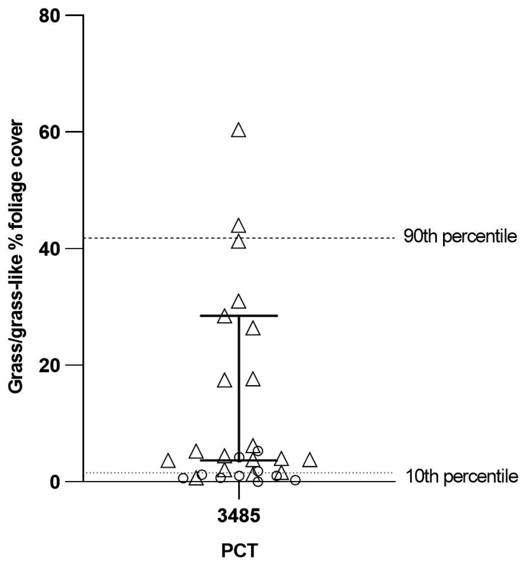
PCT	Min	Percentile				Max
		10th	25th	75th	90th	
3315	4.2	6.68	9.95	36.1	51.76	76
3431	1.5	7.33	9.05	34.9	56.13	70
3485	0.7	1.54	3.75	27.45	41.84	60.4



a)



b)



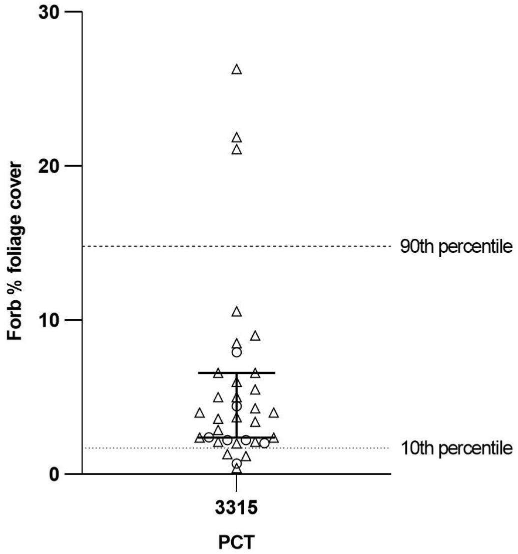
c)

Figure 6.6 % foliage cover of species allocated to grass/grass-like growth form recorded at reference sites (represented by triangles) and rehabilitation sites (represented by circles) for PCTs 3315 (a); 3431 (b); and 3485 (c).

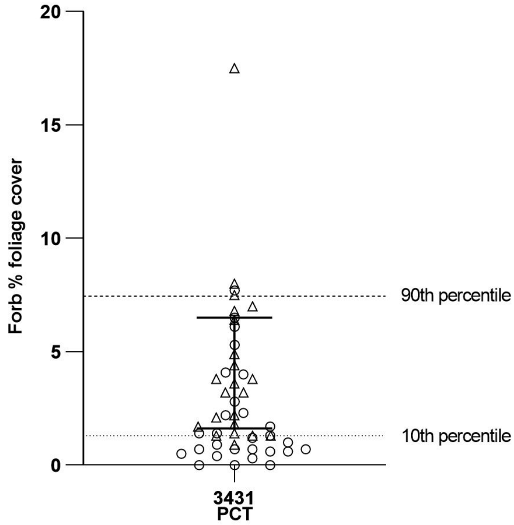
The 25th to 75th percentile (IQR) of reference sites values is represented by the bold vertical and horizontal lines, and the 10th and 90th percentiles are displayed using hatched lines.

6.5.2 Native Forb Cover

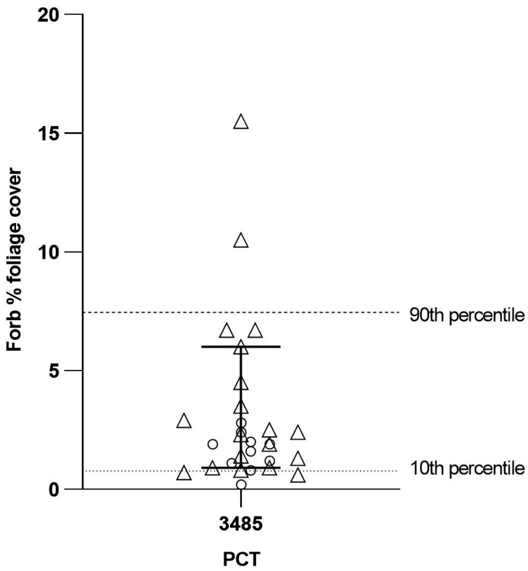
The rehabilitation sites allocated to PCT3315 and PCT3485 largely fell within the range of foliage cover of native species assigned to the forb growth form. A large number of rehabilitation sites allocated to PCT3431 fell below the minimum foliage cover of species allocated to the forb growth form. A total of 16 of the 45 rehabilitation sites considered very strongly recognisable, 11 strongly recognisable, 5 moderately recognisable and 13 weakly recognisable (refer to **Appendix 5** for the site-specific results). **Figure 6.7** displays the results of this comparison and the threshold values are shown in **Table 6.9**.



a)



b)



c)

Figure 6.7 % foliage cover of species allocated to forb growth form recorded at reference sites (represented by triangles) and rehabilitation sites (represented by circles) for PCTs 3315 (a); 3431 (b); and 3485 (c).

The 25th to 75th percentile (IQR) of reference sites values is represented by the bold vertical and horizontal lines, and the 10th and 90th percentiles are displayed using hatched lines.

Table 6.9 Reference Site % Foliage Cover Values for Forb (FG) Growth Form

PCT	Min	Percentile				Max
		10th	25th	75th	90th	
3315	0.4	1.72	2.4	6.6	14.8	26.3
3431	0.9	1.3	1.73	6.03	7.45	17.5
3485	0.6	0.78	1.1	5.25	7.46	15.5

6.5.3 Native Shrub Cover

The foliage cover of native species assigned to the shrub growth form at PCT3315 rehabilitation sites was within the range observed at reference sites (**Figure 6.8**). For PCT3431 and PCT3485 rehabilitation sites, shrub foliage cover was generally higher than the majority of reference site values. A total of 8 of the 45 rehabilitation sites considered very strongly recognisable, 13 strongly recognisable, and 24 moderately recognisable (refer to **Appendix 5** for the site-specific results). **Figure 6.8** displays the results of this comparison and the threshold values are shown in **Table 6.10**.

Table 6.10 Reference Site % Foliage Cover Values for Shrub (SG) Growth Form

PCT	Min	Percentile				Max
		10th	25th	75th	90th	
3315	0.3	0.8	2.1	11.95	20.2	35.6
3431	0	0.31	1.2	5.23	7.4	48
3485	0.2	0.4	0.5	3.3	13.1	70.7

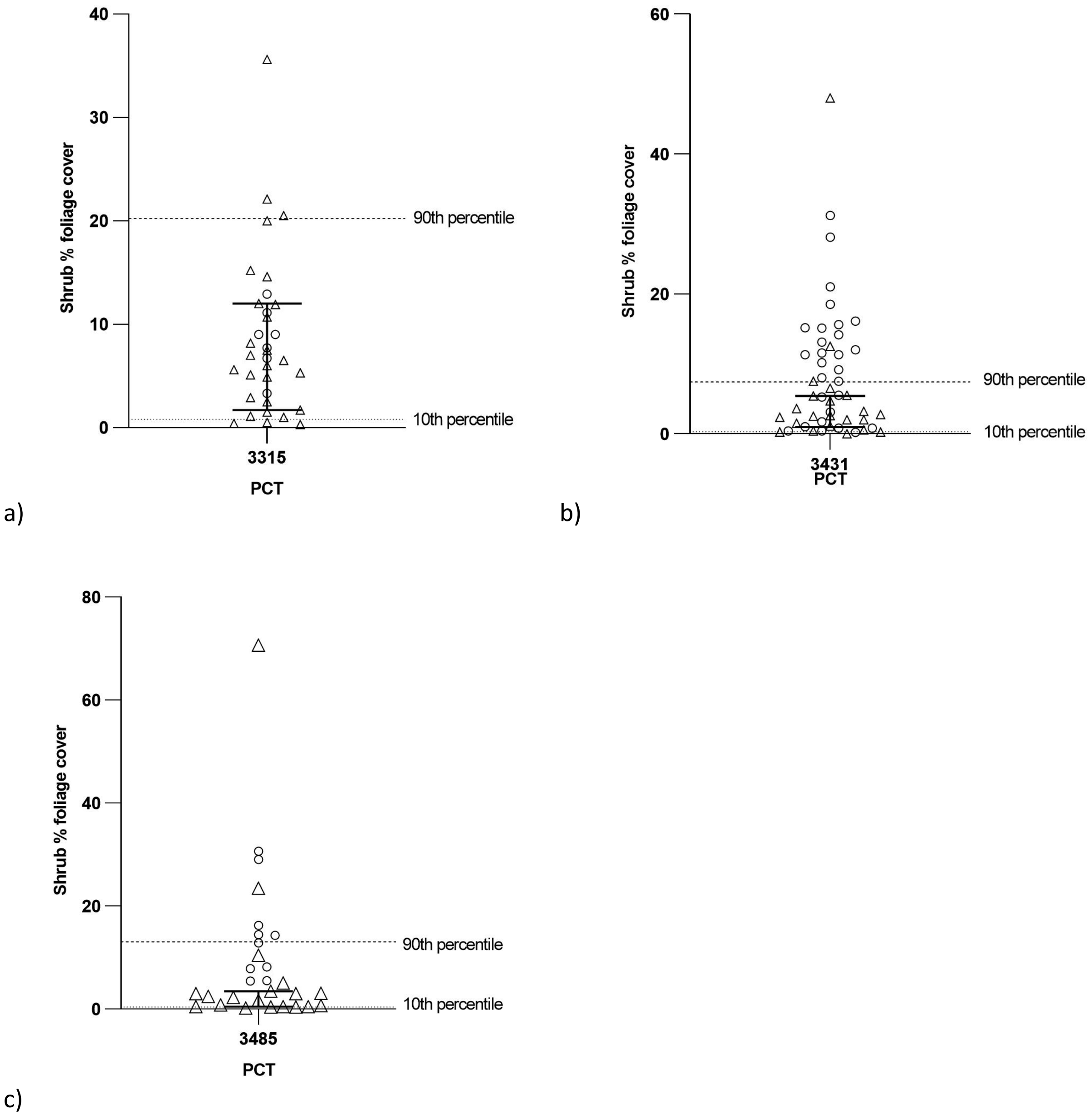


Figure 6.8 % foliage cover of species allocated to shrub growth form recorded at reference sites (represented by triangles) and rehabilitation sites (represented by circles) for PCTs 3315 (a); 3431 (b); and 3485 (c).

The 25th to 75th percentile (IQR) of reference sites values is represented by the bold vertical and horizontal lines, and the 10th and 90th percentiles are displayed using hatched lines.

6.5.4 Native Tree Cover

The majority of rehabilitation sites, across all PCTs, recorded foliage cover of native species assigned to the tree growth form below the 25th percentile of values observed at reference sites. Conversely, two PCT3315 rehabilitation sites recorded tree foliage cover above the range observed at corresponding reference sites. A total of 2 of the 45 rehabilitation sites were assessed as being very strongly recognisable, 7 strongly recognisable, 16 moderately recognisable and 20 weakly recognisable (refer to **Appendix 5** for the site-specific results). **Figure 6.9** displays the results of this comparison and the threshold values are shown in **Table 6.11**.

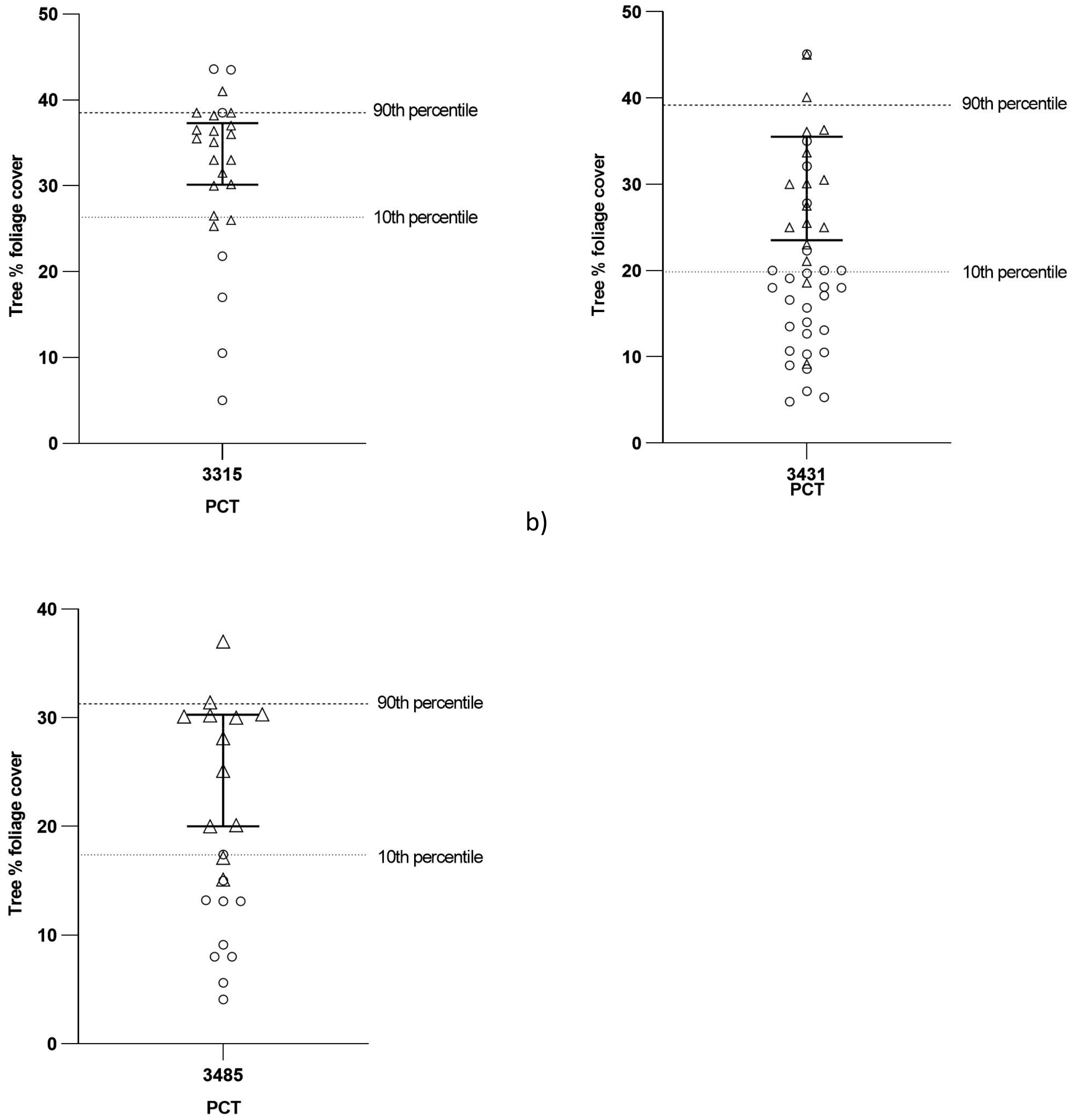


Figure 6.9 % foliage cover of species allocated to tree growth form recorded at reference sites (represented by triangles) and rehabilitation sites (represented by circles) for PCTs 3315 (a); 3431 (b); and 3485 (c).

The 25th to 75th percentile (IQR) of reference sites values is represented by the bold vertical and horizontal lines, and the 10th and 90th percentiles are displayed using hatched lines.

Table 6.11 Reference Site % Foliage Cover Values for Tree (TG) Growth Form

PCT	Min	Percentile				Max
		10th	25th	75th	90th	
3315	25.3	26.35	30.52	36.88	38.5	41
3431	9.2	19.85	24.5	34.3	38.2	45
3485	15.1	17.39	20.08	30.23	31.3	37

6.5.5 Tree Stem Counts

Across all rehabilitation sites, tree stems were recorded within the five smallest DBH size classes, being <5 cm, 5-9 cm, 10-19 cm, 20-29 cm and 30-49 cm. The 30-49 cm DBH size class was recorded at three rehabilitation sites, ranging from 12 to 21 years since establishment. Six reference sites recorded the largest size class (>80 cm DBH), which included one site from PCT3315, two sites from PCT3431 and three sites from PCT3485.

The abundance of trees with DBH <5 cm was generally higher at rehabilitation compared to reference sites (**Figure 6.10**), particularly for PCTs 3431 and 3485. With regard to the abundance of trees with DBH <5 cm, a total of 12 of 45 rehabilitation sites were assessed as being very strongly recognisable, 8 strongly recognisable, 6 moderately recognisable and 19 weakly recognisable (refer to **Appendix 5**). The recognisability threshold values developed using reference site observations, are shown in **Table 6.12**.

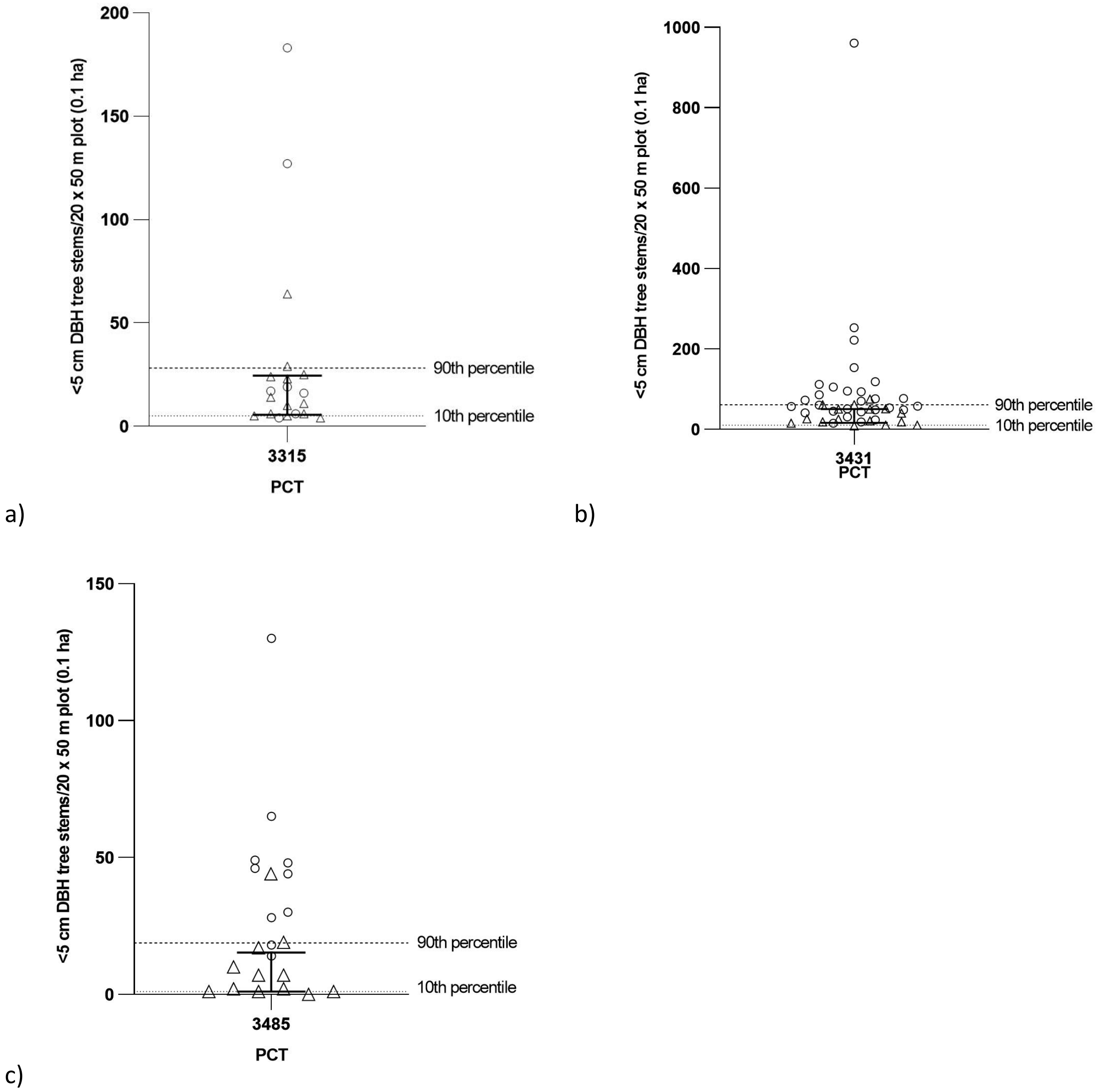


Figure 6.10 Abundance of individual trees (TG growth form) with DBH <5cm recorded in 20 x 50 m plot at reference sites (represented by triangles) and rehabilitation sites (represented by circles) for PCTs 3315 (a); 3431 (b); and 3485 (c).

The 25th to 75th percentile (IQR) of reference sites values is represented by the bold vertical and horizontal lines, and the 10th and 90th percentiles are displayed using hatched lines.

Table 6.12 Abundance of Individual Trees (TG growth form) in 20 x 50 m Reference Plots by DBH Size Class

DBH size class	PCT	Min	Percentile				Max
			10th	25th	75th	90th	
<5 cm	3315	4	5	6	24	28.2	64
	3431	9	10	18	50.25	61	75
	3485	0	1	1	11.75	18.8	44
5-9 cm	3315	10	12	13	26	31.4	40
	3431	2	6	18.5	37.75	53	101
	3485	0	0	0.75	5	8.6	30
10-19 cm	3315	7	10.2	16	22	22	23
	3431	0	1.5	9.5	27	29	36
	3485	0	0.2	2.75	11	17.3	20
20-29 cm	3315	2	4	5	9	10.8	15
	3431	0	0.5	2.5	8	10	20
	3485	1	4	4.75	10	10	13
30-49 cm	3315	0	1.2	2	5	6	7
	3431	0	0	0.75	4	8	13
	3485	2	2	2	8	8.9	10

The abundance of trees with DBH 5-9 cm recorded at rehabilitation sites was variable, however several sites from each PCT recorded values outside of the range of reference site values (**Figure 6.11**). In terms of the abundance of trees with DBH 5-9 cm, a total of 10 of 45 rehabilitation sites were assessed as being very strongly recognisable, 6 strongly recognisable, 15 moderately recognisable and 14 weakly recognisable (refer to **Appendix 5**).

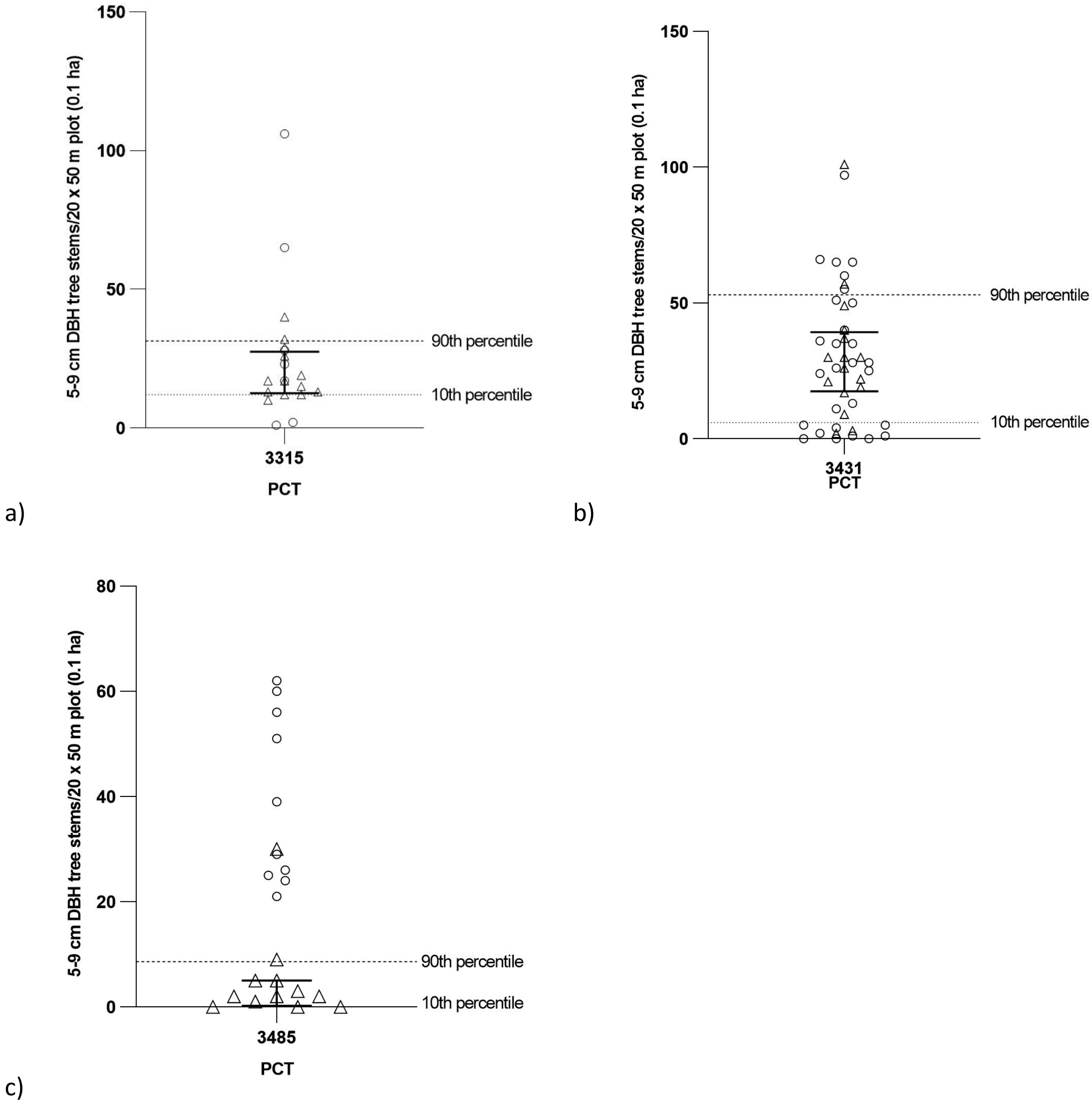
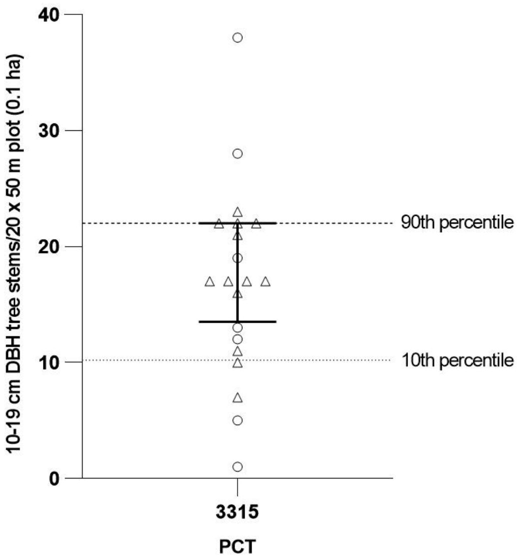


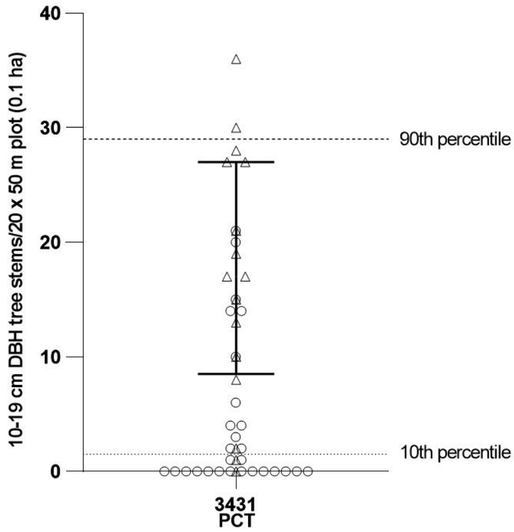
Figure 6.11 Abundance of individual trees (TG growth form) with DBH 5-9 cm recorded in 20 x 50 m plot at reference sites (represented by triangles) and rehabilitation sites (represented by circles) for PCTs 3315 (a); 3431 (b); and 3485 (c).

The 25th to 75th percentile (IQR) of reference sites values is represented by the bold vertical and horizontal lines, and the 10th and 90th percentiles are displayed using hatched lines.

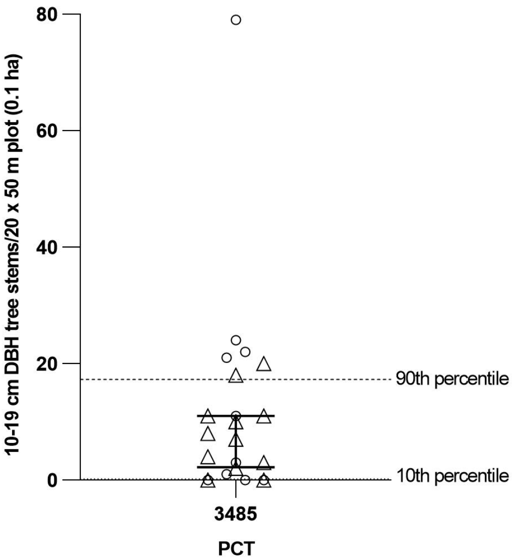
The abundance of trees with DBH 10-19 cm recorded at rehabilitation sites was variable, however several sites from each PCT recorded values outside of the range of reference site values (**Figure 6.12**). In terms of the abundance of trees with DBH 10-19 cm, a total of 8 of 45 rehabilitation sites were assessed as being very strongly recognisable, 10 strongly recognisable, 19 moderately recognisable and 8 weakly recognisable (refer to **Appendix 5**). The recognisability threshold values developed using reference site observations, are shown in **Table 6.12**.



a)



b)

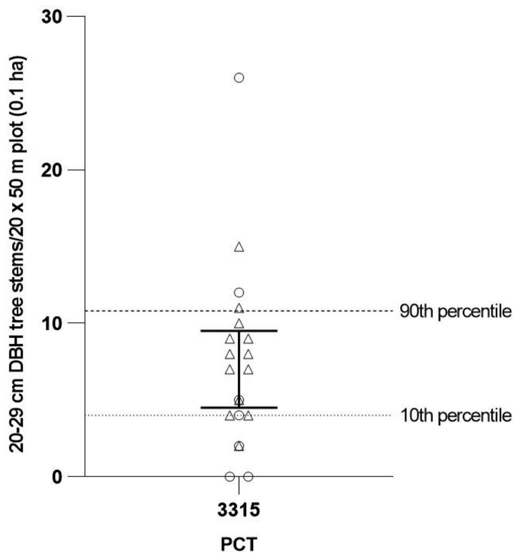


c)

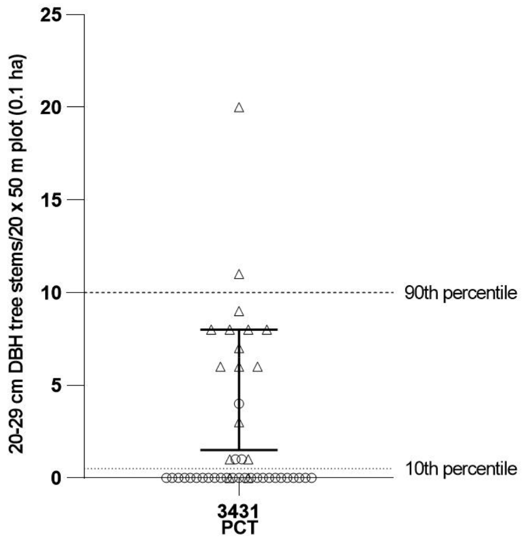
Figure 6.12Abundance of individual trees (TG growth form) with DBH 10-19 cm recorded in 20 x 50 m plot at reference sites (represented by triangles) and rehabilitation sites (represented by circles) for PCTs 3315 (a); 3431 (b); and 3485 (c)

The 25th to 75th percentile (IQR) of reference sites values is represented by the bold vertical and horizontal lines, and the 10th and 90th percentiles are displayed using hatched lines.

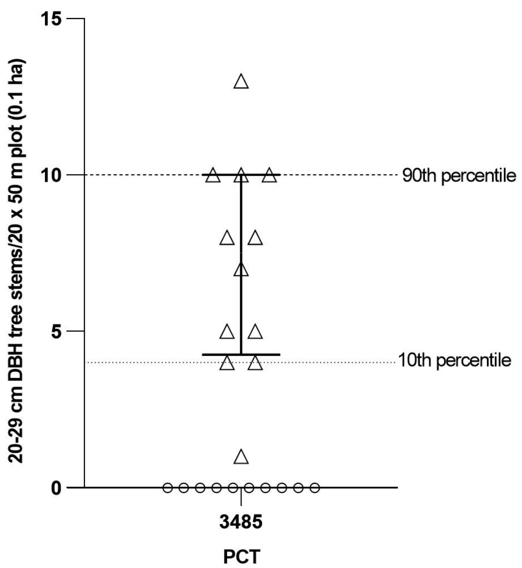
The abundance of trees with DBH 20-29 cm was generally below the 10th percentile of reference sites values, except for two PCT3315 rehabilitation sites which recorded tree abundance greater than the 90th percentile of reference site values (**Figure 6.13**). In terms of the abundance of trees with DBH 20-29cm, a total of 2 of 45 rehabilitation sites were assessed as being very strongly recognisable, 3 strongly recognisable, 27 moderately recognisable and 13 weakly recognisable (refer to **Appendix 5**). The recognisability threshold values developed using reference site observations, are shown in **Table 6.12**.



a)



b)



c)

Figure 6.13Abundance of individual trees (TG growth form) with DBH 20-29 cm recorded in 20 x 50 m plot at reference sites (represented by triangles) and rehabilitation sites (represented by circles) for PCTs 3315 (a); 3431 (b); and 3485 (c)

The 25th to 75th percentile (IQR) of reference sites values is represented by the bold vertical and horizontal lines, and the 10th and 90th percentiles are displayed using hatched lines.

Forty-two of the 45 rehabilitation sites sampled did not support any trees in the 30-49cm DBH size class, however, this tree DBH size class was also absent from some PCT3315 and PCT3431 reference sites (**Figure 6.14)**. Due to the variable abundance of trees with DBH 30-49cm at reference sites, a total of 29 of 45 rehabilitation sites were assessed as being strongly recognisable, 6 moderately recognisable and 10 weakly recognisable (refer to **Appendix 5**). The recognisability threshold values developed using reference site observations, are shown in **Table 6.12**.

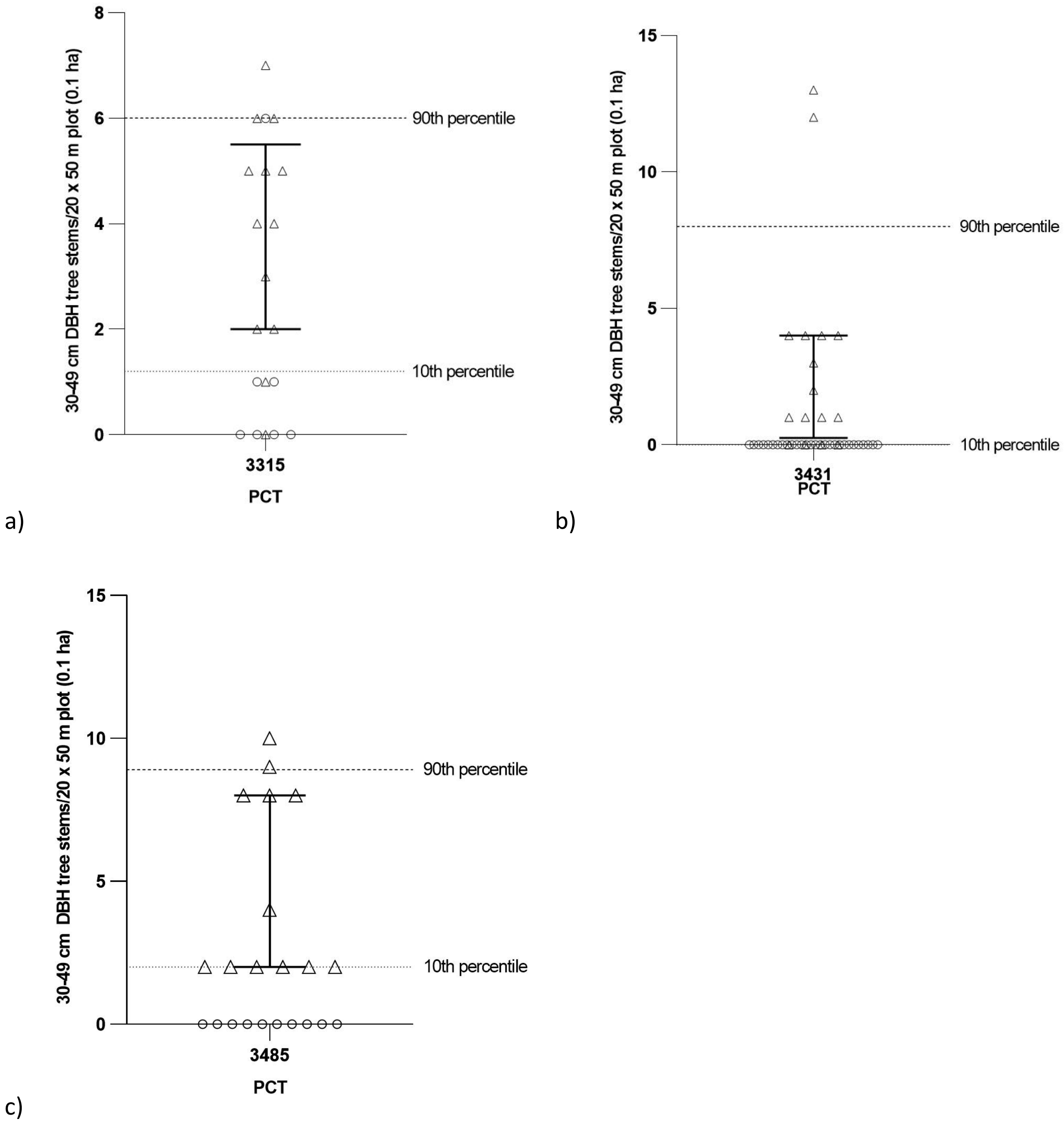


Figure 6.14Abundance of individual trees (TG growth form) with DBH 30-49 cm recorded in 20 x 50 m plot at reference sites (represented by triangles) and rehabilitation sites (represented by circles) for PCTs 3315 (a); 3431 (b); and 3485 (c)

The 25th to 75th percentile (IQR) of reference sites values is represented by the bold vertical and horizontal lines, and the 10th and 90th percentiles are displayed using hatched lines.

6.5.6 BAM Structure Condition Score

Threshold values for the BAM Structure Condition Score were calculated using the reference sites values obtained by entering vegetation integrity data into the BAM-C (**Table 6.13**). A total of 17 of the 45 rehabilitation sites were considered very strongly recognisable, 5 strongly recognisable, 9 moderately recognisable and 14 weakly recognisable.

Table 6.13 Reference Site BAM Structure Condition Scores

PCT	Min	Percentile				Max
		10th	25th	75th	90th	
3315	28.3	32.12	36.4	48.5	66.6	69.1
3431	7.9	14.5	16.68	30.58	32.1	33.2
3485	25	25.15	26.65	32.95	38.62	47.1

The BAM structure condition score for each rehabilitation site is provided in **Figure 6.15**, alongside foliage cover values for the three dominant growth forms for the associated PCT. No clear relationship was identified between the BAM structure condition score and the foliage cover of the dominant growth forms, and for several rehabilitation sites the level of recognisability identified using each attribute varied considerably. The largest difference was recorded at sites 13, 14 and 59 which were assessed as very strongly recognisable based on the BAM structure condition score, but weakly recognisability for two of the three dominant growth forms.

Site Number	PCT	BAM Structure Condition Score	TG foliage cover	SG foliage cover	GG foliage cover	FG foliage cover
3	3485	17.8	8		1.2	1.1
4	3485	9.3	4.1		0	0.8
5	3485	11.7	5.6		0.7	0.2
12	3431	5.8	6	5.3	0.8	
13	3485	30.3	13.1		0.3	2.4
14	3485	28.9	13.2		0.6	1.6
15	3485	31.4	15		1.8	2
16	3485	21.5	9.1		4.2	1.2
17	3485	29.3	13.1		1	1.9
18	3485	20.6	8		1	2.8
20	3431	26.5	32.1	11.3	1	
21	3431	17.5	13.5	15.2	7.4	
29	3431	17.4	8.6	21	9.3	
30	3485	33.7	17.4		5.3	1.9
31	3431	15	18	14.2	1.4	
32	3431	11.1	15.7	11.6	1.8	
33	3431	15	19.1	7.5	0.9	
34	3431	11.2	18.1	9.2	1.1	
35	3431	13.4	13.1	16.1	1	
45	3431	25.6	35	5.5	4.1	
46	3431	30.7	45.1	1.7	0.5	
47	3431	18.3	4.8	8	24.4	
48	3431	23.1	10.7	18.5	18	
49	3431	38.6	20	15.6	32	
50	3431	42.8	9	15.1	43	
59	3431	20.4	5.3	31.2	1.3	
60	3431	27.8	14	28.1	15.8	
64	3431	17.8	27.8	1	1.3	
65	3315	45.4	43.6	11.1	8.7	
66	3315	58.2	43.5	9	19.4	
67	3315	31.2	17	12.9	19.3	
72	3315	41.9	38.5	7.7	11.8	
73	3431	7.5	10.5	10.2	5.4	
74	3315	29	5	6.7	27.3	
75	3315	18.1	21.8	3.3	5.5	
76	3315	27.7	10.5	9	23.9	
81	3431	7.2	10.3	11.3	6.2	
82	3431	27.7	19.7	3.1	30.4	
83	3431	9.5	12.7	12	7	
88	3431	11.5	22.3	0.8	1.2	
89	3431	9.5	20	0.8	5.1	
90	3431	7.6	18	0.4	5.1	
91	3431	22.3	20	0.4	25.3	
92	3431	6.6	17.1	0.2	0.8	
93	3431	14.3	16.6	13.1	9.4	

Figure 6.15 Level of structural recognisability of rehabilitation sites based on BAM structure condition score, tree (TG) foliage cover, shrub (SG) foliage cover, grass and grass-like (GG) foliage cover and forb (FG) foliage cover

Dark green represents *very strong* recognisability, where the value falls between the 25th and 75th percentile of reference site values; light green represents *strong* recognisability, where the value falls between the 10th and 90th percentile of reference site values; yellow represents *moderate* recognisability, where the value falls below the 10th or above the 90th percentile, but within the observed range of reference site values; and orange represents *weak* recognisability, where the value falls below the minimum or above the maximum observed of reference site values. Growth forms which do not comprise one of the three most dominant growth forms for the PCT are shaded grey.

6.6 PCT Benchmarks

PCT-level benchmarks developed for PCTs 3315, 3431 and 3485 (refer to **Section 5.5.2.4** for methods and **Table 6.14** for results) show that foliage cover values for each growth forms are lower than the class level benchmark and in some cases they are significantly lower, the exception being tree cover for Western Slopes Grassy Woodlands compared to PCT3485. Conversely, the PCT-level benchmarks equalled or exceeded the class-level benchmarks for litter cover and forb richness for all three PCTs. Additionally, the PCT3315 benchmarks for shrub richness, grass/grass-like richness, and fern richness were equal to, or greater than, the class-level benchmarks, and PCT3431 also recorded a fern richness value equal to the class-level benchmark. Large trees (those with a DBH >50cm) were uncommon at reference sites, resulting in a median value of zero large trees for each PCT.

Comparison of class-level benchmarks for *dry* periods (DPIE 2021c) to *average* rainfall period benchmarks was undertaken (**Table 6.14**). *Dry* benchmarks are applicable to a BAM assessment when rainfall over the 12 months prior to assessment fell below the 20th percentile of the annual totals in long-term rainfall records (DPIE 2020b). Whilst some *dry* benchmarks were lower than *average* rainfall benchmarks, in most cases there was no difference and, in some cases, the *dry* benchmarks had the higher value for some attributes, including tree cover for all three vegetation classes.

Table 6.14 Comparison of Class Level Benchmarks (for average rainfall and dry periods) (BAM) and PCT-level Benchmarks

BAM Attribute		Coastal Valley Grassy Woodland			Hunter-Macleay Dry Sclerophyll Forests			Western Slopes Grassy Woodlands		
		Class level benchmark[1]	Class level DRY benchmark[2]	PCT3315[3]	Class level benchmark[4]	Class level DRY benchmark[5]	PCT3431[3]	Class level benchmark[6]	Class level DRY benchmark[7]	PCT3485[3]
Richness (Composition)	Tree	5	5	3	5	5	3	4	3	2.5
	Shrub	8	8	8	12	12	5	6	6	4
	Grass/Grass-like	12	12	15	11	11	10	10	9	8.5
	Forbs	14	15	19	11	11	16	13	9	14
	Ferns	2	2	2	2	2	2	1	1	0
	Other	5	4	2	5	4	2	3	2	1
Cover (Structure)	Tree	53*	58	33	56*	59	28.75	21*	22	29.05
	Shrub	16*	16	5.55	34*	34	2.55	5	5	0.75
	Grass/Grass-like	58*	57	11.35	66*	63	12.6	45*	46	3.8
	Forbs	9	9	3.15	8	8	2.7	8*	8	1.65
	Ferns	1	1	0.3	1	1	0.5	0	0	0
	Other	4	3	0.35	4	3	0.3	1	1	0.15
Number Large Trees		3	3	0	3	3	0	2	2	0
Litter Cover		40	40	85.5	65	65	77	35	35	85.5
Length of Fallen Logs		40	40	18.5	45	45	19.5	34	34	31

Notes:

1: Benchmarks for Coastal Valley Grassy Woodland in the Sydney Basin IBRA region (average rainfall) (DPIE 2021b)
2: Benchmarks for Coastal Valley Grassy Woodland in the Sydney Basin IBRA region (<20th percentile of annual totals in long-term rainfall) (DPIE 2021c)
3: PCT-level benchmarks derived from calculating median value for each attribute from reference sites using method described by DPIE (2020a)
4: Benchmarks for Hunter-Macleay Dry Sclerophyll Forests in the Sydney Basin IBRA region (average rainfall) (DPIE 2021b)
5: Benchmarks for Hunter-Macleay Dry Sclerophyll Forests in the Sydney Basin IBRA region (<20th percentile of annual totals in long-term rainfall) (DPIE 2021c)
6: Benchmarks for Western Slopes Grassy Woodlands in the Sydney Basin IBRA region (average rainfall) (DPIE 2021b)
7: Benchmarks for Western Slopes Grassy Woodlands in the Sydney Basin IBRA region (<20th percentile of annual totals in long-term rainfall) (DPIE 2021c)

* Indicate the three dominant growth forms for each Vegetation Class in the Sydney Basin IBRA region

6.7 Compositional and Structural Change of Rehabilitation Over Time

Following the assessment of consistency of methods from previous mine rehabilitation monitoring with those used for the current study (**Section 5.5.4**), it was found that several datasets could not be directly compared with the dataset from this study. The main inconsistencies with the methods used in the current study that prevented comparison of datasets included the use of plots or transects of dimensions other than 20 m x 20 m; the assessment of only a subset of the flora species present during a single monitoring event; or the cover or abundance for flora species being recorded using a method inconsistent with percent foliage cover or MBB 6-point cover-abundance scale.

Several datasets were identified as having comparable data, using methods that were consistent with the current study. However, most of these datasets were collected only in recent years and from relatively young rehabilitation and therefore the analysis of trends over time was of limited value. Other limiting factors identified during this assessment included the retirement of some monitoring sites after several years of monitoring, but prior to them attaining a comparable structure to the target community; or modifications to monitoring methods which resulted in inconsistent techniques and datasets. It is possible that with consideration of additional data, a longitudinal analysis of monitoring data may be informative, however this level of analysis was not able to be effectively undertaken due to the limited dataset and the limited time period of comparable data.

As the longitudinal analysis could not be completed with the datasets available, the possibility of using the data collected from the current study in a space-for-time substitution analysis was investigated. The aim was to determine whether composition or structural trends could be discerned on the basis of rehabilitation age. Firstly, an analysis was undertaken to determine whether observed differences at rehabilitation sites were influenced by time since establishment or the mine site on which they are situated, the results of which are provided in **Appendix 6**. The results of the GLM were variable, however they indicate that both mine site and time since establishment have a significant effect on flora species richness, foliage cover and the development of structural complexity and tree density at rehabilitation sites. Due to the influence of mine site and the variation of establishment techniques used by different operators, a space-for-time substitution analysis was not able to be undertaken.

Due to insufficient data to perform longitudinal and space-for-time substitution analysis, successional stage criteria could not be developed as part of this project.

6.8 Threatened Ecological Community Analyses

6.8.1 Nationally-listed TECs

Using the criteria and assessment approach detailed in **Section 5.5.5.1**, most sites sampled as part of this project were identified as containing vegetation consistent with the *Central Hunter Valley Eucalypt Forest and Woodland CEEC*. The number of reference sites and rehabilitation sites identified as consistent with the CEEC at each location are summarised in **Table 6.15**.

Table 6.15 Number of Sites Identified as Consistent with the Central Hunter Valley Eucalypt Forest and Woodland CEEC

PCT	Reference Sites		Rehabilitation Sites	
	CEEC	Not CEEC	CEEC	Not CEEC
3314[1]	1	0	-	-
3315	5	8	2	5
3431	13	3	11	17
3438[1]	2	2	-	-
3485	11	1	5	5
3757[1]	0	2	-	-
Total	**32**	**16**	**18**	**27**

[1] non-target PCT

The reasons for reference and rehabilitation sites being assessed as inconsistent with the CEEC are identified in **Table 6.16.** Nearly half of the rehabilitation sites assessed as inconsistent with the CEEC recorded a low proportion of characteristic species in the canopy due to the young age of the rehabilitation and the similarity in height of the eucalypts and *Acacia* spp. which would normally form part of the mid layer in a mature woodland. For this reason, it is possible that these sites, located at Mangoola and MTW, will become consistent with the CEEC as the mid-storey and canopy layers develop, assuming that all other criteria are met. Nine rehabilitation sites contained broad-leaved ironbark (*Eucalyptus fibrosa*), a contra-indicative species for the CEEC and six sites recorded understorey vegetation inconsistent with the CEEC, which in most cases contained a high proportion of perennial weeds and in one case, the absence of native grass species.

Table 6.16 Reasons for Inconsistency with the Central Hunter Valley Eucalypt Forest and Woodland CEEC

Reason for inconsistency with CEEC	Proportion of Reference Sites (%)	Proportion of Rehabilitation Sites (%)
Located on non-Permian substrates	14.6	0*
Proportion of characteristic species in the canopy is too low (≤ 50% of projected canopy cover)	12.5	35.5
Presence of contra-indicative species, being broad-leaved ironbark (*Eucalyptus fibrosa*)	16.7	22.2
Absence of native grass species	0	2.2
Proportion of native understorey is too low (<50% of perennial vegetative cover)	0	13.3

Note: * Assumed that rehabilitation sites are on Permian-derived substrates.

6.8.2 State-listed TECs

6.8.2.1 Canonical Analysis of Principal Coordinates

The CAP routine analysis of flora plots representative of the state-listed TECs (Peake 2006; NSW NPWS 2000) demonstrated high levels of alignment among the three groups, with the analysis including the dummy variable having the highest degree of alignment for the *Hunter Valley Footslopes Slaty Gum Woodland VEC* sites (**Table 6.17)**. The number of PCoA axes (*m*) to include in the refined CAP analysis was chosen by plotting the proportion of correct allocations obtained in the initial CAP with increases in the number of axes included in the analysis (**Figure 6.16**). Six PCoA axes (*m* = 6) were used as this value achieved the maximum proportion of correct allocations (93.33%) of any choice of *m* (i.e. minimum misclassification error = 6.67%). Any value of *m* greater than this would increase the within-group variability more than the between-group variability, and thus would be of no use for discrimination among groups (Anderson and Willis 2003). The first six PCoA axes explained 93.33% of the variability in the original dissimilarity matrix. The CAP analysis yielded two canonical axes with squared canonical correlations of $d1^2$ = 0.794 and $d2^2$ = 0.556.

Table 6.17 Cross-validation of Classifications among TECs during CAP analysis

TEC	Number of Classified Sites				% Correct	Number of Classified Sites (with dummy variable)				% Correct
	CHGBIW	CHISGGBF	HVFSGW	Total		CHGBIW	CHISGGBF	HVFSGW	Total	
CHGBIW	35	3	0	38	92.11	35	3	0	38	92.11
CHISGGBF	1	32	0	33	96.97	2	31	0	33	93.94
HVFSGW	0	1	3	4	75	0	0	4	4	100

CHGBIW – *Central Hunter Grey Box – Ironbark Woodland EEC*
CHISGGBF – *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC*
HVFSGW – *Hunter Valley Footslopes Slaty Gum Woodland VEC*

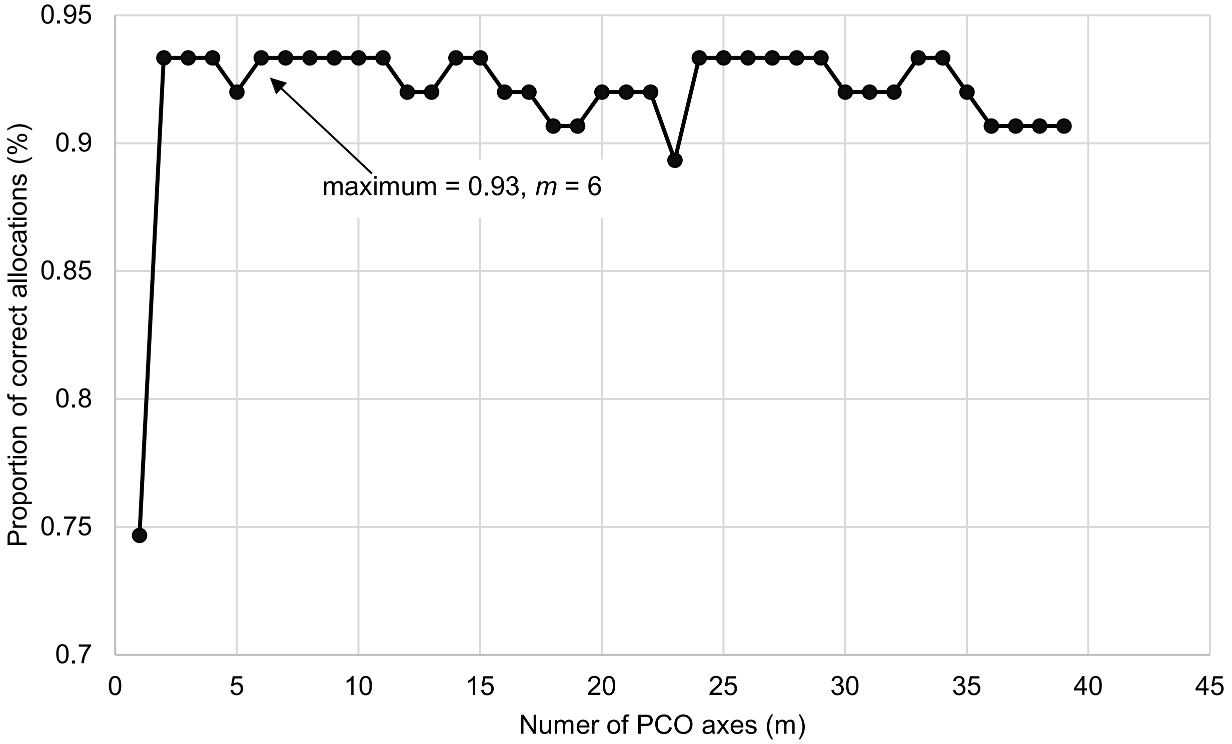


Figure 6.16 Plot of the proportion of correct allocations of observations to groups with increases in the number of principal coordinate axes (m) used for the CAP procedure

The constrained CAP ordination plot demonstrated a pattern of differences among the TECs with some overlap between the *Central Hunter Grey Box – Ironbark Woodland EEC* and the *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* (**Figure 6.17**). This is expected due to the number of species shared between these two communities. The most apparent difference among groups was for the seemingly large separation of *Hunter Valley Footslopes Slaty Gum Woodland VEC*. However, this is likely due, in part, to the limited sample size (four sites) representing this TEC (**Figure 6.17**). The rehabilitation and reference site data demonstrated an equal spread among the TECs with the most obvious grouping between the *Central Hunter Grey Box – Ironbark Woodland EEC* and the *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* (**Figure 6.17**). The minor alignment of a few sites to the *Hunter Valley Footslopes Slaty Gum Woodland VEC* is likely due to the difference in floristic composition. Further interrogation of the Peake (2006) sites representing this TEC revealed higher shrub diversity and density than sampled at rehabilitated and reference sites.

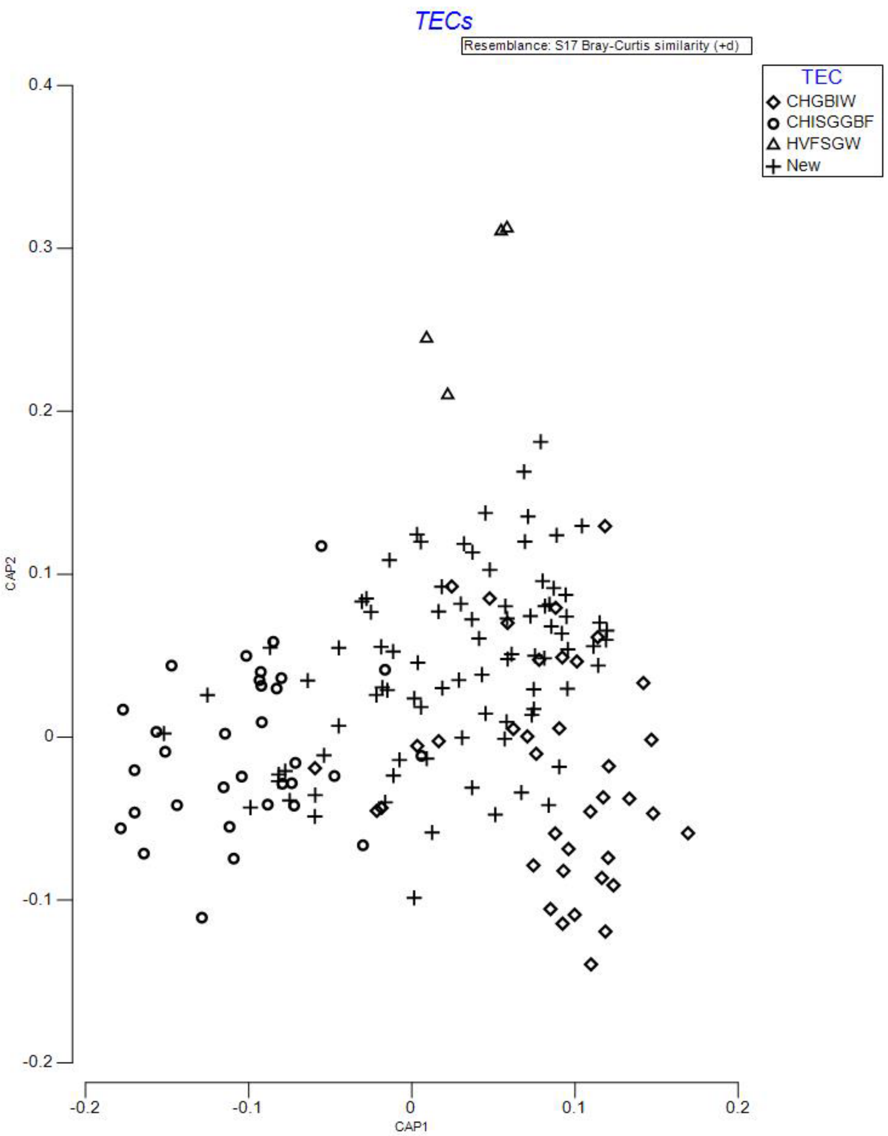


Figure 6.17 Constrained CAP ordination of floristic composition from reference and rehabilitation field sites (New) compared to floristic composition data (Peake (2006); NSW NPWS (2000)) representing three threatened ecological communities (CHGBIW, CHISGGBF and HVFSGW) within the Hunter Valley, NSW

Rehabilitation and reference sites were allocated to the TEC representing the 'best fit' of the three target PCTs based on the lowest distance to centroid value of the TEC (refer to **Section 6.3**). While the target PCTs are not directly equivalent to the TECs, according to their legal definitions, the PCTs were considered floristically similar enough to be comparable to their respective TECs for the purposes of this analysis. Definitive thresholds of 'best fit' (similar to those used in the draft PCT Assignment Tool) were not developed for measuring similarity of sites to TECs. Instead, the distances of the rehabilitation and reference sites to TEC group centroids have been provided as a heat map, which also categorises the proximity of the sites to their allocated TEC (**Figure 6.18** and **Figure 6.19**). Of the sites that were allocated to PCTs, a moderate proportion of these were subsequently aligned to a corresponding TEC (**Table 6.18**). As noted in **Section 1.3.3**, although a PCT recognisability assessment might inform the allocation of a TEC, there is no strict relationship between the two, and a TEC can exist independent of any such relationship. However, in some cases an advisory document (such as a Final Determination under the BC Act) might rely on the characterisation of a TEC through certain mapping units from a particular classification.

A high proportion of references sites allocated to PCTs 3315 and 3431 aligned with the corresponding TEC, however most reference sites allocated to PCT3485 aligned more strongly with the *Central Hunter Grey Box – Ironbark Woodland EEC.* The results for rehabilitation sites were more variable than reference sites, however they showed a similar trend, with most sites allocated to PCTs 3315 and 3431 being aligned with the corresponding TEC and most sites allocated to PCT3485 being aligned more strongly with the *Central Hunter Grey Box – Ironbark Woodland EEC*.

Table 6.18 Alignment of PCT to TEC using CAP analysis

PCT	TEC		
	Number (and proportion) of sites most similar to CHISGGBF	Number (and proportion) of sites most similar to HVFSGW	Number (and proportion) of sites most similar to CHGBIW
3315			
Rehabilitation (n=7)	4 (57%)	0	3 (43%)
Reference (n=13)	12 (92%)	0	1 (8%)
3431			
Rehabilitation (n=28)	9 (32%)	1 (4%)	18 (64%)
Reference (n=16)	0	0	16 (100%)
3485			
Rehabilitation (n=10)	0	2 (20%)	8 (80%)
Reference (n=12)	0	3 (25%)	9 (75%)

CHGBIW – *Central Hunter Grey Box – Ironbark Woodland EEC*
CHISGGBF – *Central Hunter Ironbark - Spotted Gum - Grey Box Forest EEC*
HVFSGW – *Hunter Valley Footslopes Slaty Gum Woodland VEC*
Shading indicates corresponding PCTs and TECs

Site	CHGBIW	CHISGGBF	HVFSGW	ENSW PCT
Site 51 - Mount Thorley Warkworth	0.16304	0.027936	0.31163	3315
Site 52 - Mount Thorley Warkworth	0.21578	0.041116	0.29208	3315
Site 53 - Mount Thorley Warkworth	0.23844	0.050323	0.32664	3315
Site 68 - Mount Owen	0.1613	0.041124	0.32755	3315
Site 69 - Mount Owen	0.18569	0.034844	0.34047	3315
Site 70 - Mount Owen	0.082138	0.12553	0.32879	3315
Site 71 - Mount Owen	0.1454	0.051225	0.31952	3315
Site 77 - Mount Owen	0.16701	0.025598	0.31512	3315
Site 78 - Mount Owen	0.16723	0.028022	0.31898	3315
Site 79 - Mount Owen	0.13319	0.059954	0.27462	3315
Site 80 - Mount Owen	0.13962	0.048953	0.29459	3315
Site 85 - Bulga	0.11694	0.08802	0.25026	3315
Site 87 - Bulga	0.096754	0.092666	0.29676	3315
Site 1 - Mangoola	0.16184	0.16799	0.15261	3485
Site 10 - Mangoola	0.09588	0.2317	0.2143	3485
Site 11 - Mangoola	0.15169	0.2489	0.15557	3485
Site 19 - Mangoola	0.10507	0.1831	0.19026	3485
Site 2 - Mangoola	0.13158	0.15759	0.17798	3485
Site 24 - Mangoola	0.15695	0.22579	0.13855	3485
Site 26 - Mangoola	0.20223	0.26275	0.098091	3485
Site 36 - Mangoola	0.096046	0.19396	0.19852	3485
Site 63 - Jerrys Plains	0.11668	0.16057	0.18772	3485
Site 7 - Mangoola	0.071581	0.18757	0.22294	3485
Site 8 - Mangoola	0.12916	0.18715	0.16716	3485
Site 9 - Mangoola	0.079562	0.13856	0.23452	3485
Site 22 - Mangoola	0.039576	0.17937	0.25515	3431
Site 22 - Mangoola	0.051542	0.20174	0.24696	3431
Site 25 - Mangoola	0.097523	0.18051	0.19787	3431
Site 37 - Mangoola	0.053514	0.14972	0.25516	3431
Site 38 - Mangoola	0.05136	0.18145	0.24317	3431
Site 39 - Mangoola	0.070943	0.22319	0.23862	3431
Site 40 - Mount Thorley Warkworth	0.073767	0.17106	0.22269	3431
Site 41 - Mount Thorley Warkworth	0.089004	0.11164	0.2528	3431
Site 42 - Mount Thorley Warkworth	0.049584	0.14144	0.30049	3431
Site 43 - Mount Thorley Warkworth	0.058375	0.13378	0.26979	3431
Site 44 - Mount Thorley Warkworth	0.020914	0.18954	0.31482	3431
Site 54 - Wambo	0.03653	0.17767	0.2585	3431
Site 58 - Wambo	0.034723	0.15982	0.2713	3431
Site 61 - Mount Thorley Warkworth	0.043407	0.15874	0.3173	3431
Site 84 - Bulga	0.022537	0.17176	0.30504	3431
Site 94 - Bulga	0.005589	0.1933	0.2927	3431

Figure 6.18 Heat map showing likelihood of assigned TEC (green cells for high and red for low likelihood) for reference sites based on distances to TEC centroids calculated from CAP (plus dummy) analyses

Site	CHGBIW	CHISGGBF	HVFSGW	ENSW PCT
Site 65 - Mount Owen	0.18823	0.065436	0.24718	3315
Site 66 - Mount Owen	0.093273	0.095298	0.28674	3315
Site 67 - Mount Owen	0.1156	0.093199	0.24495	3315
Site 72 - Mount Owen	0.076665	0.11198	0.2839	3315
Site 74 - Mount Owen	0.11442	0.13773	0.36965	3315
Site 75 - Mount Owen	0.1035	0.092008	0.31384	3315
Site 76 - Mount Owen	0.1475	0.059022	0.33208	3315
Site 13 - Mangoola	0.16348	0.20787	0.13218	3485
Site 14 - Mangoola	0.14181	0.21475	0.15308	3485
Site 15 - Mangoola	0.14482	0.23285	0.1548	3485
Site 16 - Mangoola	0.088916	0.20318	0.20737	3485
Site 17 - Mangoola	0.087302	0.23205	0.22558	3485
Site 18 - Mangoola	0.080929	0.22352	0.22652	3485
Site 3 - Mangoola	0.10853	0.21915	0.19126	3485
Site 30 - Mangoola	0.09278	0.23422	0.22043	3485
Site 4 - Mangoola	0.14942	0.18525	0.15084	3485
Site 5 - Mangoola	0.18454	0.24249	0.11144	3485
Site 12 - Mangoola	0.11235	0.21444	0.18512	3431
Site 20 - Mangoola	0.1014	0.20471	0.19441	3431
Site 21 - Mangoola	0.095374	0.21405	0.20402	3431
Site 29 - Mangoola	0.11678	0.21057	0.17918	3431
Site 31 - Mangoola	0.10502	0.16125	0.19721	3431
Site 32 - Mangoola	0.040773	0.16184	0.26097	3431
Site 33 - Mangoola	0.069427	0.19261	0.22559	3431
Site 34 - Mangoola	0.10249	0.20766	0.19394	3431
Site 35 - Mangoola	0.084782	0.20756	0.21321	3431
Site 45 - Mount Thorley Warkworth	0.07291	0.15304	0.23115	3431
Site 46 - Mount Thorley Warkworth	0.15058	0.085847	0.22934	3431
Site 47 - Mount Thorley Warkworth	0.092655	0.1596	0.20897	3431
Site 48 - Mount Thorley Warkworth	0.075773	0.17432	0.21997	3431
Site 49 - Mount Thorley Warkworth	0.12162	0.10987	0.22193	3431
Site 50 - Mount Thorley Warkworth	0.075473	0.20796	0.22362	3431
Site 59 - Mount Thorley Warkworth	0.11988	0.14674	0.19328	3431
Site 60 - Mount Thorley Warkworth	0.14273	0.18563	0.15598	3431
Site 64 - United	0.15927	0.058236	0.255	3431
Site 73 - Mount Owen	0.084014	0.12741	0.23993	3431
Site 81 - Bulga	0.1669	0.16996	0.14872	3431
Site 82 - Bulga	0.15587	0.11672	0.19777	3431
Site 83 - Bulga	0.10544	0.1194	0.22608	3431
Site 88 - Bulga	0.15514	0.11992	0.19505	3431
Site 89 - Bulga	0.16317	0.14721	0.16823	3431
Site 90 - Bulga	0.14746	0.11539	0.20209	3431
Site 91 - Bulga	0.12923	0.10553	0.22087	3431
Site 92 - Bulga	0.11208	0.095362	0.24591	3431
Site 93 - Bulga	0.095098	0.10914	0.24801	3431

Figure 6.19 Heat map showing likelihood of assigned TEC (green cells for high and red for low likelihood) for rehabilitation sites based on distances to TEC centroids calculated from CAP (plus dummy) analyses

6.8.2.2 Characteristic Species Analysis

The proportion of native species listed in the *Central Hunter Grey Box – Ironbark Woodland EEC* Final Determination (NSW Scientific Committee 2010a) which were recorded at Peake (2006) sites which are representative of the EEC (i.e. BioNet sites which correspond to vegetation mapping units cited in the Final Determination as comprising the EEC), ranged from 26.3% (10 species) to 71.1% (27 species) (n=38) (refer to **Figure 6.20**). The results obtained at reference sites allocated to 3431 mostly fell within the range of Peake (2006) sites, with the lowest proportion being 23.7% (9 species) and the highest being 57.9% (22 species) (n=16). The results from 15 of the 28 rehabilitation sites allocated to 3431 were within the range of Peake (2006) sites, and an additional 5 rehabilitation sites were within the range of 3431 reference sites. The proportion of native species listed in the EEC Final Determination at rehabilitation sites ranged from 5.3% (2 species) to 42.1% (16 species).

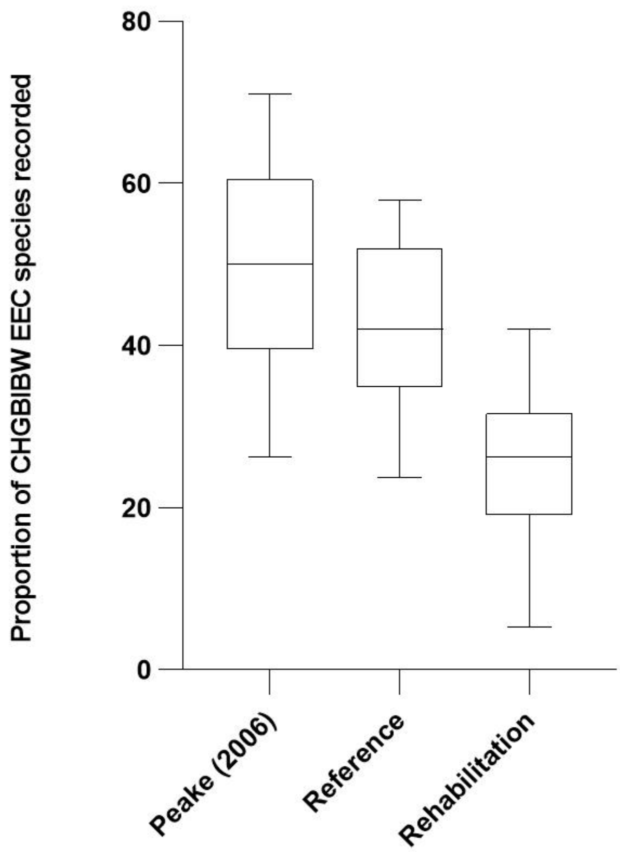


Figure 6.20 Proportion of species listed in Final Determination for *Central Hunter Grey Box – Ironbark Woodland EEC* (NSW Scientific Committee 2010a) recorded at Peake (2006) plots, PCT3431 reference sites and PCT3431 rehabilitation sites.

Box and whisker plots show the range of variation, IQR and median.

The proportion of native species listed in the *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* Final Determination (NSW Scientific Committee 2010b) recorded at Peake (2006) and NSW NPWS (2000) sites, which are representative of the EEC, varied substantially and ranged from 15.9% (7 species) to 65.9% (29 species) (n=33) (refer to **Figure 6.21**). The results obtained at reference sites allocated to PCT3315 fell within the range of Peake (2006) and NSW NPWS (2000) sites and showed less variation, with a range between 34.1% (15 species) and 56.8% (25 species) (n=13). All rehabilitation sites allocated to PCT3315 (n=7) fell within the range of Peake (2006) and NSW NPWS (2000) sites and four sites fell within the range of PCT3315 reference sites. The proportion of native species listed in the EEC Final Determination at rehabilitation sites ranged from 29.5% (13 species) to 43.2% (19 species).

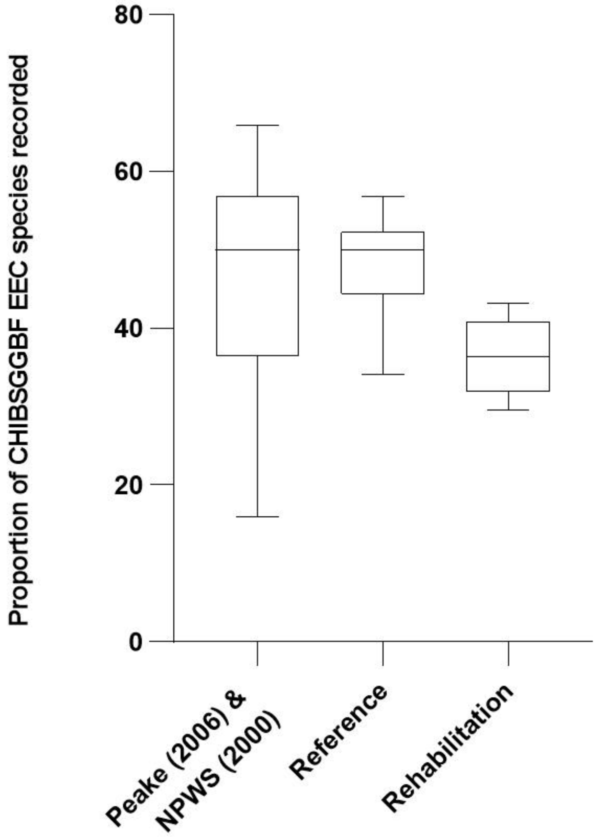


Figure 6.21 Proportion of species listed in Final Determination for *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* (NSW Scientific Committee 2010b) recorded at Peake (2006) and NPWS (2000) plots, PCT3315 reference and PCT3315 rehabilitation sites.
Box and whisker plots show the range of variation, IQR and median.

The proportion of native species listed in the *Hunter Valley Footslopes Slaty Gum Woodland VEC* Final Determination (NSW Scientific Committee 2010c) recorded at Peake (2006) sites, which are representative of the VEC, ranged from 37.9% (11 species) to 58.6% (17 species) (refer to **Figure 6.22**), however the sample size was small (n=4). The results obtained at reference sites allocated to PCT3485 ranged from 24.1% (7 species) to 51.7% (15 species), with 4 of the 12 reference sites overlapping with the range of Peake (2006) sites. Six of the ten rehabilitation sites allocated to 3485 fell within the range of reference sites and ranged from 17.2% (5 species) to 37.9% (11 species).

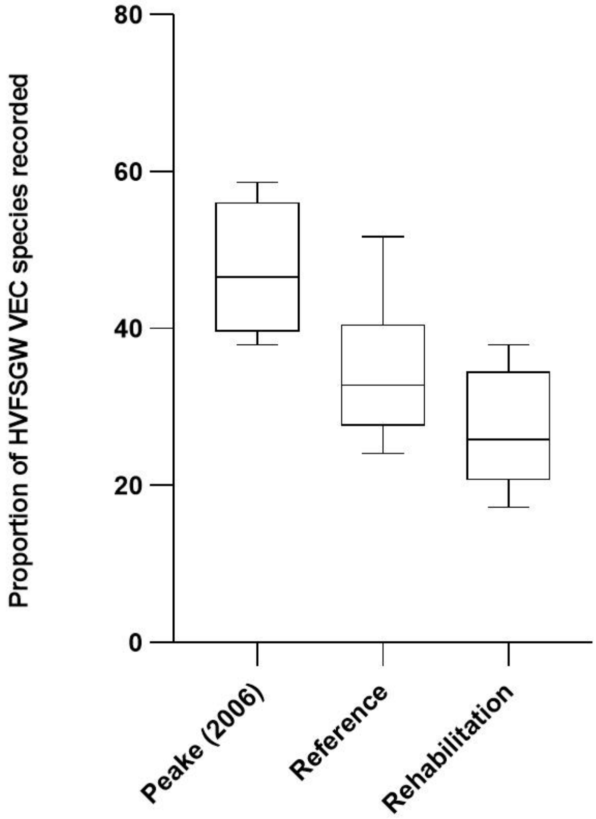


Figure 6.22 Proportion of species listed in Final Determination for *Hunter Valley Footslopes Slaty Gum Woodland VEC* (NSW Scientific Committee 2010c) recorded at Peake (2006) plots, PCT3485 reference and PCT3485 rehabilitation sites.
Box and whisker plots show the range of variation, IQR and median.

6.8.2.3 Similarity to PCTs

To investigate whether PCTs could be used as a surrogate in assessing whether rehabilitation sites are recognisable as the target TECs, the similarity of their species assemblages were assessed by calculating the number of species shared between the target TECs and the most closely aligned PCT, on the basis of species composition (**Figure 6.23**).

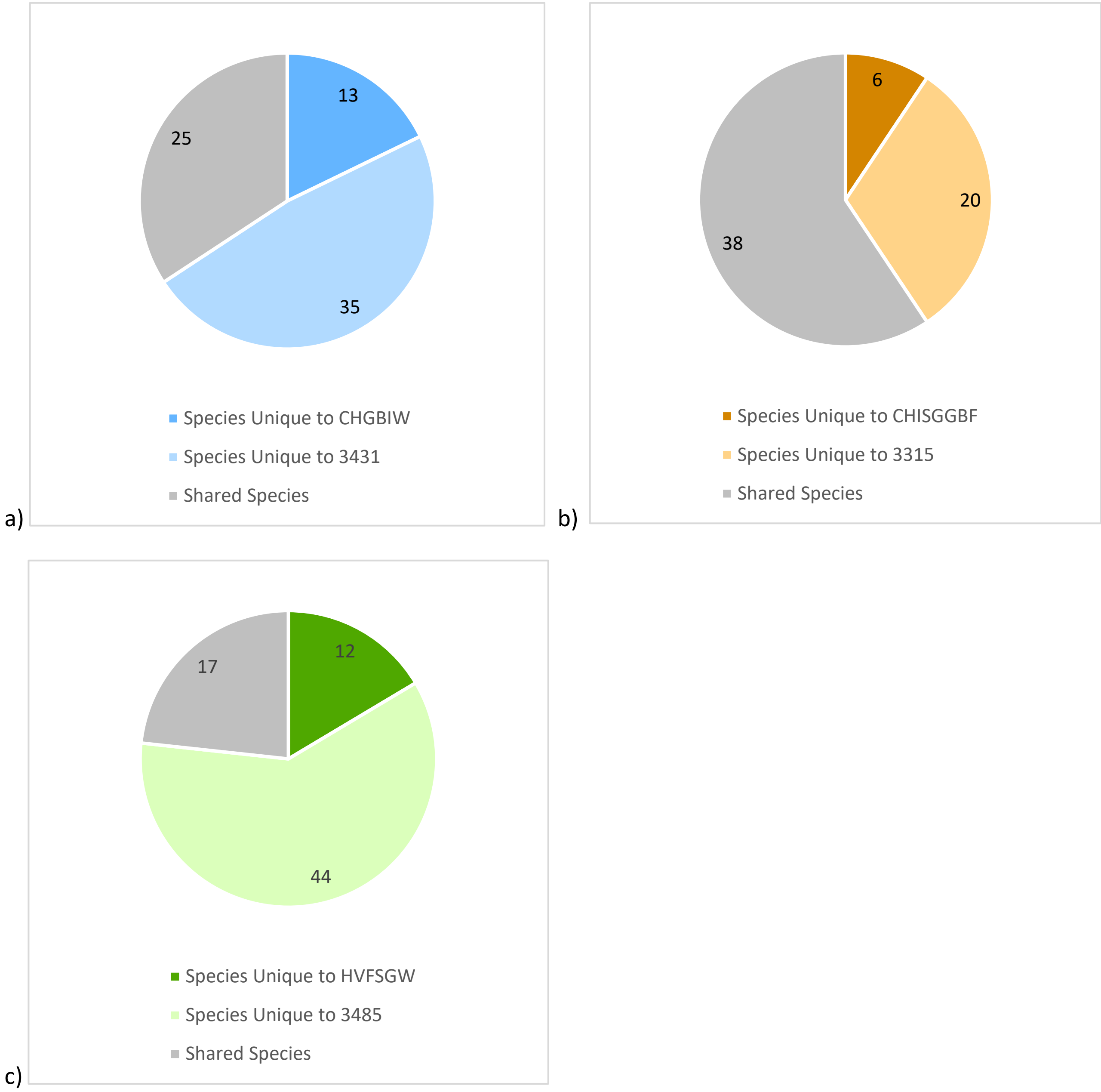


Figure 6.23 Native flora species shared between a) *Central Hunter Grey Box – Ironbark Woodland EEC* (CHGBIW) and PCT3431; b) *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* (CHISGGBF) and PCT3315; and c) *Hunter Valley Footslopes Slaty Gum Woodland VEC* (HVFSGW) and PCT3485

As shown in **Figure 6.23**, the target PCTs described by DPIE (2019b) have significantly more characteristic species than TECs and in the case of PCT3485, this PCT has more than double the number of species listed on the *Hunter Valley Footslopes Slaty Gum Woodland VEC* Final Determination. A considerable number of shared species were identified between *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* and PCT3315, with 38 species, or 86% of the EEC list. *Central Hunter Grey Box – Ironbark Woodland EEC* recorded 25 species in common with PCT3431 (66% of the EEC list) and *Hunter Valley Footslopes Slaty Gum Woodland VEC* recorded 17 species shared with PCT3485 (59% of the VEC list).

6.9 Self-sustainability Assessments

The results of analyses undertaken by DPIE (Oliver and Dorrough 2019) are summarised in the following sections, along with a selection of key results. The material presented in **Section 6.9** is a direct replication of key components of the report by Oliver and Dorrough (2019) and the full report is contained in **Appendix 1**.

6.9.1 Community-level Differences

Oliver and Dorrough (2019) investigated community-level differences based on floristic and microbial data to understand the overall difference in plant species or bacterial and fungal communities (operational taxonomic units (OTUs)) and their relative abundances at reference and rehabilitation sites. Plant composition and cover differed markedly between reference plots and rehabilitation plots among PCTs as well as between PCTs at reference sites (refer to **Appendix 1**). Some overlap of PCTs was observed at rehabilitation sites. The results for bacterial and fungal communities generally exhibited similar patterns to those observed in plants.

6.9.2 Data Reduction

Twenty-three datasets that included 84 variables were reduced to inform practical performance indicator attributes by removing variables that showed high correlations to other variables (r_s >0.7) within the same performance indicator category. The retained variables were those that were considered less expensive to collect or more commonly used.

Analysis revealed a high number of correlations between variables, including those related to soil biology, soil chemistry and litter. Data reduction analyses reduced the initial 84 available variables to 23, which are shown in **Figure 6.24**.

Ecosystem capacities & attributes	*Performance indicator categories*	*Potential performance indicators*	*No of variables*
A capacity for renewal			
Substrate regeneration	Soil-physical	LFA-stability index	1
	Soil-chemical	LFA-nutrient index Total organic carbon	1 1
	Soil-biological	Microbial biomass (total, protist, and fungi:bacteria) Microbial respiration (glucose) Microbial enzyme substrates (CB, LAP, PHOS)	3 1 3
	Litter biomass	Cover of litter (BAM) Total mass of litter	1 1
Plant regeneration	Second generation plants	Number of species flowering or fruiting Mass of fruits in litter Cover of weeds Plant health (leaf C:N and SLA)	1 1 1 2
Animal regeneration	Invertebrate abundance and diversity	Coarse woody debris	1
A capacity for stability			
Resistance	Species richness	Richness of native plants by site Richness of fungal OTUs by site Richness of bacterial OTUs by site	1 1 1
Resilience	Functional redundancy	Diversity of native plants among growth forms Diversity of fungal OTUs among functional groups	1 1

Figure 6.24 Extract from Oliver and Dorrough (2019) showing reduced variable set identified based on correlations among variables

Source: Table 2 in Oliver and Dorrough (2019)

Note: CB – cellulose degradation; LAP – protein degradation; PHOS – phosphorous mineralisation; C:N – ratio of carbon to nitrogen; SLA – specific leaf area; OTU – operational taxonomic unit

6.9.3 Box Plots for Displaying Range of Variation

Box plots demonstrated the general differences among reference and rehabilitation sites for BAM and LFA indices as well as the differences amongst the reduced set of 23 variables listed in **Figure 6.24.** A selection of the box plots from Oliver and Dorrough (2019) are provided in **Figure 6.25** to **Figure 6.29**. Oliver and Dorrough (2019) describe that each figure shows values recorded at rehabilitation plots as coloured dots, grouped by the PCT to which they have been assigned. Colours relate to rehabilitation site value distance from the reference site median. The horizontal spread of points on the x-axis (within PCT) is to aid visualisation of all points. The range of variation in the values recorded at reference plots (within PCT) is shown by the black box-and-whisker plots. The box represents the middle 50% of values observed at reference sites, and 25% of observed values lie below the box and 25% of the observed values lie above the box. The top of the box is known as the upper quartile and the bottom of the box the lower quartile. The box therefore represents the inter-quartile range (IQR). The upper whisker extends from the upper quartile to the highest value that is within 1.5 x IQR of the upper quartile. The lower whisker extends from the lower quartile to the lowest value within 1.5 x IQR of the lower quartile.

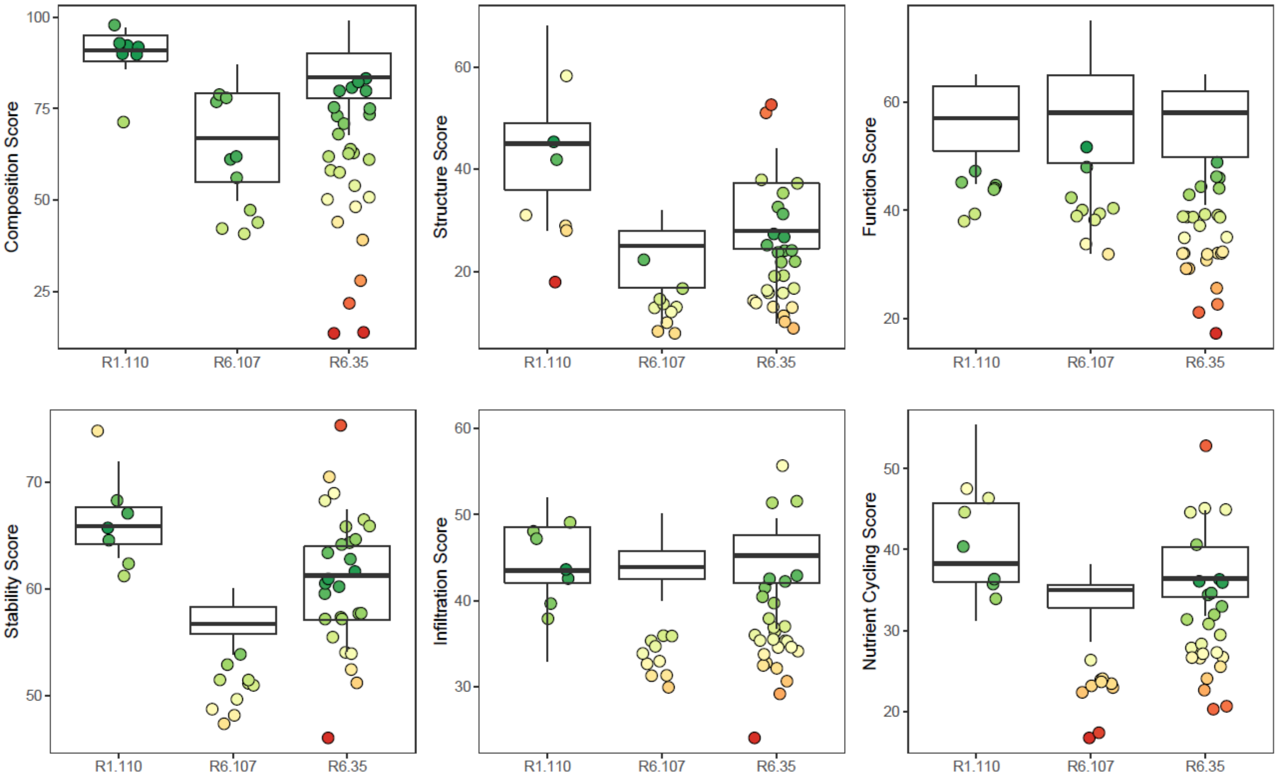


Figure 6.25 BAM (top row) and LFA (bottom row) index scores for rehabilitation plots (points) compared with the box and whisker plots showing the range of variation in index scores for reference sites.

Points are coloured according to their distance from the reference median (bold horizontal line) simply to aid visualisation and results are presented by PCT. R1.110 = PCT3315, R6.107 = PCT3485 and R6.35 = PCT3431.

Source: Figure 6 in Oliver and Dorrough (2019)

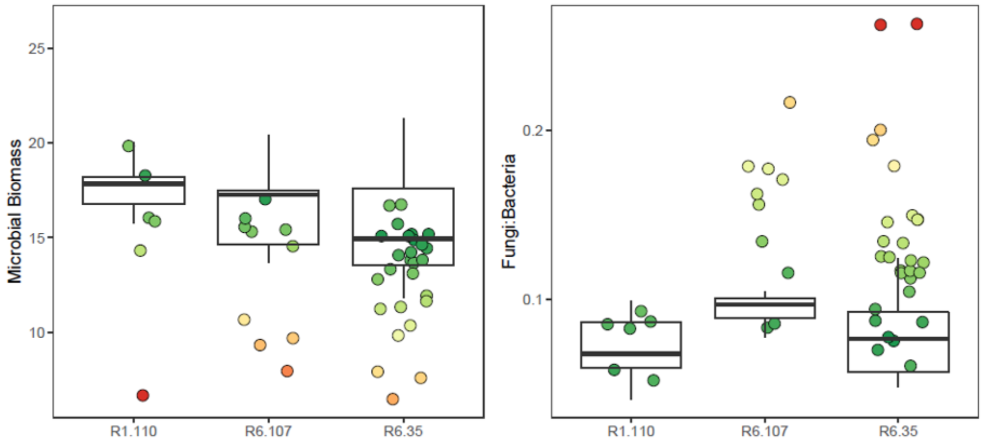


Figure 6.26 Points show the status at rehabilitation sites for microbial biomass and the ratio of fungal to bacterial biomass (from PLFA analyses) with box-and-whisker plots showing the range of variation in status for these variables at reference sites.

Points are coloured according to their distance from the reference median (bold horizontal line) simply to aid visualisation and results are presented by PCT. R1.110 = PCT3315, R6.107 = PCT3485 and R6.35 = PCT3431.

Source: Figure 7 in Oliver and Dorrough (2019)

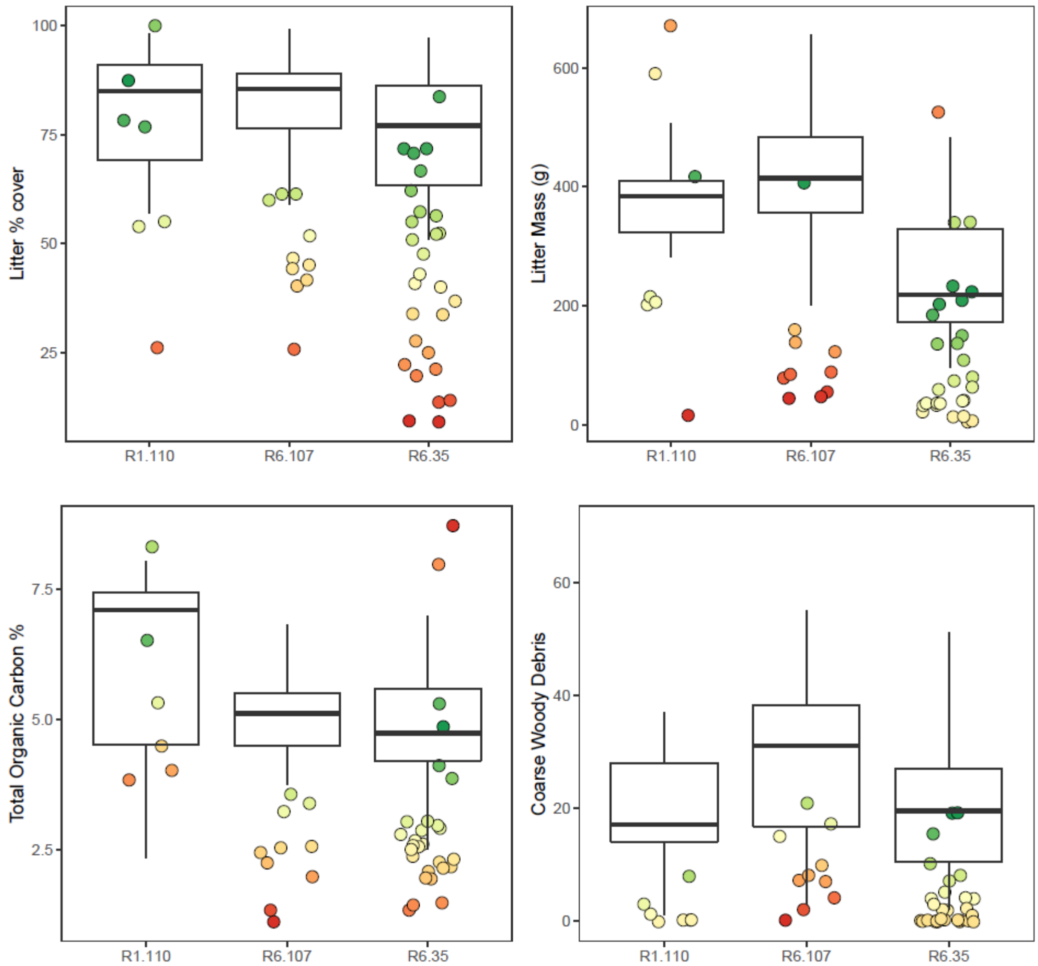


Figure 6.27 Points show the status at rehabilitation sites for litter cover (from BAM), total litter mass (sum of litter fractions), total organic carbon (using mid-infrared (MIR) spectroscopy) and the length of coarse woody debris (from BAM).

Box and whisker plots show the range of variation in status for these variables at reference sites. Points are coloured according to their distance from the reference median (bold horizontal line) simply to aid visualisation and results are presented by PCT. R1.110 = PCT3315, R6.107 = PCT3485 and R6.35 = PCT3431.

Source: Figure 9 in Oliver and Dorrough (2019)

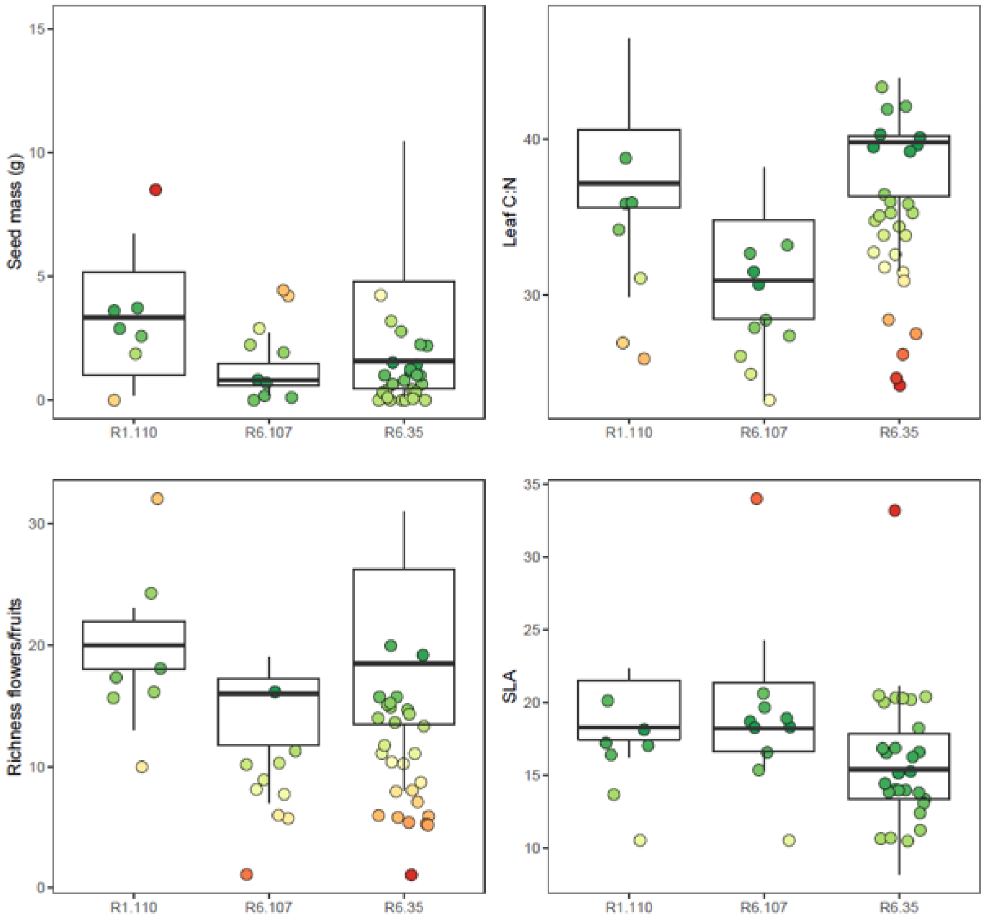


Figure 6.28 Points show the status at rehabilitation sites for the total mass of fruits/seed capsules recovered from litter samples, the ratio of carbon to nitrogen in the leaves of dominant species, the number of plant species recorded as flowering or fruiting at the time of survey, and specific leaf area (SLA) of dominant species. Box-and-whisker plots show the range of variation in status for these variables at reference sites.

Points are coloured according to their distance from the reference median (bold horizontal line) simply to aid visualisation and results are presented by PCT**.** R1.110 = PCT3315, R6.107 = PCT3485 and R6.35 = PCT3431.

Source: Figure 10 in Oliver and Dorrough (2019)

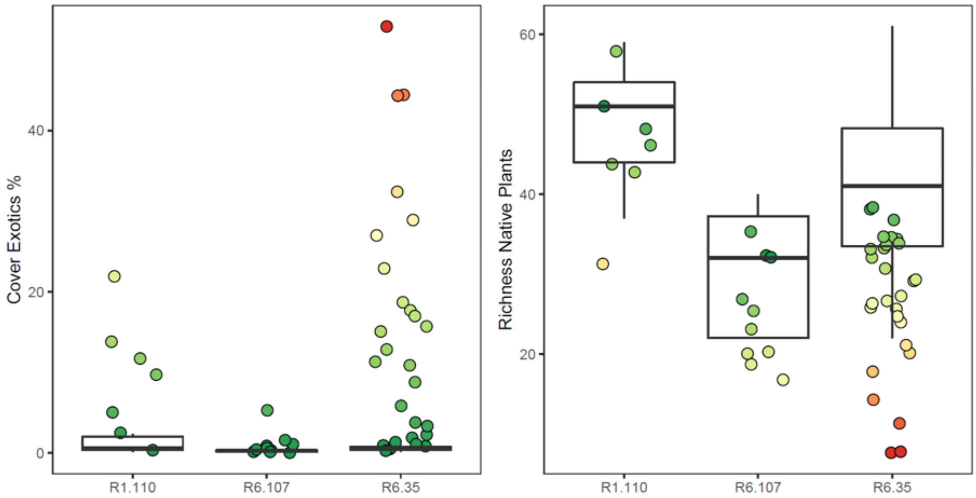


Figure 6.29 Points show the status at rehabilitation sites for total cover of exotic plant species and the number of native species (richness) recorded at each plot.

Box-and-whisker plots show the range of variation in status for these variables at reference sites. Points are coloured according to their distance from the reference median (bold horizontal line) simply to aid visualisation and results are presented by PCT. R1.110 = PCT3315, R6.107 = PCT3485 and R6.35 = PCT3431.

Source: Figure 11 in Oliver and Dorrough (2019)

6.9.4 Estimating Individual Variable Importance

Subsequent importance analyses of the 23 individual variables revealed that a range of BAM generated variables (function and floristics) were ranked highly along with several laboratory-based variables. Variables related to BAM function (litter cover) and total mass of litter fractions were ranked the highest in importance for discriminating self-sustaining (reference sites) from not self-sustaining (rehabilitation less than 10 years old), and these variables were highly correlated (r_s = 0.73). The variables ranked least important related to BAM (native plant growth form diversity), phosphorous mineralisation (using phosphorous (PHOS) enzymes), protozoa biomass (using microbial phospholipid fatty acids (PLFA)) and specific leaf area of dominant species.

6.9.5 Visualising Self-Sustainability Among Priority Variables

The results of the analysis of individual variable importance were used to generate a heat map, using the top 13 variables, to demonstrate the relationship between rehabilitation age and the number of variables that demonstrate potential self-sustainability among each site (refer to **Figure 6.30)**. The general pattern revealed that older sites contained a greater number of green coloured cells and demonstrated high potential for self-sustainability among the variables compared with the younger sites, which had red coloured cells and did not demonstrate self-sustainability (to the same extent as the reference sites). The heat map indicates that cover of exotic plants is generally independent of rehabilitation age. It also demonstrates that variables such as glucose, seed mass and leaf C:N, which display little difference among rehabilitation sites of different ages, are not likely to be informative for monitoring purposes.

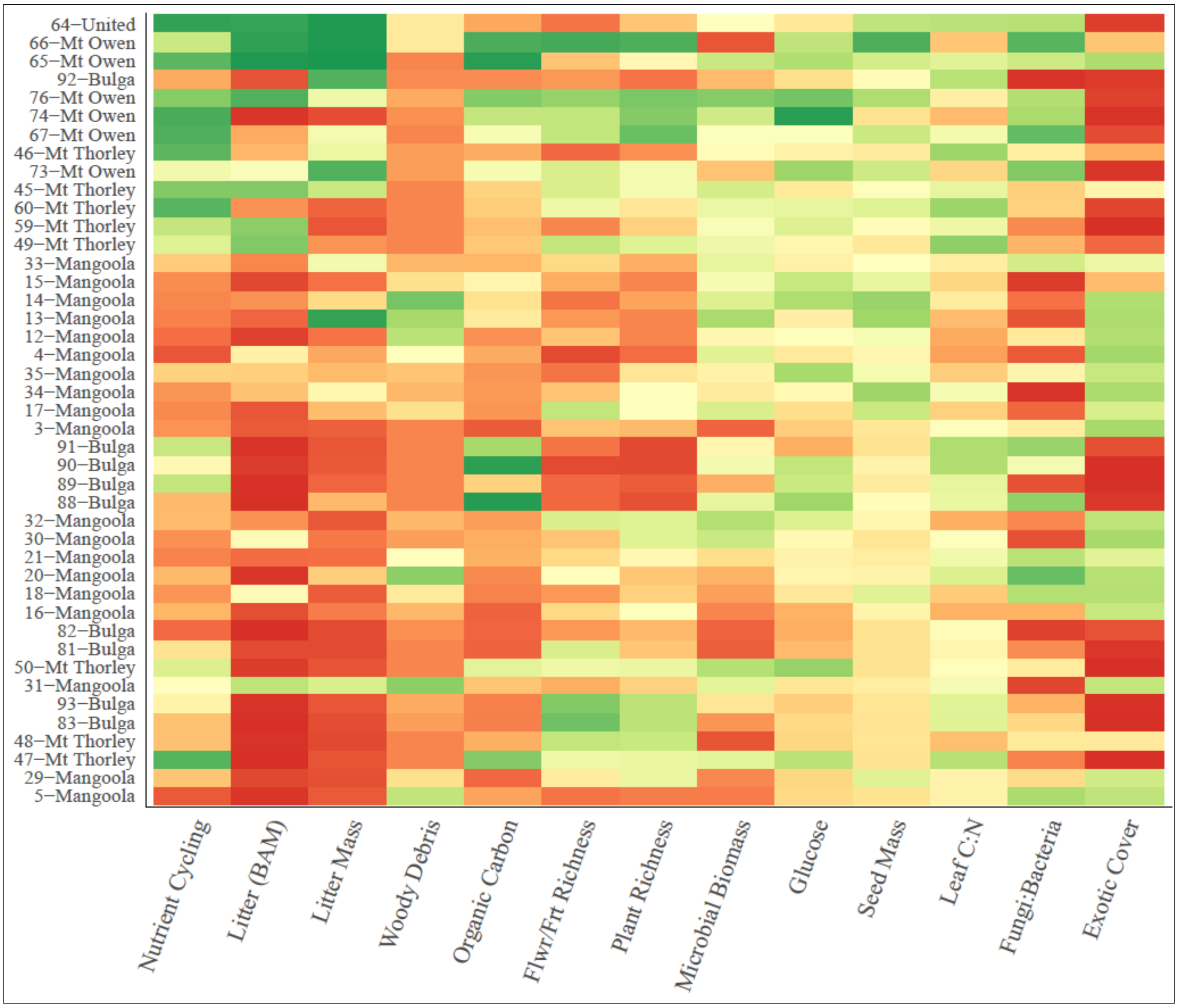


Figure 6.30 Heat map showing higher and lower potential self-sustainability (dark green through to dark red cells respectively) for the 13 priority variables for each rehabilitation site[1].

Sites are ranked from oldest (top) to youngest (bottom)

Source: Figure 13 in Oliver and Dorrough (2019)

Note: 1 Two rehabilitation sites (72 and 75) are not included due to missing data

6.9.6 Cost to Benefit of Variables

The relative costs of different survey methods for each variable as part of the cost benefit analysis are provided in **Appendix 1** and shown visually in **Figure 6.31**. These costs relate to the processing of all variables associated with the method of collection prior to data reduction and modelling. The cost benefit analysis shows that variables related to BAM function (litter cover, coarse woody debris) and litter fractions have a high benefit and low cost. Variables generated by PLFA (microbial biomass, fungal:bacterial biomass), MIR or LECO (total organic carbon) and LFA (nutrient, stability and infiltration indices) all have relatively high benefit and low cost. Variables collected by BAM floristics also have a high benefit however carry a higher cost due, in part, to the post-survey identification of a small number of flora samples and subsequent editing of data being included in the estimated cost.

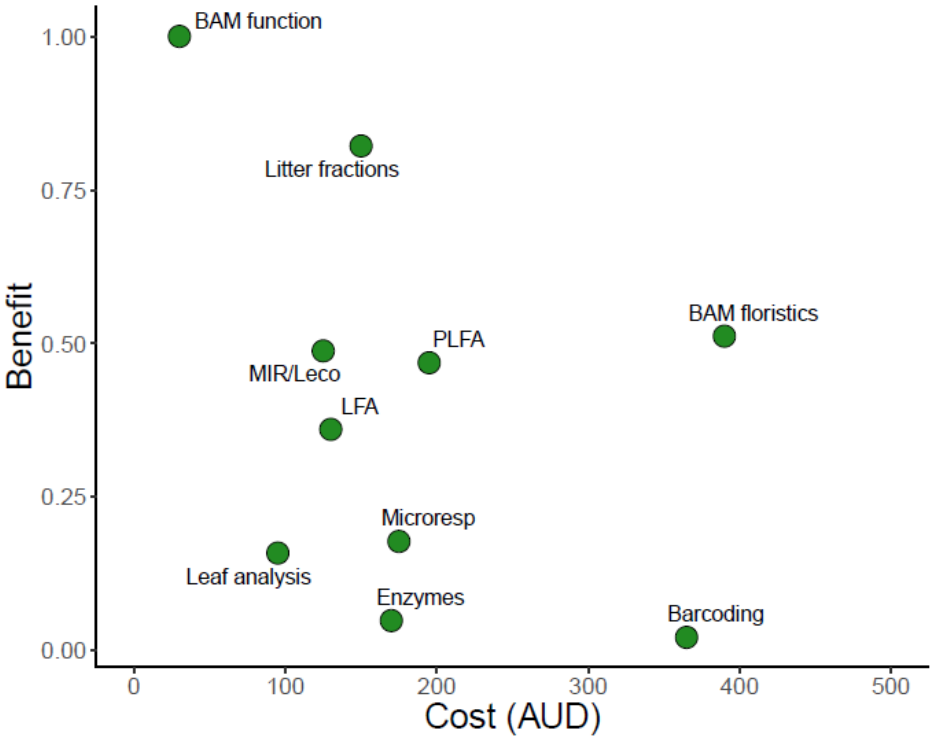


Figure 6.31 Indicative costs of each method plotted against the highest normalised marginal benefit (variables considered individually) recorded for a variable within each method

Source: Figure 14 in Oliver and Dorrough (2019)

6.9.7 Probabilistic Determination of Self-sustainability

The most parsimonious model predicting that reference sites were likely to be 'self-sustaining' to the same extent as reference sites included six explanatory variables, being litter cover, exotic plant cover, number of species flowering/fruiting, length of coarse woody debris, fungal:bacterial biomass and total organic carbon. This model indicates that the probability of self-sustainability is greater in those sites that have more litter cover, a greater number of species flowering/fruiting, higher total organic carbon, longer length of coarse woody debris, lower fungal:bacterial biomass and lower exotic plant cover. Based on the model, two of the older rehabilitated PCT3315 plots (Sites 65 and 66) have mean predicted values greater than 0.9 (i.e. >90% probability of being grouped with the reference sites) and based on the underlying assumptions, these sites are highly likely to be self-sustainable to the same extent of reference sites (refer to **Figure 6.32**). A further rehabilitation plot of the same target PCT (Site 76) has predicted probabilities greater than 0.5 (i.e. >50% probability) and is likely approaching self-sustainability.

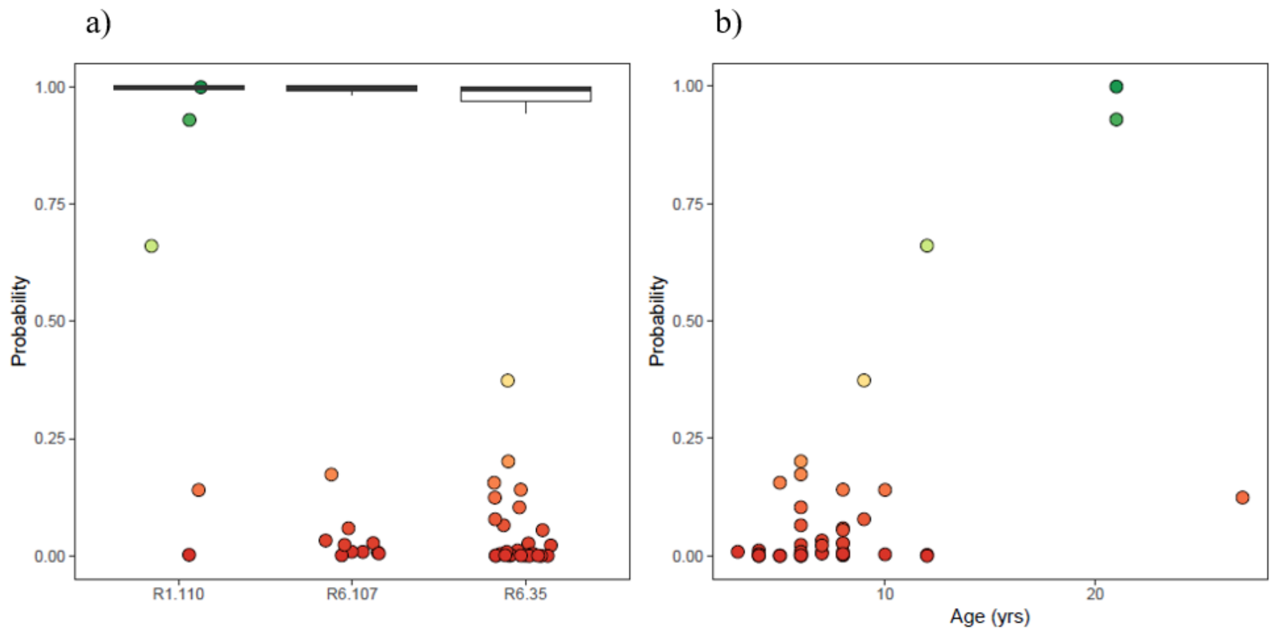


Figure 6.32 Mean probability of each rehabilitation plot being grouped with the reference plots (a), and the relationship between this probability and rehabilitation site age (b).

Points are coloured to aid interpretation and predicted probabilities approaching 1 are green while those approaching 0 are red. Box plots in (a) show the range of predicted values for the reference sites (R1.110 = PCT3315 Central *Hunter Ironbark-Spotted Gum Forest*, R6.107 = PCT3485 – *Central Hunter Slaty Gum Grassy Forest*, R6.35 = PCT3431 – *Central Hunter Ironbark Grassy Woodland*)

Source: Figure 15 in Oliver and Dorrough (2019)

6.9.8 Level of Rehabilitation Function

Using the dataset of Oliver and Dorrough (2019) the 10th, 25th, 75th and 90th percentiles of reference site values for function attributes were determined, as well as the observed range (i.e. minimum and maximum values). These values were calculated for function attributes assessed as being informative to assessing the self-sustainability of rehabilitation by Oliver and Dorrough (2019) as well as those discussed with stakeholders, which included total organic carbon (TOC), microbial biomass, fungal:bacterial biomass, litter cover (using the BAM) and percent foliage cover of high threat exotics (HTE) (BAM) (refer to **Table 6.19**).

Table 6.19 Reference Site Function Values for Total Organic Carbon (TOC), Microbial Biomass, Fungal:Bacterial Biomass, Litter Cover and % Foliage Cover of High Threat Exotics (HTE)

Function Attributes	PCT	Min	Percentile				Max
			10th	25th	75th	90th	
TOC	3315	2.344	4.241	4.507	7.437	7.489	8.030
	3431	1.895	3.247	4.205	5.588	6.470	7.728
	3485	3.755	3.838	4.501	5.497	6.685	7.667
Microbial biomass	3315	11.761	15.882	16.769	18.214	22.523	26.272
	3431	11.837	12.615	13.556	17.617	19.730	21.299
	3485	13.686	14.275	14.632	17.482	20.121	22.164
fungal:bacterial biomass	3315	0.041	0.051	0.059	0.086	0.097	0.157
	3431	0.048	0.053	0.057	0.092	0.109	0.124
	3485	0.078	0.080	0.089	0.100	0.104	0.143
Litter cover (BAM)	3315	57	63	69	91	95.4	98
	3431	51	57	63.25	86.25	95.5	97
	3485	59	72.3	76.5	89	97.4	99
HTE cover (BAM)	3315	0.1	0.12	0.2	0.4	2	2.2
	3431	0	0	0.075	0.325	0.6	2.1
	3485	0	0	0	0.125	0.2	0.25

Rehabilitation sites were assigned a ‘very strong’ level of function for values that fell between the 25th and 75th percentile (IQR) of reference site observations, and ‘strong’ for values between the 10th and 90th percentile but outside of the IQR of reference sites. Sites assessed as ‘very strong’ or ‘strong’ were regarded as self-sustaining to the same extent as reference sites for that attribute. Values that fell between the minimum value and 10th percentile, or the 90th percentile and the maximum value were categorised as ‘moderate’ and values that fell below the minimum or above the maximum of reference sites values for each attribute were assessed as ‘weak’ in terms of self-sustainability. The results of this assessment are shown in **Table 6.20** and in **Appendix 5**.

Table 6.20 Assessed level of rehabilitation site function for total organic carbon (TOC), microbial biomass, fungal:bacterial biomass, litter cover and % foliage cover of high threat exotics (HTE)

Function Attributes	PCT	Number of Rehabilitation Sites			
		Very Strong	Strong	Moderate	Weak
TOC	3315[1]	2	1	2	1
	3431	2	2	19	5
	3485	0	0	0	10
Microbial biomass	3315[1]	0	2	3	1
	3431	16	3	1	8
	3485	5	1	0	4
fungal:bacterial biomass	3315[1]	2	4	0	0
	3431	6	2	7	13
	3485	0	2	2	6
Litter cover (BAM)	3315	4	0	0	3
	3431	5	2	5	16
	3485	0	0	3	7
HTE cover (BAM)	3315	2	2	0	3
	3431	6	2	9	11
	3485	3	4	0	3

[1] No value was recorded for one rehabilitation site for this attribute

7.0 Discussion

7.1 Evidence Derived from Desktop Reviews

The review of monitoring reports for a select group of mines was primarily undertaken to assist with mine site selection and to gain an understanding of the current state of open cut mine rehabilitation in NSW and Queensland. Monitoring reports varied substantially in the monitoring methods that were used, and how the information was reported and analysed and as such this review was qualitative only and did not involve any empirical analyses. While soil and LFA analyses were common components of the reviewed monitoring programmes, self-sustainability was not directly assessed nor quantified. For this reason, it was not possible from this desktop review to assess if the rehabilitation areas were achieving self-sustainability.

The desktop review highlighted some large differences in the agency requirements for rehabilitated areas, between NSW and Queensland and also temporal progression in the requirements of NSW development consents. Open cut mining operations approved in NSW appear to have more conditions of consent associated with land rehabilitation that must be fulfilled before land can be relinquished, and these conditions of consent are also more comprehensive than the Queensland conditions of consent examined. For example, many NSW mines are now required to rehabilitate their land to a specific vegetation community, with some consent conditions requiring rehabilitated lands to support habitat for specific threatened fauna. In Queensland, for the sites that were reviewed, the mines had only high-level rehabilitation requirements, such as the requirement to progressively rehabilitate their post-mined lands. Where the mines have been committed to rehabilitating plant communities in accordance with their conditions of consent, the desktop review suggests that they have been achieved or will likely be achieved in the future.

From review of the monitoring reports there is evidence that many of the Hunter Valley mines are establishing plant communities dominated by native species, with emerging structural layers that are appropriate to the age of the rehabilitated ecosystem. However, without comprehensive analysis it was difficult to empirically determine if rehabilitation was developing into a recognisable PCT. Some of the most common concerns highlighted in the monitoring reports were a deficiency in native groundcover establishment, a high density of shrub or canopy individuals and high exotic groundcover. As noted earlier, the mine rehabilitation assessed through the desktop review was not established to meet modern PCT or TEC classifications.

Despite the management issues identified above it was determined from the desktop review that the NSW mine rehabilitation areas had a reasonable potential to be developing into recognisable plant communities consistent with those stipulated in consent conditions. The Queensland rehabilitation sites reviewed for this project were not developed enough, both in species composition and vegetation structure, to be able to make any positive conclusions about achieving recognisable or self-sustainable ecological communities. Future studies investigating legislative requirements of rehabilitation, legislative allowance to use rehabilitation as part of offsetting requirements, and rehabilitation outcomes, coupled with more detailed and targeted ecological monitoring, may further explain this finding.

The review of fauna monitoring results from four Hunter Valley mine sites indicated that rehabilitated areas provide habitat for threatened fauna species, particularly woodland birds and micro-bats, as evidenced by their presence during monitoring events spanning several years to nearly 20 years in the case of Mt Owen Mine. Based on the consistency of records of several threatened species across successive monitoring periods, it could be assumed that rehabilitated areas provide foraging habitat for these species, however there is not currently enough information to ascertain whether rehabilitation provides breeding habitat. The identification of threatened fauna species at these mine sites is consistent with current literature which indicates that mine rehabilitation can, with appropriate time, support a diversity of fauna species (Ruiz-Jaen and Aide 2005; Cristescu et al. 2012). However, records of less mobile mammals, including the brush-tailed phascogale and New Holland mouse were limited to one of the mine sites investigated, which is located near the edge of the Hunter Valley floor and adjoins intact remnant woodland, which are likely to be contributing factors supporting their presence. The spotted-tailed quoll, which is more mobile than the brush-tailed phascogale and New Holland mouse, was also recorded from rehabilitation on this mine site. The current study did not aim to investigate this subject beyond identifying the presence of threatened fauna species in mine rehabilitation, however, research into the extent of rehabilitation use by threatened fauna species and the role of habitat augmentation, such as installed nest boxes and hollow-bearing stag trees, would contribute to a greater understanding of this subject and by extension, the self-sustainability of ecological mine rehabilitation.

7.2 PCTs and Compositional Recognisability

DPIE's draft PCT Assignment Tool (DPIE 2019c) was designed to assist with the identification of PCTs which are floristically most similar to the site being investigated and also to give an indication of whether the candidate PCTs are likely to occur in the location of the subject site, based on the environmental attributes of elevation, mean annual temperature and mean annual rainfall. A third output which measures the percentage of each PCT's characteristic species recorded within the target site was under development at the time it was used, and was therefore not utilised for this study. In most cases, the distance to PCT centroid and environmental attributes outputs of the draft PCT Assignment Tool were consistent with the PCTs that would have been selected as the 'best fit' in the absence of the Tool, on the basis of species composition and location. The draft PCT Assignment Tool also assisted with the identification of sites influenced by soils derived from geological strata that occur on the periphery of the Hunter Valley, which are floristically similar to the three target PCTs that occur on the Hunter Valley floor. In all cases, reference sites were allocated to the PCT with the lowest distance to centroid measure that was within the range of all three environmental variables, which resulted in most sites being allocated to one of the three target PCTs (3315, 3431 and 3485). Reference sites which were not allocated to the one of the target PCTs were situated the furthest from mining activities, occurred near the edge of Permian-aged strata, were influenced by Triassic-aged strata and therefore ecotonal in nature.

A different approach was taken for rehabilitated sites, being reconstructed ecosystems intended to represent a particular vegetation community. For the purposes of this project, it was assumed that all rehabilitation was located on soils and parent material derived from Permian-aged strata and sites were allocated to the PCTs identified adjacent to the mine site and/or which were previously present within the mining footprint and from which topsoil may have been sourced, in addition to consideration of the species composition. All mining in the central Hunter is undertaken within Permian-aged coal measures and on that basis PCTs that do not occur on Permian substrates were not considered during the allocation of rehabilitation sites to PCTs. The goal was not necessarily to identify the 'best fit' PCT for rehabilitation sites, but rather to acquire a measure of similarity to the PCT which was most likely to have been the intended target, and for which a distance to centroid measure could be obtained using the draft PCT Assignment Tool, which was limited to the ten nearest PCTs.

The results from the draft PCT Assignment Tool identified a strong negative correlation between native species richness and the distance to PCT centroid, with the latter generally decreasing with increasing native species richness. The results also indicated that one third of rehabilitation sites recorded distance to centroid values below the 0.695 threshold value used in the draft PCT Assignment Tool, meaning that these sites are *very strongly* aligned to, or recognisable as, the allocated PCT. There was no evidence that the distance to centroid measure decreased with increasing time since establishment. These results show that it is possible for rehabilitation that is recognisable as a PCT to be established and that recognisability does not necessarily increase with time since establishment.

Similar results were obtained using a subset of 'secondary' ENSW Classification plots (n=78) to develop levels of recognisability as a proof-of-concept approach, compared to use of the entire dataset of 'secondary' plots (n=4153). This included the use of 'strong', 'moderate' and 'weak' levels of compositional recognisability for those sites that fall above the draft PCT Assignment Tool threshold (which indicates 'very strong' alignment). After utilising the entire dataset of 'secondary' sites, the threshold for 'strong' recognisability increased by a distance of 0.003 (from 0.733 to 0.736) and the threshold for 'weak' recognisability increased by a distance of 0.009 (from 0.759 to 0.768), which resulted in very few changes to the initial assessments of compositional recognisability for the 45 rehabilitation sites. These results indicate that the level of variation in 'secondary' site distances to PCT centroid values identified in the smaller sub-set, is fairly consistent with the variation of the entire dataset of secondary sites. We hypothesise that these thresholds are suitable for assessing compositional recognisability of post-mining rehabilitation, and as such, these thresholds have been included in the proposed completion criteria for assessing whether the rehabilitation vegetation composition is recognisable as the target PCT (**Section 8.5**).

7.2.1 Benchmarks

Benchmarks are an integral part of the BAM and are used to determine the relative condition or 'integrity' of native vegetation at a site (Oliver et al. 2019). Benchmarks were considered in this study to inform the development of suitable completion criteria and performance indicators for ecological mine rehabilitation, as they should ideally represent a standard point of reference, against which rehabilitated landscapes can be compared. The difference between the existing class-level benchmarks developed for the BAM (for average rainfall and drought periods) and the PCT-level benchmarks derived through this project was investigated using the method for the development of benchmarks based on local reference sites as described in the BAM (DPIE 2020a. The guidelines stipulate that local benchmark data must be collected from 'best-on-offer' reference sites as well as meet several other criteria as much as practicable (DPIE 2020a). Some, but not all, reference sites fully met the Guideline's recommendation for "minimal modification through past land-use activities such as timber harvesting, firewood collection, grazing, erosion, dieback and/or exotic weed infestation"; "be located at least 20m, and where possible 50m from a roadside, track or other major disturbance"; and "plot locations must not be closer than 1km". Where sites were in proximity to tracks, they were pre-existing monitoring sites. Despite all of the Guideline's recommendations not being met for 'best-on-offer' reference sites in all cases, the sites sampled were considered, for the most part, the 'best available' within areas that could be readily accessed and representative of some of the best available examples of the target PCTs.

Field data informing this study were collected during a very dry period and therefore conditions were not optimal for the collection of data that is representative of periods of average or above average rainfall. The results indicated that the cover of flora species, predominantly groundcover species, was lower than has been previously recorded in the Hunter Valley during periods of higher rainfall and it is possible that species richness was also reduced, although not confirmed by this study. Therefore, the PCT-level benchmarks developed using local reference sites for this study are only suitable for comparison to data collection during comparable climatic conditions.

Class-level BAM benchmarks that are regarded as more appropriate to use during periods of very high or low rainfall, termed 'wet' and 'dry' benchmarks were provided for this study (DPIE 2021c). The 'dry' benchmarks are based on data that are in the 10th percentile of long-term rainfall records and the 'wet' benchmarks are based on data from >90th percentile (DPIE 2020a). However, the guidance document for the application of these benchmarks to BAM assessments indicates that the 'dry' and 'wet' benchmarks are applicable when the rainfall for the preceding 12 months is below the 20th percentile and above the 80th percentile of long-term rainfall records, respectively (DPIE 2020b). Based on rainfall data from the weather stations located nearest to the mine sites (refer to **Appendix 2**), Mangoola and MTW recorded less than the 10th percentile for the average long-term rainfall and United and Bulga recorded less than the 20th percentile of long-term rainfall. MTO was the only site to recorded greater than the 20th percentile in the

12 months prior to survey, however, below average rainfall was recorded. Therefore, the use of 'dry' benchmarks would be permitted for all sites except MTO for an assessment under the BAM. It was noted, however, that the accuracy of the rainfall data used in this study may not be reliable, with many observations listed on the BOM website (BOM 2019) being identified as 'not fully quality controlled' and a large disparity being observed between the Mangoola meteorological data (35.6 mm) and the nearest weather station (85 mm) in October 2018. Irrespective of whether the 'dry' benchmarks were applicable to the vegetation sampled for this study, comparison of 'dry' and 'average' rainfall benchmarks indicated that the 'dry' benchmarks did not reflect the decrease in foliage cover which is likely to occur during drought conditions, which was confirmed by DPIE (J Dorrough 2021, personal communication).

Despite the influence of low rainfall on the data collected, the results highlight the inherent differences between species richness and foliage cover values for growth forms of individual PCTs, which may be lost at the class level. PCT 3485 has been observed to typically contain very sparse ground cover vegetation and instead has high levels of deep litter resulting from the shedding of bark, foliage and branches from the dominant canopy species slaty gum (*Eucalyptus dawsonii*), irrespective of the climatic conditions. The density of shrubs within this community is also demonstrated to be highly variable across its distribution. The results showed that PCT 3485 generally has significantly lower cover across all growth forms, except trees, when compared to class-level benchmarks, which provide unattainable, and therefore unsuitable, benchmarks for this vegetation type. The foliage cover benchmarks for each growth form developed at the PCT-level for PCTs 3315 and 3431 are also considerably lower than the class-level benchmarks, including the shrub growth form, which was not observed to have been significantly affected by the drought during surveys. However, data collected during average rainfall conditions would be more appropriate for comparisons to class-level benchmarks for PCTs 3315 and 3431.

7.3 Structural Recognisability

Further to species composition, the structural characteristics of a vegetation community have important implications for habitat complexity and associated biodiversity values of an ecosystem (Gould 2012). For this reason, among others, rehabilitation sites should aim to adequately restore a vegetation community with similar structural attributes to its reference site/s. In order to determine this, individual rehabilitation sites were compared to reference sites observations. The analysis method, using the 10^{th} and 90^{th} percentiles to indicate 'strong' recognisability, or the "acceptable range of variation" for restoration sites (Oliver et al. unpublished manuscript), enabled the comparison of a single rehabilitation site to the range of variation present among the intact vegetation used as reference sites, but excluding the influence of outliers. The structural attributes which were the focus in this study were % foliage cover of native grass and grass-like, forb, shrub and tree growth forms; and abundance of tree stems in the five smallest DBH size classes (<5cm, 5-9 cm, 10-19 cm, 20-29 cm and 30-49 cm) within a 0.1 ha BAM plot.

The results from the structural recognisability analyses in this study indicate that ecological mine rehabilitation can achieve vegetation structure comparable to intact vegetation when each attribute is assessed individually. However, no sites were identified as very strongly or strongly recognisable for all nine structural attributes (cover of four growth forms and abundance of five tree DBH size classes). The assessment of structural recognisability of rehabilitation sites based solely on the BAM structure condition score was also found to provide inconsistent results to those obtained from assessing the dominant growth forms separately, and for this reason it is not considered a suitable standalone measure. These results differ from the compositional recognisability results which identified 15 rehabilitation sites as *very strongly* recognisable and a further 9 sites as *strongly* recognisable, based on the outputs of the draft PCT Assignment Tool. The PCT Assignment Tool uses data which relates to structure, in that it utilises MBB cover abundance scores, rather than species presence only which is used in the BAM.

Although vegetation development on post-mined land is relatively poorly studied, research has indicated that it is difficult to establish and develop native groundcover comparable to that of reference sites (Nussbaumer et al. 2012) which, in this study, is largely represented by the 'grass and grass-like' and 'forb' growth forms due to the composition of the target PCTs. However, the results of this study show that nearly half of the rehabilitation sites recorded values between the 10^{th} and 90^{th} percentile of reference site values for these growth forms. At face value this is a promising result in the field of restoration ecology, especially considering the climatic conditions of the sampling period and the variation in age of the rehabilitation sites. An observed difference between rehabilitation and reference sites was the prevalence of ground cover vegetation in troughs compared to banks in situations where deep ripping along the contours of rehabilitated areas was still obvious. This is not surprising given that the purpose of the troughs is to capture resources and eroded soils from adjacent banks and prevent gully erosion from occurring (Tongway and Hindley 2004). Over time, with the continued erosion of banks and the filling of troughs with eroded material, the ground surface should become more even and vegetation growth and the spread of resources, such as leaf litter, may occur more randomly and be influenced by the presence of other barriers to the movement of resources. Consideration was also given to whether the analysis of foliage cover by growth form, as per the BAM, may have masked where a small number of native species had very high foliage cover and were potentially out-competing others in the rehabilitated landscape. However, the small number of sites where this may have been occurring were assessed as not being compositionally recognisable based on the distance to centroid measure which considers the relative cover and abundance of each species using MBB, rather than solely species richness. Therefore, the grouping of growth forms to assess structural recognisability is considered appropriate, in conjunction with the assessment of compositional recognisability using the PCT Assignment Tool.

In two of the target PCTs (3485 and 3431) shrub cover was found to be substantially higher in the rehabilitation sites compared to the reference sites, with the third PCT (3315) having similar results between reference and rehabilitation sites. This result has also been found in other mine rehabilitation studies (Gould 2012; Brady and Noske 2010). This can partly be explained by *Acacia* species being a more dominant component of early rehabilitation along with eucalypt species compared to more established vegetation communities (including remnant eucalypt woodland). Other non-*Acacia* shrub species are also present and often dominant in the shrub layer, the most common of which is *Dodonaea viscosa,* however *Acacia* species generally dominate the shrub layer. Due to the high species richness and cover of short-lived *Acacia* species it would be expected that the cover of shrubs in rehabilitation areas will reduce, over time, as the cohort of *Eucalyptus* grows and resembles a more eucalypt-dominated community.

The results for tree stem counts and tree foliage cover were as expected. Generally, the rehabilitation sites contained higher abundance of trees in the smaller DBH size classes compared to reference sites, whereas the foliage cover of tree species and the abundance of higher tree DBH size classes (e.g. 20-29 cm and 30-49 cm) was found to be lower than in the reference sites. This finding is likely a result of the relatively young age of rehabilitation areas compared to remnant woodland, and in time the rehabilitation ecosystems, in most instances, would be expected to develop foliage cover comparable to reference sites (Brady and Noske 2010; Gould 2012). However, sites with a high abundance of tree stems may require management actions before a recognisable groundcover could develop, which was not analysed in this study due to a lack of rehabilitation sites with a range of stem densities. Very high tree stem abundance was recorded at several sites including one which recorded a tree stem density substantially higher than reference sites and 15 times greater than the median value of PCT 3431 rehabilitation sites, however the tree foliage cover was within the range of reference sites. This site, which was ten years old, had a lower stem class diversity than other rehabilitation sites of similar age, only recording trees <10 cm DBH, and the understorey vegetation was very sparse and species poor. Consequently, this site is not expected to develop a comparable structure or composition to reference sites over time without management intervention. Selective thinning of trees is likely to be required, to increase the cover of understorey species and decrease competition between the remaining trees such that tree stem class diversity and foliage cover of individual trees increases over time. The results from this site also suggest that the analysis of tree foliage cover in the absence of tree stem counts may not be appropriate when assessing the progress of ecological mine rehabilitation.

7.4 TEC Recognisability

Determining the degree to which vegetation at reference and rehabilitation sites was recognisable as the *Central Hunter Valley Eucalypt Forest and Woodland CEEC* listed under the EPBC Act required the application of diagnostic and condition criteria provided in the Approved Conservation Advice (TSSC 2015). These criteria are comprehensive and leave little room for interpretation. One criterion that has been regarded as potentially ambiguous relates to the determinative nature of being present only on soils derived from Permian-aged strata. Due to the constructed nature of the landscape supporting rehabilitated sites, assumptions relating to soils and patch size were made during the process of applying the criteria. For example, coal mines in the Hunter Valley mine Permian-age geological strata and therefore it was assumed that the substrates on which rehabilitation has been established are derived from Permian-age sedimentary rocks, and it was also assumed that all areas of rehabilitation met the minimum patch size requirement. This approach overlooks the low possibility that some overburden material might comprise geological strata that are not of Permian age and are composed of soils derived from geological strata that are contra-indicative.

The results of the analysis identified most sites as supporting vegetation consistent with the *Central Hunter Valley Eucalypt Forest and Woodland CEEC*, including 67% of reference sites and 40% of rehabilitation sites. Ten rehabilitation sites assessed as being inconsistent with the CEEC did not support the required proportion of characteristic *Eucalyptus* spp. in the canopy due to their young age and co-dominance of *Acacia* spp. in the upper stratum. Consequently, these sites will most likely meet the requirements for being considered consistent with the CEEC in future, once a taller eucalypt-dominated canopy develops, which would result in a total of 62% of sampled rehabilitation sites being consistent with the CEEC in future. Additionally, the use of management actions, such as the selective removal of broad-leaved ironbark (*Eucalyptus fibrosa*), which is a contra-indicative species, and improved control of weeds (a key contributor to not meeting condition criteria), could result in additional rehabilitation sites being consistent with the CEEC.

There is a high level of flexibility built into the descriptions for TECs listed under the BC Act which limits the capacity to create ‘rules’ or ‘criteria’ around whether the TECs are present in any given situation. This is intentional so that areas of a TEC cannot be inadvertently excluded due to restrictive diagnostic criteria. Explicitly diagnostic information contained within the Final Determinations for the three relevant state-listed TECs is limited to the area of occurrence (i.e. the bioregion in which they occur). Where the Final Determination states specific map units from previous studies which describe the TEC, the plots that are attributed to these map units can be considered a true floristic representation of the TEC (and therefore diagnostic) and can therefore be used in analyses with other standard floristic plots. The list of characteristic species indicates the commonly recorded species present, however the inclusion of this information in analyses is more restricted, as this list is not representative of the composition of the TEC within a standard floristic sampling plot and therefore comparison at this level is not straightforward.

Floristic plot data from map units stated in the Final Determinations for the three relevant state-listed TECs (Peake 2006; NSW NPWS 2000) were exported from BioNet for the purpose of determining the similarity of these plots to those sampled for this study. Several non-hierarchical clustering methods have been previously used in developing standard distance-based measures for assigning floristic plots to groups such as PCTs and TECs. For this project, a constrained ordination technique, CAP (Anderson and Willis 2003), was used to compare the floristic composition of field data collected from the rehabilitated and reference sites to floristic plots used in the determination of the three TECs listed under NSW legislation. The CAP method was chosen as it anchors the predefined TEC plots as the groups used to then assign new plots from the rehabilitation and reference sites to them. Similar processes have been followed for the draft PCT

Assignment Tool (e.g. k means clustering; DPIE 2019b) and in mapping various TECs on NSW Crown Forest Estates (e.g. fuzzy clustering; State of NSW and EPA 2016). These studies have assigned floristic plots to groups such as PCTs and TECs by developing thresholds for determining whether a new plot can be assigned to a predefined group. The threshold values for these methods were 0.695 and 0.5, respectively.

However, there is no single evaluation measure to be preferred on theoretical considerations, and all measure different characteristics of clustering results. Furthermore, the development of thresholds is generally data-dependent and there is no standardised approach that is applicable to all situations. As such, a conservative approach has been taken in the assignment of floristic plots to TECs in this study by not explicitly defining a distance threshold, but rather producing a heat map to display the variation among plots and their 'best fit' alignment with the three TECs.

The use of the CAP analysis was affected by the unavailability of some plot data corresponding to the three TECs and the resulting small sample size. In the case of *Hunter Valley Footslopes Slaty Gum Woodland VEC* only four Peake (2006) plots could be obtained from BioNet and these sites all sampled a shrubby form of the TEC, which was structurally and floristically different to the plots sampled for this study in which a shrub layer was largely absent. Consequently, the majority of reference and rehabilitation plots allocated to 3485 did not align with Peake (2006) plots, despite it being plausible that these sites, particularly reference sites, are likely to be consistent with the TEC.

Different results were obtained from the CAP analysis for the two remaining state-listed TECs, *Central Hunter Grey Box – Ironbark Woodland EEC* and *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC*, which are represented by much larger sample sizes of plots (Peake (2006) and NPWS (2000)). PCT3315 is very floristically similar to *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC*, which was supported by the results of the CAP analysis. This was also the case for PCT3431 and the floristically similar *Central Hunter Grey Box – Ironbark Woodland EEC*. Unsurprisingly, reference sites more often aligned with their corresponding TEC compared to rehabilitation sites, however the majority of PCTs 3315 and 3431 rehabilitation sites also grouped with their corresponding TEC. The results indicate that the CAP analysis is not informative where there is a small sample size of plots and where the plots are not representative of the floristic variation observed in the TEC. In the absence of a large sample size of plots which represent each TEC and the development of a 'threshold' value which indicates a strong level of similarity, this method is unlikely to be appropriate as a performance indicator which assesses whether a rehabilitation site is 'recognisable' as a TEC.

To better understand the relationship between the characteristic species listed in the Final Determinations of the three state-listed TECs and their corresponding floristic plots (from Peake (2006) and NPWS (2000)), an analysis was undertaken to determine the proportion of the characteristic species (as documented in the Final Determinations) recorded at each plot. This analysis was undertaken for reference and rehabilitation sites allocated to PCTs 3315, 3485 and 3431. This analysis showed that the proportion of characteristic species recorded at PCT3431 reference sites, PCT3315 reference sites and PCT3315 rehabilitation sites largely overlapped with the range of proportions recorded at Peake (2006) and NPWS (2000) plots. A substantial overlap of PCT3431 rehabilitation sites with the range of Peake (2006) sites was also observed. These results indicate that most PCT3315 reference and rehabilitation sites, all PCT3431 reference sites and over half the PCT3431 rehabilitation sites are as similar to the list of characteristic species listed in the corresponding Final Determinations, in terms of composition, as the plots sourced from the products (Peake 2006; NPWS 2000) which are stated in the TEC Final Determinations as being true representations of the TECs. Conversely, a much higher proportion of characteristic species listed in the *Hunter Valley Footslopes Slaty Gum Woodland VEC* Final Determination (NSW Scientific Committee 2010c) were recorded at Peake (2006) plots compared to PCT3485 plots sampled for this study, and no overlap was observed, with the exception of one rehabilitation site. However, significant overlap of PCT3485 reference and rehabilitation sites was observed, indicating that rehabilitation sites are just as similar to the

TEC as reference sites. Based on the outcome of the characteristic species analysis, there is evidence that ecological rehabilitation consistent with TECs listed under the BC Act can be established.

The similarity between the TECs listed under the BC Act and their corresponding PCTs was also explored to investigate whether confirmed recognisability as a PCT could possibly be used as a surrogate for direct comparison to plots which represent the TEC or analysis of the proportion of characteristic species present. For example, if a site was *strongly recognisable* as PCT3315, determined by a distance to centroid ≤0.695 as measured by the draft PCT Assignment Tool, is it reasonable to conclude that the site is recognisable as *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC*? Whilst a high number of shared species was identified between PCT3315 and *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* (38 species), the results were quite different for PCT3485 and *Hunter Valley Footslopes Slaty Gum Woodland VEC* (17 species), quite likely due, at least in part, to the reduced supply of plots to inform both the TEC and PCT descriptions of the latter. These results reconfirm that although a PCT recognisability assessment might inform the allocation of a TEC, there is no strict relationship between the two, and a TEC can exist independent of any such relationship. Indeed, a TEC can correspond with one or many PCTs, and one PCT may correspond to one or many TECs. It is important for a TEC to be assessed through the direct knowledge of the field situation compared to the Final Determination and any specified relationships between the TEC and certain mapping units from an existing classification. However, it may be possible to compare a rehabilitation site directly to a reference site, where it can be clearly demonstrated that the reference site is consistent with the target TEC. This could be achieved using one of the techniques described above that rely on list of characteristic species and/or the vegetation classification (and associated plots) detailed in the Final Determination.

7.5 Self-sustainability

Oliver and Dorrough (2019) investigated 84 variables as potential indicators for assessing progress of rehabilitation toward self-sustainability, with the assumption that reference sites were self-sustaining and young rehabilitation sites (<10 years old) were not yet self-sustaining. They found that rehabilitated sites were more variable than reference sites, which was expected given the variable age of the rehabilitation, different establishment techniques and resources (e.g. topsoil), which vary across mine sites according to their pre-mining disturbance history. The results from some rehabilitation sites fell within the interquartile range (IQR) of reference sites for some of the sampled variables, which suggest that the sites themselves are self-sustaining for that variable to the same extent as the reference sites. The results also indicate that sites generally become more self-sustainable as they age, however, not all older sites performed well (Oliver and Dorrough 2019). Subsequent analysis by Oliver et al. (unpublished manuscript) indicates that use of the 10^{th} and 90^{th} percentiles of reference site values to assess the "acceptable range of variation" of rehabilitation is more appropriate than the use of the IQR.

It is important to note that the variables measured are generally proxies, rather than direct measures of ecological processes and thereby, self-sustainability. This is especially clear for variables that can be readily modified through management actions, such as the emplacement of coarse woody debris (CWD). The presence of CWD on a site does not necessarily reflect that the site is self-sustaining, however its presence, over at least several years, has been shown to have a positive effect on ecological processes, and therefore on self-sustainability (Oliver and Dorrough 2019).

Nine variables were identified by Oliver and Dorrough (2019) as potential performance indicators for measuring self-sustainability at rehabilitation sites. These nine variables include those that revealed significant differences between reference sites (assumed to be self-sustaining) and rehabilitation sites less than 10 years old (assumed not to be self-sustaining) and are commonly used in other studies; and they are also shown in **Section 6.9.6** to provide higher benefit and lower cost. These variables are:

1. litter cover (BAM function)

2. coarse woody debris (CWD) (BAM function)
3. exotic species cover (BAM function)
4. number of native plant species flowering/fruiting (addition to BAM floristics)
5. total organic carbon (MIR or LECO)
6. fungal:bacterial biomass (PLFA)
7. total microbial biomass (PLFA)
8. number of native plant species (BAM floristics)
9. nutrient cycling index (LFA).

Tree regeneration was not included in analyses due to a miscommunication about data availability. Tree regeneration was recorded at the majority of reference sites by the presence of stems of less than 5 cm DBH, but at only one rehabilitation site through separate specific data, as the presence of trees of less than 5 cm DBH does not indicate the presence of recruitment of second-generation trees in young rehabilitation. Due to the disparity between reference and rehabilitation sites for this variable, the presence of second-generation tree recruitment would have been included as a high priority attribute in the model (Oliver and Dorrough 2019). However, these results suggest that second-generation trees are not abundant in the rehabilitation that was sampled, and if present, they may not be effectively sampled using a standard 20 m x 50 m BAM plot. Therefore, consideration should be given as to how this variable is best sampled, if it is to be used as a performance indicator.

Oliver and Dorrough (2019) note that consideration of multiple variables must be undertaken when determining the self-sustainability of a site, however they also conclude that rehabilitation sites can be considered to be self-sustaining without performing well for all variables. Following the reduction in variables through the removal of those that were highly correlated, the heat map comparing the results for 13 variables at rehabilitation sites (Figure 6.29) demonstrated that no rehabilitation site could be regarded as self-sustaining based on all variables. Further predictive modelling by Oliver and Dorrough (2019) which aimed to identify the most parsimonious model (a single model with the best predictive power but the fewest variables), identified six variables that determine the probability of a rehabilitated site being grouped with reference sites, which for the purposes of this study were assumed to be self-sustaining. These six variables are identified as variables 1–6 in the list above. Using the further reduced model of 6 variables, Site 65 and Site 66 were assessed as having a greater than 90% probability of being grouped with reference sites and therefore greater than 90% probability of being self-sustaining. Site 65 did not perform well for two of the six variables, being CWD and number of native plants flowering or fruiting, whereas Site 66 performed poorly for exotic species cover and CWD. This is important to note when considering performance indicators and completion criteria for ecological mine rehabilitation. Hypothetically, if completion criteria stated that these rehabilitation sites need to achieve the IQR of reference sites for all six variables, Sites 65 and 66 would fail to satisfy these criteria and would not be certified and relinquished, despite analyses showing that these sites are most likely self-sustaining. Further research into the use of predictive models, or similar, which consider multiple variables at a time, may be beneficial in assessing overall performance of a site in terms of self-sustainability, as well as structural recognisability.

The oldest rehabilitation site used in the analysis, Site 64, which was estimated to be 27 years old at the time of sampling (the exact date of establishment could not be confirmed), performed poorly in four of the six variables and had a 20% probability of grouping with reference sites. This site performed well for litter cover and fungal:microbial biomass, but performed poorly for CWD, exotic plant cover, total organic carbon and the number of native species flowering or fruiting. This site performed particularly poorly for exotic plant cover as its canopy was co-dominated by sugar gum (*Eucalyptus cladocalyx*), which is not native to

NSW, but was historically widely used in rehabilitation in the Hunter Valley. Had sugar gum been removed from this site, the cover of exotics would have been 0.1% of the plot, which is comparable to reference sites rather than the 15.1% used in the analyses. In addition, had these trees been felled and left on site, those trees greater than 10 cm DBH would have also contributed positively to the length of CWD. The presence of CWD is demonstrated to provide habitat for a range of vertebrate and invertebrate species (Tongway et al. 1989; MacNally et al. 2002; Bowman and Facelli 2013) and provides a measure of the extent of faunal recolonisation (Oliver and Dorrough 2019). Oliver and Dorrough (2019) stress that the thinning of trees to contribute to CWD and eventually total organic carbon, however, would take several years to yield benefits to ecological processes and self-sustainability and therefore should not be undertaken late in the rehabilitation process.

Although CWD is a key variable with which one can assess a monitoring site's performance in relation to self-sustainability, this is not straightforward. Where possible, a mine site should emplace CWD obtained from nearby tree clearing operations (or from stockpiles from previous clearing) directly onto re-shaped lands prior to rehabilitation seeding. It is difficult to do this once seedlings have established. The presence of CWD and its gradual decomposition will contribute substantially to the increasing function of the site through potentially acting as a barrier to movement of soil, seeds, litter and water, and providing habitat for invertebrates and small vertebrate animals. However, where CWD has been emplaced, its presence is not necessarily a measure of how the site is itself developing towards self-sustainability, but rather it is a proxy for ecological processes which are likely to confer self-sustainability (Oliver and Dorrough 2019). This is further complicated because some mine sites can readily emplace CWD due to the nature and timing of tree clearing operations and rehabilitation; however some mine sites cannot, either because clearing of woody vegetation occurs after some or much rehabilitation has commenced (where pasture areas are mined first, for example), or because the mine site does not clear any substantial treed areas (providing a source for CWD), but is nonetheless rehabilitating a woodland/forest vegetation type. For these reasons, CWD is not recommended by Umwelt as a rehabilitation performance measure for all operations establishing ecological mine rehabilitation, however we recommend that it be considered for inclusion where removal of woody vegetation containing CWD is required and where salvage of this material is achievable.

The most notable differences in the functional attributes between rehabilitated sites and reference sites were microbial biomass and fungal:bacterial biomass (Oliver and Dorrough 2019). Microbial biomass at the rehabilitation sites was consistently below the median values for the reference sites, particularly for PCTs with the youngest rehabilitation (3485 and 3431) and the fungal to bacterial biomass ratio was substantially higher than reference sites. Both variables appear to be highly influenced by the age of the rehabilitation. Microbial biomass is shown to increase as an ecosystem develops and the fungal biomass is shown to be greater than bacterial biomass in more degraded ecosystems (Oliver and Dorrough 2019). Whilst these attributes appear to be useful in distinguishing between reference sites and rehabilitation sites, there is uncertainty within the mining industry regarding the use of these attributes as completion criteria, as to date they have not been widely used in rehabilitation monitoring in NSW. The provision of further evidence regarding the value of these attributes and the cost effectiveness of data collection may be required to justify the inclusion of these measures in rehabilitation monitoring programmes.

Cost-benefit analyses demonstrated that BAM function attributes (litter cover, CWD) provided the highest benefit to cost ratio of the nine potential performance indicators listed above. Variables measured using MIR/LECO (e.g. total organic carbon) and PLFA (e.g. fungal:microbial biomass) were also shown to provide high benefit to cost. BAM floristics measures provided the least benefit to cost in this analysis, however the collection of this information is required for assessing compositional and structural recognisability and therefore the inclusion of this data provides no additional cost for use in self-sustainability assessments. Consideration of the cost of variables to be collected during routine rehabilitation monitoring events is important. Sampling techniques that are viewed as too costly for the benefit that they provide might not be completed regularly enough to be informative or might divert funds from knowledge and resources that would provide better rehabilitation outcomes.

Oliver and Dorrough (2019) state that the development of performance indicators for monitoring the progress of rehabilitation sites towards self-sustainability is highly dependent on the state and variability of the reference sites. This accounts for seasonal variations and stochastic events (e.g. drought) and allows for natural ecosystem fluctuations for both rehabilitation and reference sites over time. Oliver and Dorrough (2019) suggested that the rigour of the self-sustainability assessment may be enhanced by including larger numbers of reference sites, and by expanding this work to include other vegetation types and other regions, however subsequent analyses have determined that the replication of reference sites used in this study was sufficient (Oliver et al. unpublished manuscript).

The work of Oliver and Dorrough (2019) appears to be the first attempt to develop a rigorous and scientifically sound process for determining whether mine rehabilitation sites are self-sustaining (Oliver and Dorrough 2019). Using this approach, two rehabilitation sites were assessed as being self-sustaining and one was assessed as approaching self-sustainability. All three of these sites were assessed as being 'strongly recognisable' as PCT PCT3315. Sites 65 and 66 were assessed as being consistent with the *Central Hunter Valley Eucalypt Forest and Woodland CEEC*, while Site 76 was consistent with the CEEC in all aspects except for the proportion of the canopy comprising the characteristic species (being co-dominated by a grey gum hybrid (*Eucalyptus canaliculata–punctata*)). All three sites recorded a proportion of *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* characteristic species, which was consistent with those recorded at Peake (2006) and NPWS (2000) sites which define the EEC, and are therefore considered recognisable as the EEC. The results of Oliver and Dorrough (2019) and this study combined demonstrate that it is possible to establish ecological rehabilitation that is recognisable as PCTs and TECs listed under the EPBC Act and BC Act that are also considered to be self-sustaining, or approaching self-sustainability.

Part Three – Application to Industry

This section addresses Objectives 4 and 5 of the project, being:

4. Develop a set of principles to inform the establishment of appropriate rehabilitation objectives, performance indicators and completion criteria for the establishment of recognisable and self-sustaining ecological communities (focusing on temperate woodlands).

5. Provide guidance to industry to inform the establishment of benchmark successional stage criteria and a monitoring programme to guide progressive ecological rehabilitation success or adaptive management.

These sections have been informed by the results and outcomes of the investigations described in **Part Two** of this report. The results demonstrate that recognisable ecological communities can be established in mine rehabilitation and that it is possible for ecological mine rehabilitation to achieve a level of self-sustainability comparable to reference sites.

Effective closure planning over the short, medium and long term is essential to achieve target post-mine land uses and to minimise risks of regulatory non-compliance and delays to relinquishment. The rehabilitation of target vegetation communities, such as PCTs, is nowadays more commonly being stipulated by the consent authorities in NSW when granting a project approval. This requires detailed rehabilitation plans, procedures, controls and monitoring programmes to be developed, and adhered to, for rehabilitation to be successful and for rehabilitation objectives and completion criteria to be met. The Commonwealth government is also providing conditional approval to coal mines which includes the establishment of vegetation recognisable as a TEC. It is anticipated that such requirements will also continue to grow in other state and territory jurisdictions.

To inform the development of appropriate rehabilitation objectives, completion criteria and performance indicators for ecological mine rehabilitation, as well as to provide guidance for monitoring programmes and successional stage criteria, several questions need to be considered:

1. What is an appropriate end goal or target that demonstrates recognisability and self-sustainability (completion criteria)?

2. How are recognisability and self-sustainability best measured (performance indicators)?

3. Is there a clear trajectory toward the end goal or target (performance guidance)?

4. How should progress toward the end goal or target be monitored?

These questions are considered in the following sections, followed by proposed rehabilitation objectives, completion criteria and performance indicators for ecological mine rehabilitation.

8.0 Development of Rehabilitation Objectives, Completion Criteria and Performance Indicators

8.1 Measures of Recognisability and Self-Sustainability

Recognisability can be considered in terms of both composition and structure, while self-sustainability relates to functional attributes, as illustrated in **Figure 8.1**.

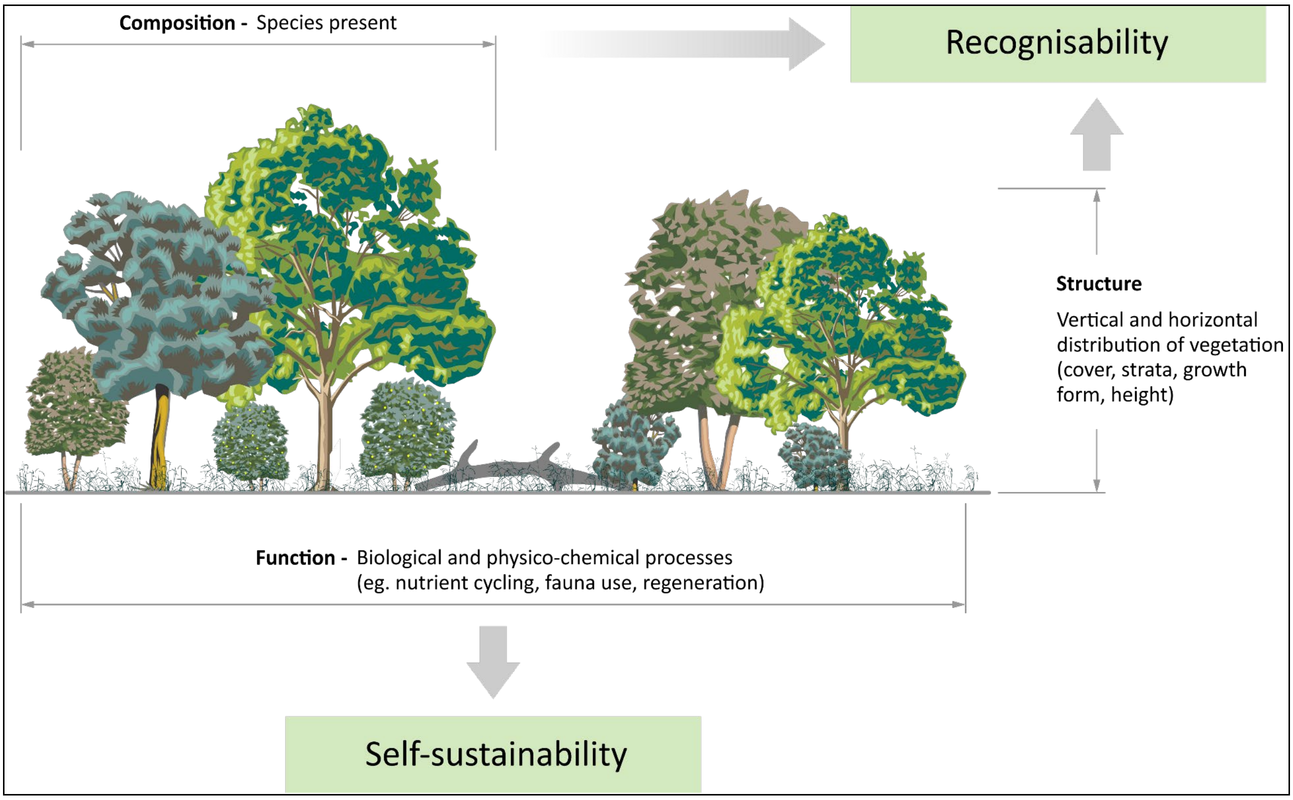


Figure 8.1 Components of ecological community recognisability and self-sustainability

A number of potential measures of recognisability and self-sustainability have been discussed in **Part Two** of this report and by Oliver and Dorrough (2019) (**Appendix 1**). When assessing rehabilitation success, it is preferable to use measures, or indicators, that are cost-effective and have standard approaches that are simple to employ and produce results that are easily interpreted (Dey and Schweitzer 2014). Similarly, the acronym 'SMART' summarises what should ideally be included in completion criteria, being 'specific', 'measurable', 'attainable', 'relevant' and 'time bound' criteria in order to avoid any potential ambiguity. With this in mind, an assessment of the suitability of measures as potential performance indicators and completion criteria for ecological mine rehabilitation was undertaken and is provided in **Table 8.1**. It includes potential performance indicators which relate to recognisability, as identified by Umwelt, and those which relate to self-sustainability, as identified by Oliver and Dorrough (2019). The indicators selected as 'suitable' are those deemed to be ecologically relevant in relation to the identification of trends in, or the achievement of, ecosystem restoration and which satisfy, as much as possible, the ideal attributes of performance measures and completion criteria discussed above, whilst attempting to minimise overlap.

Measures have been considered separately for the type of ecological community being rehabilitated:

- PCT, as used in NSW
- TEC listed under NSW legislation
- TEC listed under Commonwealth legislation.

Table 8.1 Measures for Recognisable and Self-Sustaining Ecological Mine Rehabilitation

Rehabilitation Type	Measure	Assessment of Suitability as Performance Measure
Composition Measures		
PCT	PCT Assignment Tool	Easy to use and input data is readily available from standard 20 m x 20 m floristic sampling plot and BAM, which is widely used in NSW. Output is a distance to centroid value which is an easily interpreted direct measure of similarity to all BioNet plots representative of the PCT. **Suitable**
	BAM composition score against benchmark	Benchmarks (class-level and PCT-level) are limited to the assessment of native species richness within growth forms and not the identity of the species present. **Not suitable for assessing recognisability**
	Presence of diagnostic species listed in PCT profiles	A strong correlation was identified between the number of species recorded at a site that are listed as characteristic of the community on the draft ENSW PCT profile and its distance to centroid value. **Potentially suitable (in the absence of PCT Assignment Tool), subject to confirmation of correlation with distance to centroid value using final ENSW data and PCT profiles.**
TEC (BC Act)	Comparison to floristic plots from map units stated in Final Determination as representative of the TEC	This measure usually requires the use of complex statistical analyses and the results require a level of interpretation by the user and relies on access to plots held in the BioNet database, which may be difficult to obtain, as demonstrated by this study. There is unlikely to be consistent interpretation of results between observers and when used for this study; the results were inconsistent with results obtained from the analysis of similarity to PCTs and the EPBC Act-listed TEC. **Unsuitable**

Rehabilitation Type	Measure	Assessment of Suitability as Performance Measure
	Presence of species listed in TEC Final Determination	The species assemblage list cited within a TEC Final Determination is potentially diagnostic, however direct comparison to plot-based data is not appropriate due to the difference of scale. Consideration also needs to be given to the spatial distribution of the TEC which will determine whether all species in the list could occur at a single location, or whether the list includes species that occur at only one extreme of the TEC's distribution, for example. There are several ways to assess this attribute: 1. the number/proportion of the TEC species list present at a site; or 2. the number/proportion of the species recorded at a site which are on the TEC species list; or 3. a combination of above. Assessing the proportion of the native species recorded at a site which are on the TEC list (option 2 above) could give skewed results in favour of sites with low species richness. For example, a site may record a very low number of native species, all of which are included on the TEC Final Determination, resulting in 100% of native species present being indicative of the TEC. Therefore, native species richness also requires consideration. On the other hand, at a site with high species richness, only considering the number or proportion of species from the TEC list present (option 1) may return a positive TEC result despite there potentially being a high proportion (and possible dominance) of non-TEC species within the site. Therefore, a combination of options 1 and 2 is an appropriate method of using the species listed in a TEC Final Determination to assess TEC presence. Due to the variability in the number of species included on each TEC Final Determination, the appropriate proportion and overall species richness which is indicative of recognisability needs to be determined for each individual TEC. **Suitable, with approach tailored to specific TEC**
	Alignment with a strongly associated PCT	This approach requires consideration of the specific TEC in question and the strength of the relationship between the TEC and the PCT. For the target PCTs discussed in **Part Two** of this report, there appears to be a reasonably strong relationship between two of the three PCTs and their corresponding TECs. This approach is best utilised where there is a clear relationship between the PCT and TEC that is justified by relevant authorities, such as DPIE in NSW. **Potentially suitable, depending on the strength of the relationship between the TEC and the associated PCT/s**

Rehabilitation Type	Measure	Assessment of Suitability as Performance Measure
	Similarity to reference sites	It may be possible to assess the similarity of mature reference sites to listed TECs compared to rehabilitation sites, particularly if the TEC in question occurs over a large area and an understanding of the local species composition of the TEC is required. If there is marked variation across its range, it may be more appropriate to compare rehabilitation sites to local reference sites as a proxy for the TEC. However, this requires that the local reference sites are confirmed as representative of the TEC using an appropriate method. The presence of a similar proportion of TEC characteristic species at rehabilitation and local reference sites may be a suitable approach to determine whether the rehabilitation is recognisable as the TEC in some circumstances. **Potentially suitable**
TEC (EPBC Act)	Direct application of diagnostic and condition criteria provided in Approved Conservation Advice	The Approved Conservation Advice for a TEC generally specifies the diagnostic and condition criteria that are required to be met, however the inclusion of particular flora species may not be provided. Direct application of the diagnostic and condition criteria is the most appropriate method for determining the compositional recognisability of a site as an EPBC Act-listed TEC, where this information is provided. **Suitable, with appropriate consideration given to the species composition where the Approved Conservation Advice does not provide specific detail**
Structure Measures		
PCT	BAM structure score against benchmark	Interrogation of the data collected for the project has shown that this single measure can fail to highlight deficiencies in the cover of one growth form, where another has high cover, due to the weightings allocated to certain growth forms, based on vegetation class. For this reason, consideration of the representation of key growth forms is considered more important to the assessment of structural recognisability than the use of the BAM structure score in isolation. **Not suitable as a stand-alone measure**
	Cover of specific growth forms (TG, SG, GG, FG, OG, EG)	The foliage cover of each key growth form can be compared to suitable reference sites or appropriate benchmark values. For consistency with the BAM, priority for assessment should be given to growth forms that are weighted more heavily according to vegetation class (i.e. those with the highest foliage cover). For example, the 'Grass and Grass-like' (GG) growth form is given the highest weighting in Coastal Grassy Woodland class of PCTs, followed by 'Trees' (TG), 'Shrubs' (SG) and 'Forbs' (FG). 'Other' (OG) and 'Ferns' (EG) are given very low, or no, dynamic weighting as they contribute little to the PCT in terms of species richness and cover. It is recommended that the cover of growth forms that are weighted more heavily for the target PCT be assessed individually, which for vegetation in the central Hunter Valley for example, would generally include 'Grass and Grass-like' (GG), 'Trees' (TG), 'Shrubs' (SG) and 'Forbs' (FG). **Suitable**

Rehabilitation Type	Measure	Assessment of Suitability as Performance Measure
	Tree abundance	It was observed that when tree abundance was significantly higher than reference sites, it had detrimental effects on understorey vegetation and that this would not necessarily be evident through the assessment of growth form cover (i.e. overall tree cover may be comparable to reference or benchmark values, but abundance may be significantly different). This measure can be effectively assessed by the BAM, however abundance of stems in each stem size class would need to be counted/estimated rather than presence/absence noted. **Suitable**
	Height of growth forms	The measurement of growth form height is not a requirement of the BAM. Height data are susceptible to observer bias and error, particularly for upper strata, often being estimated, rather than measured, in the field. Whilst height is a suitable measure of vegetation structure, we suggest that the use of tree abundance within DBH size classes is a measure of canopy development that can be collected more accurately and consistently across different observers. The heights of shrub and groundcover species can be collected more accurately than tree heights in advanced rehabilitation and may provide a useful measure of vegetation structure. However, a combination of attributes collected for the BAM are preferred, to maintain consistency in data collection and reduce the need for collection of additional attributes. **Suitable but not recommended for completion criteria**
TEC (BC Act)	Presence of strata in appropriate density, as described in the Final Determination	The TEC Final Determinations generally contain a description of the strata and/or growth forms present and an indication of their relative density, or at least an indication of the canopy structure, such as forest or open woodland. These terms are defined in Walker and Hopkins (1990) and should be referred to. The different strata or growth forms described in the Final Determination for the target TEC should be present at the rehabilitated site, in an appropriate density, or evidence of a trend toward this structure should be provided. **Suitable**
TEC (EPBC Act)	Direct application of diagnostic and condition criteria provided in Approved Conservation Advice	Due to the level of detail provided in each Approved Conservation Advice, and the requirement that diagnostic and condition criteria are met, direct application of the criteria is the most appropriate method for determining the structural recognisability of a site as an EPBC Act-listed TEC. **Suitable**
Function Measures		
All types	Litter cover	This measure was found to be a simple and cost-effective method which indicated a significant difference between reference sites and young rehabilitation sites and was therefore considered as a potentially suitable performance indicator by Oliver and Dorrough (2019). This measure is assessed using the BAM. **Suitable**

Rehabilitation Type	Measure	Assessment of Suitability as Performance Measure
	Coarse woody debris (CWD)	This measure is assessed using the BAM. Whilst its presence is not technically indicative of self-sustainability (as it could be emplaced after rehabilitation establishment), Oliver and Dorrough (pers. comm.) suggest that its presence is very important for the establishment of a self-sustaining ecological community and should therefore be considered. In terms of whether CWD should be used as a function performance measure, we argue that due to the difference in availability of suitable and salvageable CWD from the pre-mining landscape at each operation, it is not appropriate for use as a standard performance measure across all operations. However, we recommend its inclusion in rehabilitation establishment wherever possible due to its positive effect on ecosystem function, and the potential inclusion of CWD as a performance measure for specific operations on a case-by-case basis. **Suitable but not recommended as a standard performance measure across all operations**
	Exotic species cover	The presence of a high proportion of exotic species, particularly highly invasive species, will impact the ongoing persistence of native flora species. This measure is assessed using the BAM. **Suitable**
	Presence of second-generation individuals (recruitment)	The presence of plant recruitment is considered an important measure of the self-sustainability of the ecological community which is relatively easy to assess. However, assessing the presence of second (and subsequent) generations is different for short-lived species or those that may reproduce asexually, compared to trees or shrubs for which new individuals are more likely to be obvious. The scale at which recruitment is assessed should be considered, such as within a sampling plot compared to a larger unit of rehabilitation established at the same time (e.g. rehabilitation domain), and whether the presence of a single second-generation individual is sufficient or whether multiple individuals should be present. **Suitable**
	Number of plant species flowering/fruiting	This measure is most informative when the number or proportion of flowering/fruiting species in the floristic sampling plot is compared to that of reference sites sampled at a similar point in time. This assumes that individuals present at rehabilitation sites are of a suitable age to produce reproductive material and that a similar suite of species are present at the reference and rehabilitation sites and therefore are comparable. The presence of flowering/fruiting does not guarantee that recruitment will occur, however the absence or very low occurrence of fruiting will limit the potential for recruitment, and it may indicate deficiencies in soil health. **Suitable but not recommended for completion criteria; more informative as a component of regular monitoring**
	Number of native plant species	This attribute is considered as part of compositional recognisability and is not strictly a measure of function, though it is a potential indictor of self-sustainability, as greater species richness increases the potential for ecosystem resilience. **Suitable but not recommended for completion criteria**

Rehabilitation Type	Measure	Assessment of Suitability as Performance Measure
	Total organic carbon	This measure is a relatively straightforward measure of soil chemistry and substrate regeneration and was identified as a potential indicator by Oliver and Dorrough (2019) due to its high benefit and low cost. **Suitable**
	Total microbial biomass	This measure of biological soil regeneration was identified as a potential indicator by Oliver and Dorrough (2019) due to its high benefit and low cost. However, this is a measure that has not yet been included in mine rehabilitation monitoring in the Hunter Valley and mine site representatives have indicated that further evidence of its value to rehabilitation monitoring programmes would be required before large-scale uptake of this method is likely to occur. **Suitable pending further evidence**
	Fungal:Bacterial biomass	This measure of biological soil regeneration was identified as a potential indicator by Oliver and Dorrough (2019) due to its high benefit and low cost. However, this is a measure that has not yet been included in mine rehabilitation monitoring in the Hunter Valley and mine site representatives have indicated that further evidence of its value to rehabilitation monitoring programmes would be required before large-scale uptake of this method is likely to occur. **Suitable pending further evidence**
	Nutrient cycling index	This attribute is one of three indices measured using LFA. LFA has been widely used in mine rehabilitation monitoring programmes, however some mine sites have recently opted for alternative monitoring approaches as a result of ongoing debate about its efficacy in temperate woodland environments. Whilst this method is relatively easy and repeatable to collect, its use is not recommended due to the time required to collect and the identification of only one of the three indices as potentially suitable by Oliver and Dorrough (2019). **Suitable but not recommended for completion criteria**

8.2 Demonstration of Recognisability and Self-sustainability

Determining the level at which rehabilitation demonstrates recognisability and self-sustainability, and the values that should be used as completion criteria, are not straightforward. Entities that form ecological communities exist on a continuum, a concept that is recognised in the description of TECs listed under the BC Act which are intentionally lacking in prescriptive detail so that examples of the community are not inadvertently excluded through arbitrariness. The inherent natural variation in the composition, structure, and function of ecological communities, as well as the varying degrees of disturbance that they have been subjected to, leads to challenges in the development of suitable completion criteria for ecological mine rehabilitation. In an ideal world, completion criteria would not be so high that they are unrealistic and unachievable, and not so low that poor condition and low-quality rehabilitation sites meet or surpass them.

In the development of proposed completion criteria and consultation with industry and government authorities (DPIE and NSW Resources Regulator), consideration has been given to the thresholds that are considered most appropriate. The first iteration of thresholds included discussion of the difference between using the observed range of reference sites for a given attribute, compared to the IQR for that attribute, as the range to be achieved at rehabilitation sites. The IQR sets a more scientifically robust target that minimises the risk of sites that have not achieved, or that are not trending towards, appropriate levels of recognisability and self-sustainability meeting the completion criteria and being certified for relinquishment, however, use of the IQR as a threshold value requires a rehabilitation site value to be closer to the median value of reference sites than 50% of the reference sites themselves. On the other hand, if we accept the assumption that appropriately selected reference sites are recognisable and self-sustaining, it stands to reason that achieving a value that falls within the range exhibited by reference sites would be suitable. However, the benchmark may be set too high or low and inadvertently include atypical values (i.e. anomalies or outliers). An alternative threshold suggested by Oliver et al. (unpublished manuscript) which has been adopted in the draft Ancillary Rules for Mine Site Ecological Rehabilitation (DPIE 2021a), includes the use of the 10^{th} and the 90^{th} percentiles of reference site values for a given attribute. This results in a wider 'acceptable' range for rehabilitation sites to be assessed as having achieved recognisability or self-sustainability, while removing the influence of outliers or anomalies.

Completion criteria that do not rely on direct comparison to specific reference sites may be more appropriate for some attributes. For example, the development of thresholds used to assess the recognisability of rehabilitated sites as a PCT, as undertaken using the PCT Assignment Tool and distance to PCT centroid values (refer to **Section 5.5.2.1**), could provide a suitable value to be measured against. However, attributes which are shown to fluctuate over time, such as foliage cover of plant species during wet and dry weather periods, are likely to be better suited to direct comparison to reference sites monitored concurrently with rehabilitation sites. Static values for attributes of this type, such as the BAM structure benchmarks which approximate the 75^{th} percentile of all observations within a vegetation class (Oliver et al. 2019), are not as accurate as PCT-level benchmarks derived from local reference sites (**Section 6.6**).

Consideration also needs to be given as to whether it is reasonable to expect a rehabilitated site to achieve all stated completion criteria. The premise of the completion criteria is that they set the level that must be achieved for each measured attribute for that site to be considered 'complete' and subsequently relinquished. Failure to meet or exceed a completion criterion would indicate that additional time or management intervention is required, depending on the attribute. However, Oliver and Dorrough (2019) demonstrated that a site may not perform well for every functional attribute measured, but it can still be assessed as meeting, or approaching, self-sustainability, because overall its performance is strong. This approach holds promise for the practical assessment of self-sustainability.

8.3 Trajectory Toward Recognisability and Self-sustainability

As discussed in **Section 6.7**, the data available for this project was insufficient to determine whether mine rehabilitation follows clear progress toward recognisability or self-sustainability that could then inform the development of successional stage criteria. Successional stage criteria are useful in that they could potentially assist with the early identification of attributes unlikely to be on a trajectory toward a given completion criterion, and potentially allow for early use of mitigation measures to resolve issues and increase the likelihood that completion criteria will be met in the desired timeframe.

In the absence of successional stage criteria, performance guidance was developed to assist with the identification of sites that are unlikely to achieve completion criteria on the basis of their trajectory and where active management may be required. For example, research indicates that the flora species composition in rehabilitation is largely determined at establishment, and not through species immigration, therefore, if completion criteria that relate to composition are not being met early, then achievement of this goal is unlikely without intervention. The progress of rehabilitation attributes toward completion criteria have been broadly considered at three periods in time post-establishment, being early (approximately 5 years), medium-term (approximately 10 years) and longer-term (approximately 15 years).

8.4 Monitoring Progress Toward Recognisability and Self-sustainability

Regular monitoring is critical for assessing the progress of rehabilitation attributes toward completion criteria and identifying when management intervention is required. The monitoring of progress is particularly important for those attributes that may not reach the target or end goal until after certification for relinquishment is being sought.

The following principles are recommended when undertaking rehabilitation monitoring:

1. Monitoring design must be informed by the rehabilitation objectives, performance indicators and completion criteria

The main purpose of monitoring is to determine whether the specific rehabilitation attributes (performance indicators) are progressing toward those required for relinquishment (completion criteria) and to identify any management issues that would negatively impact the composition, structure or function of the rehabilitation and require specific intervention. Measurement should be undertaken in a manner that allows an assessment to be made as to whether the completion criteria have been achieved.

Where a completion criterion is unlikely to be met until after relinquishment is being sought, the capacity to measure the changes in the attribute being measured, over time, is essential in demonstrating that a trajectory toward this value is being maintained and likely successful completion can be predicted.

2. Use of appropriate reference sites

Reference, or analogue, sites are generally the best point of reference for comparison to rehabilitation sites and measuring progress toward completion criteria. In addition to acting as a benchmark for rehabilitation attributes, the sampling of reference sites in conjunction with rehabilitation sites enables the response of reference sites to different climatic conditions and stochastic events, as well as seasonal and other temporal changes, to be measured and recorded. The collection of reference site and rehabilitation site data in the same monitoring period increases the capacity to determine whether the variation observed at rehabilitation sites can be attributed to natural events and fluctuations or whether the response of rehabilitation sites is markedly different to reference sites and that management intervention is required.

Suitable reference sites are those that represent good quality and mature examples of the target community, where evidence of disturbance or modification, including vegetation clearing, timber harvesting, weed infestation, grazing, fire, erosion, dieback or disease, is absent or minimal in nature. A sufficient number of reference sites should be used for each target vegetation type being monitored to capture the variation in the attributes and determine the typical range for values being measured. Oliver et al. (unpublished manuscript) conducted a *post hoc* evaluation using the data from this study and found that 8-10 reference sites were required for the 10^{th} and 90^{th} percentiles (the “acceptable range of variation”) of TOC% and Leaf C:N values to stabilise, while the 90^{th} percentile for seed mass did not stabilise until approximately 15 reference sites were assessed. For small sample sizes (≤5 sites) Oliver et al. (unpublished manuscript) observed that the “acceptable range of variation” was underestimated, meaning that there was a narrower target range for rehabilitation sites to be assessed as self-sustaining to the same extent as reference sites when low reference site replication was used. Our study suggests that variance in floristic composition does not begin to stabilise until a minimum of six reference sites are surveyed.

Reference sites are no longer considered suitable in the event that exotic species, particularly high threat exotics (HTEs) or listed ‘priority’ weeds for the region, become established, proliferate and/or impact the persistence of native flora species. This is an important factor, as the foliage cover of HTEs is recommended as a performance indicator for assessing the function of rehabilitation (see **Table 8.1**).

The proposed HTE threshold value for completion criteria (**Table 8.4**) only uses an upper threshold, as any level of HTE cover is undesirable. As the reference sites should exhibit lower weed cover than would normally be observed for the community, being 'best-on-offer' examples, we propose the use of the maximum observed value for this attribute, as opposed to the 90th percentile. Weed cover should be used as a key attribute guiding the selection of suitable reference sites, in conjunction with native species and structural diversity, which can be readily assessed by a suitably qualified and experienced person (e.g. ecologist or botanist).

Guidance on selecting 'best-on-offer' reference sites for the purposes of the BAM is provided in the BAM manual (DPIE 2020a), however it is acknowledged that it may not be possible to meet all the stated recommendations when sampling in highly disturbed and modified landscapes.

3. Use of standard sampling techniques, where appropriate

The capacity to compare the progress and performance of rehabilitation over time and across sites is impeded by the utilisation of various data collection methods. As discussed in Principle 1 above, monitoring design, and thereby sampling techniques, should be guided by the performance indicators and completion criteria. The use of industry standard sampling methods, which are proven to collect sufficient data to understand the composition, structure and/or function should be prioritised. For example, the use of standard 400 m^2 sampling plots for the collection of floristic data has been used widely in NSW historically and has been incorporated into the BAM. The very large number of plots that have been sampled in a relatively consistent manner over a long period of time, and which can be accessed through BioNet, potentially increases the number of reference sites that can be considered in assessing the range of variation present in remnant stands of the target community. The use of standard methods in current monitoring programmes could also potentially allow for the sharing of data between mine sites that are establishing the same target communities in their rehabilitation. The use of unique sampling techniques that are designed for a single site limit the potential for comparable data to be obtained from other sources which may increase understanding of variation present at both reference and rehabilitation sites.

4. Targeted analysis and reporting of results

Further to Principle 1 above, the analysis and reporting of monitoring results should be focused on the rehabilitation objectives, completion criteria and performance indicators. An adequate level of analysis should be undertaken to determine whether measured attributes have met, or are trending toward, completion criteria. For those sites that are not trending toward completion criteria, an assessment of whether management intervention is required should be clearly identified.

5. Outcomes trigger management intervention, where required

As discussed in Principle 4 above, where sites are identified as not trending toward completion criteria, an assessment of whether management intervention is required should be clearly identified. A Trigger, Action, Response Plan (TARP) should be developed for ecological rehabilitation, to facilitate the early identification of trends that are likely to lead to underperformance or failure. Consideration should be given to the age of the rehabilitation and whether the attribute(s) in question change very little over time. Research has shown that the species present in rehabilitation in the long-term are mostly determined by what was seeded or planted at the time of establishment, and therefore, if monitoring five years post-establishment identifies that species richness is likely to be inadequate to meet completion criteria, this should trigger further investigation and potentially management intervention. Likewise, the lack of persistence of a substantial number of flora species that were once present, particularly groundcover species, should trigger an investigation of inhibitory factors, such as soil issues, pests and diseases. However, for certain attributes that take time to develop or which may fluctuate year to year, such as some function measures, it may be prudent to assess the results of several years of monitoring data prior to management intervention being triggered.

8.5 Proposed Rehabilitation Objectives, Completion Criteria and Performance Indicators

Proposed rehabilitation objectives, completion criteria and performance indicators for ecological mine rehabilitation were developed using the results of investigations detailed in **Part Two** of this report and based on the assessment of indicator suitability provided **Table 8.1**.

The completion criteria relating to rehabilitation *composition* provided in **Table 8.2** were developed with consideration of the target community, such as a PCT or TEC. A single completion criterion for PCT compositional recognisability was developed with the assumption that the PCT Assignment Tool developed by DPIE will be publicly available in the near future and, at the time of writing, it is expected to be released in early 2022. For assessing recognisability of a TEC, it was assumed that the most suitable completion criterion would be developed for each specific TEC on a case-by-case basis, with reference to the information/data available for the specific TEC, which can vary considerably. Within this in mind, two completion criteria are present in **Table 8.2** to assess whether the native flora species present are characteristic of the target TEC under the NSW legislation, however it is expected that only the most suitable criterion will be used. The most appropriate completion criterion to use in a specific situation should be informed by the relationship of the target TEC to PCT, as well as the information contained within the relevant Final Determination.

As discussed in **Section 1.2**, a restored ecosystem should demonstrate a trend towards compositional and structural recognisability and effective functionality while also demonstrating evidence of self-sustainability, relative to a reference ecosystem of the same category/type. The results of this study demonstrate that sites that appear to be performing well in terms of recognisability and self-sustainability, may not perform well for every measured attribute. This raises the question of whether it is unrealistic to expect a rehabilitation site to meet the desired target for every attribute that is assessed in completion criteria. We suggest that the completion criteria are used as a *guide for decision making*, rather than a strict method to 'pass' or ‘fail’ and that evidence of trajectories toward the end goal over time also be considered. Using this approach, ongoing rehabilitation monitoring using consistently applied methods is critical to demonstrating rehabilitation success and achieving relinquishment, in addition to its value in identifying when management actions are necessary to address deficiencies in compositional, structural or functional attributes.

It is important to note that the completion criteria provided in **Table 8.2** to **Table 8.4** were developed with a focus on the ecological communities present in the NSW Hunter Valley, with the intention that they would also apply in principle to ecological communities beyond this region, however in some instances different approaches or rehabilitation targets may need to be considered.

It is possible that some ecological mine rehabilitation may be intended to represent another type of target vegetation community that is not a PCT or TEC, such as rehabilitation established outside of NSW. Consideration was given to a general approach to how recognisability may be assessed in this situation. With regard to compositional recognisability, analyses undertaken as part of this study demonstrate that identifying the presence of a suitable number of native species at rehabilitation sites that also occur at reference sites can provide similar results to recording the presence of a suitable number of species characteristic of the PCT (as listed in PCT profiles) (see **Section 6.4.3**). Further investigations are likely required to determine the number of species required to confirm recognisability, however the use of reference sites and comparison of species composition is recommended where the target community for mine rehabilitation is not a PCT, TEC or another community type described as part of a classification system. In terms of structural recognisability, data typically collected as part of floristic sampling can be used, including foliage cover of individual species or their relative abundance using a cover-abundance scale. The relative space occupied by each species can then be grouped with other species according to growth form (trees, shrubs, etc), height range or stratum. Whichever attributes are selected for inclusion in completion criteria, it is imperative that they adequately address rehabilitation objectives and performance measures and that the approach is consistently applied across reference and rehabilitation sites, and over successive monitoring periods.

Table 8.2 Proposed Rehabilitation Objectives, Performance Indicators, Completion Criteria and Performance Guidance for the Vegetation Composition of Ecological Mine Rehabilitation

Rehabilitation Objective	Performance Indicator	Completion Criterion	Example Justification/validation methods	Performance Guidance
1. Composition Objectives				
1a: The vegetation **composition** of the rehabilitation is **recognisable** as the target **PCT** contained within the NSW VIS.	Native plant species are characteristic of the target PCT.	Using the PCT Assignment Tool, the distance to centroid is either *very strongly*[1] or *strongly*[1] associated with the PCT.	Use of BAM where all flora species present in a 20 x 20 m plot are recorded, with foliage cover and abundance of each species. PCT Assignment Tool provides a direct measure of the distance of a site to the centroid of PCT sites which have been used in its delineation.	By 5 years post-establishment the distance to centroid is at least *strongly*[1] associated with the PCT.
1b: The vegetation **composition** of the rehabilitation is **recognisable** as the target **TEC** under NSW and/or Commonwealth legislation.	Native plant species are characteristic of the target TEC under **NSW** legislation.	Presence of a suitable number or proportion of the assemblage of species listed in TEC Final Determination. [*Recommend that the minimum value exhibited by the relevant TEC plots be used as the threshold value*][2].	Use of standard 20 x 20 m floristic sampling plot where all (native) flora species present are recorded. The proportion or number of native species listed in the TEC Final Determination recorded at the site is calculated and compared to threshold value.	This criterion should be met early (i.e. at 5 years post-establishment), otherwise it is unlikely to be met in the long-term without management intervention.

Rehabilitation Objective	Performance Indicator	Completion Criterion	Example Justification/validation methods	Performance Guidance
		The site is recognisable as a strongly associated PCT. [*Where a clear and justified relationship exists, the site is considered as recognisable as the TEC where recognisability as the relevant PCT is confirmed*].	Where a PCT is confirmed as being strongly aligned with a TEC, the site may be considered recognisable as that TEC where it is assessed as recognisable as the PCT.	This criterion should be met early (i.e. at 5 years post-establishment), otherwise it is unlikely to be met in the long-term.
	Native plant species are characteristic of the target TEC under **Commonwealth** legislation.	The diagnostic and condition criteria of the target TEC that relate to composition, as defined in Approved Conservation Advice (or equivalent document) which defines the TEC under the EPBC Act, are satisfied. [*Precise values to be determined for the specific target TEC*].	Floristic sampling undertaken in a manner that allows an assessment to be made as to whether the diagnostic and condition criteria are satisfied, as detailed in the Approved Conservation Advice or equivalent document which defines the TEC under then EPBC Act.	Criteria that relate to species presence/richness should be satisfied early (i.e. at 5 years post-establishment), otherwise they are unlikely to be met in the long-term.

[1] Based on the investigations described in **Section 6.4.1**, where 'very strongly' equates to a distance to PCT centroid ≤0.695 and 'strongly' equates to a distance to PCT centroid >0.695 and ≤0.736.

[2] Based on the outcome of this study, in which the complete datasets could not be obtained, the minimum value for *Central Hunter Grey Box – Ironbark Woodland EEC* plots was 26.3% (or 10 of 38 species) listed in the Final Determination; *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* plots was 15.9% (or 7 of 33 species) listed in the Final Determination; and *Hunter Valley Footslopes Slaty Gum Woodland VEC* plots was 37.9% (or 11 of 17 species) listed in the Final Determination.

Table 8.3 Proposed Rehabilitation Objectives, Performance Indicators, Completion Criteria and Performance Guidance for the Vegetation Structure of Ecological Mine Rehabilitation

Rehabilitation Objective	Performance Indicator	Completion Criterion	Example Justification/validation methods	Performance Guidance
2. Structure Objectives				
2a: The vegetation **structure** of the rehabilitation is **recognisable** as, or is trending towards, the target PCT in the NSW VIS.	Cover and abundance of plant growth forms are characteristic of, or are trending towards, the target PCT.	Tree stem abundance in the four smallest DBH size classes[1] is between the 10^{th} and 90^{th} percentile of values from suitable reference sites[2].	Counts of tree stems (for species allocated to Tree (TG) growth form under the BAM) are collected within the BAM plot.	Tree stem abundance is trending towards target range.
		Foliage cover of species allocated to the three dominant growth forms[3] is between the 10^{th} and 90^{th} percentile of values from suitable reference sites[2].	Use of BAM where all flora species present in a 20 x 20 m plot are recorded, along with foliage cover and abundance of each species.	Foliage cover of each dominant growth form is trending towards the target range.
2b: The vegetation **structure** of the rehabilitation is **recognisable** as, or is trending towards, the target TEC under NSW and/or Commonwealth legislation.	Diversity and cover of growth forms are characteristic of, or are trending towards, the target TEC under **NSW** legislation.	The growth forms present are consistent with, or are trending toward, those described in the Final Determination for the target TEC. [*Precise values to be determined for the specific target TEC*].	Standard floristic sampling where all flora species present in a 20 x 20 m plot are recorded, with foliage cover and abundance of each species. Each species is allocated to a growth form based on existing literature or classifications.	Species that characterise the typical structure of the TEC should be present in an appropriate abundance to be trending toward the mature structure of the TEC, as defined in Final Determination.

Rehabilitation Objective	Performance Indicator	Completion Criterion	Example Justification/validation methods	Performance Guidance
	Diversity and cover of plant growth forms are characteristic of, or are trending towards, the target TEC under **Commonwealth** legislation.	The diagnostic and condition criteria of the target TEC that relate to structure (e.g. formation, projected canopy cover), as defined in Approved Conservation Advice (or equivalent document) which defines the TEC under then EPBC Act, are satisfied. [*Precise values to be determined for the specific target TEC*].	Floristic sampling undertaken in a manner that allows an assessment to be made as to whether the diagnostic and condition criteria are satisfied, as detailed in the Approved Conservation Advice or equivalent document which defines the TEC under the EPBC Act.	Cover and abundance of species should be trending toward the mature structure of the TEC, as defined in Approved Conservation Advice (or equivalent document).

[1] The first four DBH sizes classes are: <5 cm, 5-9 cm, 10-19 cm and 20-29 cm.

[2] Suitable reference sites are those that represent good quality and mature examples of the target community, where evidence of disturbance or modification, including vegetation clearing, timber harvesting, weed infestation, grazing, fire, erosion, dieback or disease, is absent or minimal in nature. Published information may also be used, where appropriate. Refer to **Section 8.4** for more information.

[3] The three growth forms with the highest average foliage cover values at suitable reference sites.

Table 8.4 Proposed Rehabilitation Objectives, Performance Indicators, Completion Criteria and Performance Guidance for Function of Ecological Mine Rehabilitation

Rehabilitation Objective	Performance Indicator	Completion Criterion	Example Justification/validation methods	Performance Guidance
3. Function Objectives				
3: Levels of ecosystem **function** have been established that demonstrate the rehabilitation is **self-sustainable**, or is trending towards self-sustainability.	Evidence of plant reproduction and regeneration is present.	The number of second generation trees are ≥10th percentile of values recorded at suitable reference sites[1].	Count of second-generation trees within the BAM plot or belt transect of defined area.	No performance guidance. The presence of second-generation trees may not be evident for many years post-establishment.
	Competition from exotic species is low.	Cover of 'high threat exotic' (HTE) species is less than or equal to the maximum value observed at suitable reference sites[1] (which by definition should have lower than average weed cover for the PCT).	Data collected in accordance with BAM. Sum foliage cover of species categorised as 'high threat exotic' under the BAM.	Cover of HTE species are declining towards target value.
	Indicators of nutrient cycling are suitable for sustaining the target plant community type.	Litter cover is between the 10th and 90th percentile of values from suitable reference sites[1], or an ongoing trend toward this target range is observed.	Data collected in accordance with BAM.	Litter cover is increasing towards target value.
	Soil health is suitable, or is trending towards being suitable.	Total organic carbon is between the 10th and 90th percentile of values from suitable reference sites[1], or an ongoing trend toward this target range is evident through monitoring data.	Soil samples are collected as pooled random samples and total organic carbon is measured using appropriate techniques (e.g. MIR, LECO).	Total organic carbon is increasing towards target value.

Rehabilitation Objective	Performance Indicator	Completion Criterion	Example Justification/validation methods	Performance Guidance
		Total microbial biomass is between the 10th and 90th percentile of values from suitable reference sites[1], or an ongoing trend toward this target range is observed.	Soil samples are collected as pooled random samples and microbial biomass is measured using PLFA as indicators.	Total microbial biomass is increasing towards target value.
		Fungal:bacterial biomass is between the 10th and 90th percentile of values from suitable reference sites[1], or an ongoing trend toward this target range is observed.	Soil samples are collected as pooled random samples and fungal:bacterial biomass is measured using PLFA as indicators.	Fungal:bacterial biomass is decreasing toward target value.

[1] Suitable reference sites are those that represent good quality and mature examples of the target community, where evidence of disturbance or modification, including vegetation clearing, timber harvesting, weed infestation, grazing, fire, erosion, dieback or disease, is absent or minimal in nature. Published information may also be used, where appropriate. Refer to **Section 8.4** for more information.

9.0 Conclusions

The following conclusions are made, based on outcomes of the work undertaken during this study, including our analysis of the outcomes of the work of Oliver and Dorrough (2019). The specific findings of Oliver and Dorrough (2019) are available in **Appendix 1**.

1. Mine rehabilitation can support ecological communities which are recognisable as three different PCTs in the Hunter Valley of NSW which occur in proximity to mined areas. One third of rehabilitation sites recorded distance to PCT centroid values below the 0.695 threshold value used in the draft PCT Assignment Tool, meaning that these sites are *very strongly* aligned to, or recognisable as, the allocated PCT.

2. The analysis of variation amongst 'secondary' ENSW Classification plots to develop three levels of compositional recognisability above the 0.695 threshold (*strong, moderate* and *weak*) shows promise as an approach to assessing the recognisability of ecological mine rehabilitation. 'Secondary' ENSW Classification plots are those which were assessed by DPIE as recognisable as a specific PCT, but which displayed lower species richness, atypical cover scores or potential disturbance effects (DPIE 2019b). Using these thresholds, the compositional recognisability of 20% of rehabilitation sites were assessed as *strongly recognisable*, 18% were *moderately recognisable* and 29% were *weakly* recognisable.

3. The outputs of the PCT Assignment Tool are regarded as very useful measures for compositional recognisability at the PCT level. Its use is therefore recommended for inclusion in ecological mine rehabilitation completion criteria in NSW, as based on current information, it is expected to be a free web-based tool publicly available from early 2022. Based on the experience of the authors, the PCT Assignment Tool is expected to be cost-effective; outputs are easily interpreted; it utilises data from all plots allocated to a PCT from the entire ENSW PCT Classification; and it is understood that there will be capacity for new floristic plots to be added to the ENSW PCT Classification dataset, meaning that any compositional changes to the PCTs occurring over time, such as those due to changing climatic conditions, may be incorporated in the dataset.

4. There is a strong negative correlation between native flora species richness and the distance to PCT centroid (using the draft PCT Assignment Tool), meaning that sites generally become more recognisable as a PCT with increasing native species richness. However, all mine sites where rehabilitation data were collected exhibited variation in the level of PCT recognisability recorded and there was no evidence that the recognisability of rehabilitation as a target PCT increases with time since establishment.

5. The class level benchmarks which are applied as part of the BAM, including 'dry' benchmarks which are applicable during drought conditions, were found to be less suitable as potential performance measures across all three target PCTs, compared to PCT-level benchmarks, despite the influence of low rainfall on the data collected for this study.

6. The results of the floristic compositional assessment against Hunter Valley vegetation types are promising in relation to the likelihood of establishing recognisable ecological rehabilitation elsewhere in temperate woodlands in Australia.

7. The results of the structural recognisability analyses undertaken for this study indicate that ecological mine rehabilitation can achieve vegetation structure comparable to intact vegetation when each measured attribute (% foliage cover of native grass and grass-like, forb, shrub and tree growth forms; and tree stem abundance within the five smallest DBH size classes) is assessed individually. However, no rehabilitation sites were assessed as *strongly* or *very strongly* recognisable across all nine attributes.

8. Generally, the rehabilitation sites were within range, or higher, than reference sites for stem counts, whereas the foliage cover of tree species was found to be lower than at the reference sites. The results suggest that both foliage cover and tree stem abundance are required to adequately assess structural recognisability of ecological mine rehabilitation for woodland communities compared to reference sites.

9. A total of 18 (40%) of rehabilitation sites sampled were assessed as recognisable as the *Central Hunter Valley Eucalypt Forest and Woodland CEEC* listed under the EPBC Act. These sites satisfied the key diagnostic characteristics and condition thresholds stated in the Approved Conservation Advice (TSSC 2015).

10. Management intervention could increase the recognisability of rehabilitation sites as the *Central Hunter Valley Eucalypt Forest and Woodland CEEC* with the selective removal of broad-leaved ironbark (*Eucalyptus fibrosa*), where all other diagnostic characteristics and condition thresholds are met.

11. Assessing the recognisability of the rehabilitation sites as TECs listed under the BC Act is not as straightforward as the CEEC listed under the EPBC Act, the latter being subject to more prescriptive diagnostic criteria and condition thresholds. Analyses of recognisability were affected by unavailability of data from plots that are a true representation of *Hunter Valley Footslopes Slaty Gum Woodland VEC*, according to the Final Determination, and variation in the structure of this community (shrubby vs. non-shrubby). However, most of the reference and rehabilitation sites allocated to PCTs 3315 and 3431 were assessed as being recognisable as *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* and *Central Hunter Grey Box – Ironbark Woodland EEC* respectively.

12. The self-sustainability analyses identified two rehabilitation sites (Sites 65 and 66) (both 21 years old) that were likely to be self-sustaining and a third site (Site 76) (12 years old) was assessed as approaching self-sustainability (Oliver and Dorrough 2019). All three sites were assessed as being very *strongly* recognisable as their target PCT (3315) and recognisable as the *Central Hunter Ironbark – Spotted Gum – Grey Box Forest EEC* listed under the BC Act. Two sites (65 and 66) were also assessed as consistent with the *Central Hunter Valley Eucalypt Forest and Woodland CEEC* and while Site 76 was not recognisable due to the co-dominance of a non-characteristic eucalypt. All three sites did not perform well for tree foliage cover and abundance of trees in various DBH size classes. Site 76 recorded v*ery strong* or *strong* levels of function, compared to values recorded at reference sites, for all five assessed function attributes, while Sites 65 and 66 recorded variable levels of function.

13. Variables related to BAM function (litter cover) and total mass of litter fractions were ranked the highest in importance for discriminating self-sustaining (reference sites) from not self-sustaining (rehabilitation less than 10 years old), and these variables were highly correlated (rs = 0.73) (Oliver and Dorrough 2019). The cost benefit analysis showed that variables related to BAM function (litter cover, coarse woody debris) and litter fractions have a high benefit and low cost, in addition to variables generated by PLFA (microbial biomass, fungal:bacterial biomass), MIR or LECO (total organic carbon) and LFA (nutrient, stability and infiltration indices) (Oliver and Dorrough 2019).

14. Nine variables were identified by Oliver and Dorrough (2019) as potential performance indicators for measuring self-sustainability at rehabilitation sites. These nine variables include those that revealed significant differences between reference sites and rehabilitation sites less than 10 years old, are commonly used and are shown to provide higher benefit and lower cost. A tenth variable, being the presence of second generations canopy trees, was noted by Oliver and Dorrough (2019) as likely to have been included in this list had there not been miscommunication around data availability. These nine variables were:

    a) litter cover (BAM function)

    b) coarse woody debris (BAM function)

c) exotic species cover (BAM function)

d) number of native plant species flowering/fruiting (addition to BAM floristics)

e) total organic carbon (MIR or LECO)

f) fungal:bacterial biomass (PLFA)

g) total microbial biomass (PLFA)

h) number of native plant species (BAM floristics)

i) nutrient cycling index (LFA).

15. The efficacy of LFA has been questioned in recent years, resulting in reduced utilisation of this method as part of rehabilitation monitoring programmes in the NSW Hunter Valley. However, the results presented by Oliver and Dorrough (2019) suggest that the nutrient cycling index is successful in distinguishing between young rehabilitation sites and reference sites, as well as being cost-effective.

16. A separate assessment of suitability of function measures as rehabilitation performances measures was undertaken by Umwelt as part of this study. Litter cover, exotic species cover, presence of second-generation individuals (recruitment), total organic carbon, total microbial biomass and fungal:bacterial biomass were assessed as suitable and recommended for inclusion in completion criteria. CWD, number of plant species flowering/fruiting, number of native plant species and the LFA nutrient cycling index were assessed as suitable but were not recommended for completion criteria. CWD was not recommended due to the variability of availability of this resource across different mining operations; plant flowering and fruiting was not recommended as presence of second-generation individuals was considered a more appropriate measure of recruitment; native plant species richness was not recommended due to the overlap with compositional recognisability; and the LFA nutrient cycling was not recommended as the two other LFA indices were assessed as less informative by Oliver and Dorrough (2019) and due to the time required to collect all LFA attributes at a site.

17. Oliver and Dorrough (2019) note that consideration of multiple variables must be undertaken when determining the self-sustainability of a site, however they also conclude that rehabilitation sites can be regarded as self-sustaining without performing well for all variables. Management intervention could improve the performance of rehabilitation sites with regard to self-sustainability assessments, including maximising native species richness, the selective removal of species that are not native to the state in which the rehabilitation is established, thereby reducing exotic species cover, and early emplacement of coarse woody debris which promotes increased microbial activity, among other ecological functions.

18. Based on the results of ecological monitoring of four Hunter Valley open cut coal mines, mine rehabilitation has been shown to support habitat for a range of threatened fauna species, including mammals and birds. This study did not aim to investigate this subject beyond identifying the presence of threatened fauna species in mine rehabilitation, however, research into the extent of rehabilitation use by threatened fauna species and the role of habitat augmentation, such as installed nest boxes and hollow-bearing stag trees, would contribute to a greater understanding of faunal use in rehabilitation and by extension, the self-sustainability of ecological mine rehabilitation.

19. Due to insufficient data to perform longitudinal and space-for-time substitution analysis, successional stage criteria could not be developed as part of this project.

20. Ecological rehabilitation objectives, performance indicators, completion criteria and performance guidance have been developed to guide the successful establishment of recognisable and self-sustaining ecological rehabilitation of PCTs. A single completion criterion was developed to assess composition, based on the assumption that the PCT Assignment Tool will be publicly available in the near future and provide the most cost-effective measure of similarity to the PCTs from the forthcoming ENSW PCT Classification. Two proposed completion criteria have been developed for PCT structure, and six criteria for function. It is recommended that completion criteria be used as a guide to assessing rehabilitation success in conjunction with performance trends over time.

21. Ecological rehabilitation objectives, performance indicators, completion criteria and performance guidance have also been developed to guide the successful establishment of recognisable and self-sustaining ecological rehabilitation of three BC Act listed TECs and one EPBC Act listed TEC. These draw upon analyses against the specific criteria documented in the Final Determinations and Approved Conservation Advice for these TECs. The approach established here could be applied, in principle, to other EPBC Act and BC Act listed TECs elsewhere in NSW, and potentially other EPBC Act listed TECs in other jurisdictions.

10.0 Recommendations

To maximise the possibility of achieving recognisable and self-sustaining ecological communities in mine rehabilitation, the following recommendations are made:

1. Seed mixes and plantings should include a very high proportion of native flora species known to occur in the target community. Previous studies indicate that species diversity is unlikely to increase significantly over time after rehabilitation establishment and prior to closure, and that the resulting composition is largely determined at the time of establishment.

2. Emplacement of coarse woody debris at the ecosystem establishment phase will assist with self-sustainability in the long-term, as it provides habitat for invertebrates and small fauna species and assists with the retention of resources, including soil, litter and seed material. We recommend the inclusion of CWD in completion criteria for operations clearing woody vegetation containing CWD and where salvage of this material is achievable.

3. Adequate funding and resources should be allocated to control of exotic species, particularly HTEs, that have potential to significantly modify the composition and structure of vegetation and reduce the self-sustaining capacity of rehabilitation.

4. Where the target vegetation community is a TEC with stated contra-indicative species, these species should be removed from seed mixes and plantings. Contra-indicative species should be selectively removed from established rehabilitation, with the resulting CWD potentially retained on the site to contribute to nutrient cycling and retention, as appropriate.

5. Implementation of monitoring programmes that are informed by the relevant rehabilitation objectives, performance indicators and completion criteria, with consideration given to the age of the rehabilitation (e.g. monitoring methods employed at initial establishment may differ from those used for more advanced rehabilitation).

6. Establishment of a sufficient number of suitable reference sites as part of the monitoring programmes. Oliver et al. (draft manuscript) suggest that 8-10 reference sites are required to reduce the variation in the 10^{th} and 90^{th} percentile values for function attributes (TOC% and Leaf C:N), and that a sample size of ≤5 reference sites results in higher 10^{th} percentile values and lower 90^{th} percentile values, resulting in a smaller “acceptable range of variation”. Regardless of the number of reference sites sampled, they should represent good quality and mature examples of the target community, where evidence of disturbance or modification, including vegetation clearing, timber harvesting, weed infestation, grazing, fire, erosion, dieback or disease, is absent or minimal in nature.

7. The outcomes of monitoring should trigger management intervention, where and as required.

It is also recommended that further investigations be undertaken to:

8. Determine whether there are clear trends in rehabilitation composition, structure or functional attributes over time that would inform the development of benchmark successional stage criteria.

9. Further consideration of the global threshold of 0.695 as the appropriate threshold for *very strong* compositional recognisability, compared with a PCT-level threshold, such as median distance to centroid value.

10. Further consideration of Oliver et al. (unpublished manuscript) in relation to the optimum number of reference sites for assessing the function of rehabilitation sites, as well as possible replication of this approach for structural attributes.
11. Further consideration of the inclusion of total microbial biomass and fungal:bacterial biomass as suitable attributes for inclusion in completion criteria for ecological mine rehabilitation, as they have not been previously used in mine rehabilitation performance measures, and consequently there is some uncertainty within the mining industry regarding their relevance and value.
12. Determine the maximum value of high threat exotic (HTE) cover which should be used as a completion criterion threshold relating to the performance indicator “competition from exotic species is low”, in acknowledgement of exotic species cover being one of the main management issues associated with rehabilitation establishment, and the current knowledge gap regarding the point at which exotic species cover significantly impacts the composition, structure and function of native woodland communities.
13. Assess how key threats could be incorporated into rehabilitation objectives and completion criteria in such a manner that they can be quantitatively and repeatedly assessed.

Lastly, we recommend that the outcomes of this study be considered in light of any PCT and TEC classification work currently being undertaken by DPIE that relates to eastern NSW.

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APPENDIX 1

Evaluation of potential self-sustainability performance indicators for rehabilitated vegetation on mined land (Oliver and Dorrough 2019)

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Evaluation of potential self-sustainability performance indicators for rehabilitated vegetation on mined land

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INTRODUCTION

Assessment of self-sustainability

In this study we focus on measuring the success of terrestrial ecosystem rehabilitation on mined land against the 9th attribute of restored ecosystems from the SER International Primer on Ecological Restoration (hereafter “SER Primer”; SER 2004) – “self-sustainability”. Measuring progress towards, and achievement of, ecosystem self-sustainability is arguably the most challenging SER Primer attribute, given the requirement to meet the following conditions: *A self-sustaining ecosystem has the potential to persist indefinitely under existing environmental conditions, but its composition, structure and function may fluctuate in response to periodic stress or disturbance, or may evolve as environmental conditions change* (adapted from SER 2004).

The SER Primer states for the attribute “self-sustainability”, that the “restored ecosystem is self-sustaining to the same degree as its reference ecosystem”. This statement sets the context for measuring success, being that rehabilitated ecosystems need to meet the capabilities of their reference ecosystem within the contemporary landscape. Within this context, reference ecosystems and sites need not be long-undisturbed, which for many ecosystems may be an unrealistic expectation (Hobbs and Norton 1996). Reference sites and ecosystems may therefore not be completely self-sustainable and may need a level of ongoing management.

This pragmatic position recognises that even in our conservation lands many ecosystems have chronic health issues resulting from a range of ongoing threats such as invasive exotic plants, animals and pathogens, modified fire or flood regimes, and climate change. Most of our terrestrial ecosystems may therefore require some level of on-going management intervention to maintain self-sustainability. Therefore, it is important to acknowledge that even when rehabilitation is deemed successful, some on-going management may be required to maintain self-sustainability, consistent with the level of management required to maintain self-sustainability in reference ecosystems.

We posit here that self-sustainability be predicted via assessment of indicators understood to be proxies for ecological processes that are likely to confer self-sustainability. And that the status of these indicators be compared to the range of variation in those same indicators recorded from a pool of reference sites that may have a range of disturbance histories but are still recognisable as being in the desirable stable state (Oliver et al. unpublished). Our study design, variables and analyses are based on this conceptual framework. The study was undertaken in parallel to Umwelt’s ACARP funded project (C27038) Self-sustaining Ecological Mine Rehabilitation that Achieves Recognised Ecological Communities.

METHODS

DATA COLLECTION AND LABORATORY ANALYSES

Sampling design

Within each 20 x 20 m floristic plot established by Umwelt, eight 25 cm x 25 cm quadrats were located. Four points A, B, C, D were located 5 m to the left and right of the midline at the 5 m and 15 m positions (Figure 1). The four Tree quadrats (labelled T) were placed adjacent to the base of the tree (diameter at breast height, DBH > 5 cm) nearest to each point (A, B, C, D). Tree quadrats were placed on the side of the tree base opposite or farthest from the midline (see Figure 1). Open quadrats (labelled O) were placed either side of the midline at the 5 m and 15 m positions where tree canopy cover was lowest or approximately equidistant from the two nearest trees (> 5 cm DBH, see Figure 1).

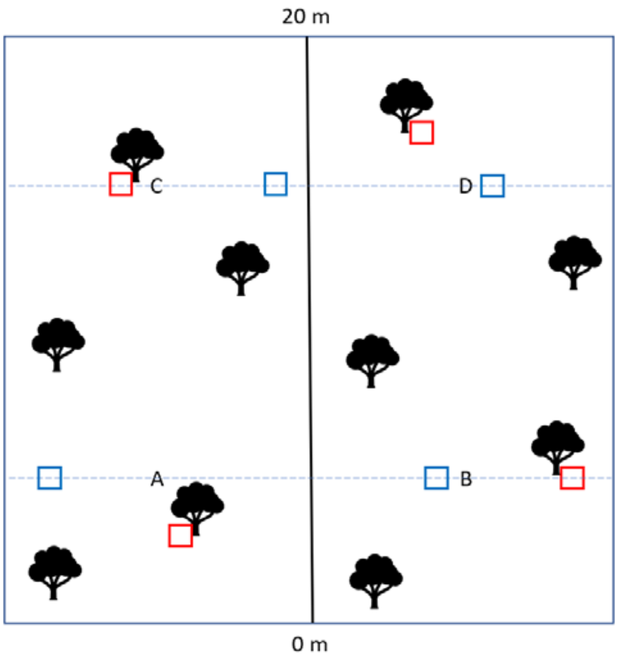


Figure 1. Example location of the four Tree quadrats (red squares) and four Open quadrats (blue squares) within the 20 m x 20 m floristic plot

Quadrat cover assessment

Within or immediately above each quadrat the following was visually assessed: Below a height of 50 cm, groundcover was recorded as percentage; foliage cover, logs, litter, compost/woodchip, cryptogam, bare rock, bare soil. Cover of all components totalled 100 % such that only the highest component of groundcover was recorded. For example, if there was 25% cover of tussock grasses, litter or bare soil beneath the tussock grasses was not recorded. Then above a height of 50 cm, the foliage cover of trees, shrubs or other growth forms were separately recorded. Total cover of trees, shrubs and other growth forms could exceed 100%. In essence, these two measures recorded cover below and cover above a horizontal plane located at 50 cm above ground level.

Quadrat litter sampling and processing

Following cover assessment, all litter (to bare soil or > 2 mm diameter) and sticks (to 5 mm diameter) were collected from each quadrat into paper bags. Litter from the four Open and four Tree quadrats were pooled into one labelled Open bag and one labelled Tree bag.

In the laboratory, the litter from each bag (93 sites x 2 bags = 186 bags) was weighed and sorted, using a series of sieves, into the following categories: sticks and bark; tree and shrub leaves (overstorey); grass and forb leaves (groundstorey); coarse frass (litter fragments > 4 mm diameter and < 40 mm long); fine frass (litter fragments < 4 mm but > 2 mm diameter); reproductive material (seeds/seedpods, fruits and flowers); woodchips; other mulch.

Animal dung found in the litter sample were identified (macropod, possum, pig, rabbit, deer, fox, glider) and weighed. Likewise, all invertebrates found during the litter sort were identified to major groups (ants, beetles, spiders etc) and counted.

Soil sampling

Following the collection of litter, a single soil sample 0-5 cm was collected from the centre of each Tree quadrat and pooled to yield approximately 300 ml volume of soil from the four Tree quadrats. The process was repeated for the four Open quadrats. Soil samples were immediately placed in a cooler box with ice and at the end of each day each sample was gently mixed and then split into two samples with one sample refrigerated and one sample frozen. All samples were initially transported to Western Sydney University for microbial analyses.

Soil microbiology

Frozen soils (for DNA and Phospholipid-derived fatty acids (PLFA) analyses) were freeze-dried for 2 days before processing, while fresh soils (for enzyme and respiration assays) were stored at 4 °C until processing. In both cases, each sample was gently mixed and passed through a 2 mm sieve before subsampling. Additional subsamples were collected for gravimetric soil moisture content estimated by comparing fresh weight and following 48 hours at 105 °C. pH was measured in a 1:5 soil:H_2O slurry for a few representative samples to determine best approaches for enzyme assays.

Microbial enzyme activity (coordinated by Dr Uffe Nielsen, Western Sydney University)

The activity of particular extracellular microbial enzymes is related to the potential cycling of carbon (C), nitrogen (N) and phosphorus (P). Potential microbial enzyme activity therefore provides some insight into the potential functioning of the ecosystem. Extracellular enzyme activity was measured for seven enzymes representing different aspects of C, N and P cycling following Bell et al. (2013). See Appendix for further details.

Microbial respiration (coordinated by Dr Brian Wilson, University of New England)

Following enzyme analyses, the fresh soils were transported at 4 ^{o}C to the University of New England for analysis of microbial respiration. The relative differences in community composition or "functional diversity," is generally measured based on differences in patterns of carbon (C) substrate utilization (Campbell et al. 2003, Burton et al. 2010, Knox et al. 2014). Carbon source utilization patterns (often referred to as community level physiological profiles, or CLPP (Burton et al. 2010)) was assessed using the MicroResp™ technique (Burton et al. 2010, Knox et al. 2014, Trivedi et al. 2015). This method is widely used in forest research and gives rapid results (Grayston and Prescott 2005). See Appendix for further details.

PLFA (coordinated by Dr Yolima Carrillo Espanol, Western Sydney University)

Microbial phospholipid fatty acids (PLFA) were assessed as these serve as indicators of total microbial biomass in soil and abundance of general microbial functional groups such as bacteria (gram negative, gram positive), actinobacteria, fungi, mycorrhizae, as well as of protists, which are members of the soil microfauna. See Appendix for further details.

Microbial community composition (coordinated by Dr Jeff Powell, Western Sydney University)

DNA was extracted from soil samples to characterise microbial communities using high-throughput sequencing (Illumina MiSeq) of the bacterial 16S rRNA gene and the fungal internal transcribed spacer between the 5.8S and 28S rRNA genes (ITS2). These analyses allow us to calculate diversity of operational taxonomic units (OTUs) detected within samples, assign putative taxonomic identities and functional attributes to these OTUs through comparisons with databases and to estimate the degree that each OTU is exclusive to a particular environment. See Appendix for further details.

Soil chemistry *(coordinated by Dr Brian Wilson, University of New England)*

Extractable phosphorus (Colwell-P), pH and EC (1:5 H_2O) were determined following standard procedures (Rayment and Lyons 2011). Total nitrogen and soil organic carbon fractions were estimated using mid-infrared (MIR) spectroscopy techniques. All MIR analyses for total organic carbon (TOC), particulate organic carbon (POC), humic organic carbon (HOC) and resistant organic carbon (ROC) were undertaken at the *NSW Department of Planning, Industry and Environment Soil Health and Archive Laboratory*. See Appendix for further details.

Leaf sampling and leaf area and nutrient analysis

(Coordinated by Dr Jennifer Fern, Queensland University of Technology, QUT)

Leaves were collected from the three most abundant shrub and/or tree species in or around each 20 m x 20 m plot for estimation of leaf nutrients. The three species with most contribution to total shrub and tree foliage cover were identified from the floristic survey. For each species, up to five individuals were selected and from each individual a minimum of three fully expanded leaves were sampled from an outer canopy stem. Leaves from different individuals of the same species were placed in a paper bag labelled with plot id and species name.

Leaf area (mm^2) of three randomly selected leaves from each sample was measured using a flatbed scanner (Epson perfection V300) and image analysis software (ImageJ; Abramoff et al. 2004). These leaves were dried at 60 ºC for 48 h and then weighed (dry weight; g). Specific Leaf Area (SLA) (Firn et al. 2019) was calculated as leaf area divided by dry weight averaged across the three leaves randomly selected from each sample.

All leaves were then dried as above and then ground, bulked per species and analysed by *Queensland University of Technology's Central Analytical Services* for leaf nutrient concentrations (total; N, C. ppm; B, Na, Mg, P, K, Ca43, Ca44, Mn, Fe, Cu, Zn66, Zn67, Sr, Mo, Pb). See Appendix for further details.

DATA ANALYSES

Conversion of patch-scale data to site-scale data

Data were collected by Umwelt and DPIE to be representative of the site scale (floristics, Landscape Function Analysis (LFA), Biodiversity Assessment Method (BAM), BioBanking Assessment Methodology (BBAM)), or to be representative of Open and Tree base patches (litter fractions, soil chemistry and soil biology), or at the plant scale (leaf nutrients and specific leaf area (SLA)). Prior to undertaking analyses all datasets were converted to the site scale.

For the Open and Tree patch data, we converted these patch-level data to the site-level using overstorey percentage foliage cover values recorded under the BBAM methodology. Tree patch data were weighted according to the BBAM overstorey percentage foliage cover, and Open patch data weighted according 100 % – the observed foliage cover % for the site. Weighted Open and Tree patch data were then summed to provide a site-level estimate. This process replicates the calculation of the site-level LFA indices created from patch-level LFA indices. Using this process all litter fraction, soil chemistry and soil biology datasets were converted from Tree and Open patch datasets to site-level datasets and these were used in all subsequent analyses.

Leaf nutrients and SLA were converted to the site scale by taking into account the relative abundance of each of the three sampled species. Within each site a species SLA and leaf nutrients were weighted by their proportion contribution to the summed foliage cover of the three dominant species. These were summed to provide a site level value.

Data reduction

Twenty-three datasets including 84 variables collected by Umwelt and DPIE were available for analysis (Table 1). A number of processes were followed to reduce the number of variables submitted to self-sustainability analyses. Initially, datasets were grouped according to performance indicator categories, which were themselves grouped according to the essential ecosystem categories and attributes of self-sustainability developed by Oliver et al. (unpublished; Table 1).

Spearman rank correlations were then calculated among variables within potential performance indicators and where pairs of variables were highly correlated ($r_s > 0.7$), one was omitted from further consideration. Choice of which variable to retain was guided by the likely cost of collection and processing (retaining the cheaper) or based on frequency of use of one of the variables in other studies (retaining the more commonly used).

Table 1. Suggested ecosystem capacities[1] and potential performance indicators explored

Ecosystem capacities & attributes	*Performance indicator categories*	*Potential performance indicators*	*No of variables*
A capacity for renewal			
Substrate regeneration	Soil-physical	LFA-stability index	1
		LFA-infiltration index	1
		SSC: soil texture, surface roughness, crust resistance, crust brokenness, crust stability, cryptogam cover, erosion cover, deposited material cover, soil hardness	9
	Soil-chemical	Soil EC, pH, P, N, C, HOC, POC, ROC	8
		LFA-nutrient index	1
	Soil-biological	Microbial biomass: total, by functional group, bacteria/fungi ratio (PLFA)	9
		Microbial respiration (Microresp)	8
		Microbial organic matter decomposition (enzymes)	7
	Litter	Cover of litter (BAM)	1
		Litter cover, origin, incorporation, depth, plant foliage and basal cover (SSC)	6
		Mass of: total litter, sticks/bark, overstorey leaves, understorey leaves, coarse frass, fine frass (leaf litter sort)	6
Plant regeneration	Second generation plants	Presence of tree recruits (BAM)[2]	na
		No of native species flowering or fruiting (floristics)	1
		Mass of fruits (litter fraction)	1
		Cover of weeds	1
		Plant health (leaf nutrients and SLA)	18
Animal regeneration	Invertebrate abundance and diversity	Invertebrate abundance and diversity[3]	na
		Coarse woody debris	1
A capacity for stability			
Resistance	Species richness	Richness of native plants by site	1
		Richness of fungal OTUs by site	1
		Richness of bacterial OTUs by site	1
Resilience	Functional redundancy	Diversity of native plants among growth forms	1
		Diversity of fungal OTUs among functional groups	1

[1] From Oliver et al. (unpublished). [2] All except 3 sites recorded tree recruitment according to BAM however these data are not appropriate for assessing second generation recruits on rehabilitation sites where many planted/seeded trees have dbh < 5cm. True second generation data was collected, but we were unaware of this at the time of analyses so these data were not included (see Discussion). [3] Very few records. These data were therefore not included in subsequent analyses.

Box plots for displaying range of variation at reference sites

Our definition of self-sustainability considers the status of variables measured at rehabilitation plots in relation to the range of variation in those variables at reference plots. To illustrate this concept graphically we have used box-and-whisker plots showing the three target PCTs (R1.110 - Central Hunter Spotted Gum-Ironbark Forest, R6.107 - Central Hunter Slaty Gum Grassy Forest, R6.35 - Central Hunter Grey Box-Ironbark Woodland).

Figure 2 below shows box plots for the LFA Nutrient Cycling score. Index scores recorded at rehabilitation plots are shown as coloured dots. Each dot represents the nutrient cycling index value (y-axis) for one rehabilitation plot. The horizontal spread of points on the x-axis (within PCT) is simply to aid visualisation of all points. The range of variation in the nutrient cycling index values at reference plots (within PCT) is shown by the black box-and-whisker plots. The box represents the middle 50% of values observed at reference plots, that is, 25% of observed values lie below the box and 25% of the observed values lie above the box. The top of the box is known as the upper quartile and the bottom of the box the lower quartile. The box therefore represents the inter-quartile range (IQR). The upper whisker extends from the upper quartile to the highest value that is within 1.5 x IQR of the upper quartile. The lower whisker extends from the lower quartile to the lowest value within 1.5 x IQR of the lower quartile.

The horizontal bold line within the box represents the median. Points (rehabilitation sites) are coloured according to their distance from the median, simply to aid visualisation. We would expect therefore that rehabilitation points that fall close to the reference median are self-sustainable to the same extent as the reference sites. For example, in Figure 2 we would not expect any Central Hunter Slaty Gum Grassy Forest rehabilitation plots (R6.107) to be self-sustainable on the basis of the LFA Nutrient Cycling Score.

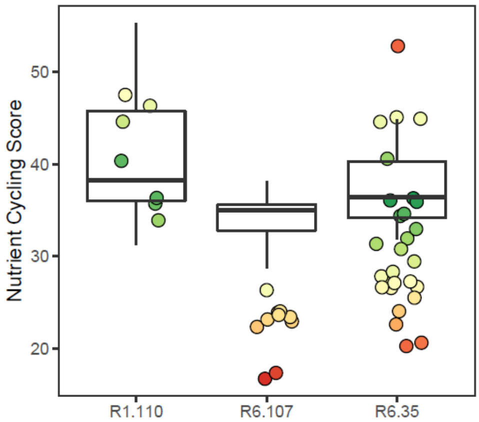


Figure 2. Example of a box plot for the nutrient cycling score for the three plant communities, R1.110 - Central Hunter Spotted Gum-Ironbark Forest, R6.107 - Central Hunter Slaty Gum Grassy Forest, R6.35 - Central Hunter Grey Box-Ironbark Woodland

Estimating variable importance

Our data reduction process reduced 84 available variables to 23. Routine monitoring of 23 self-sustainability indicators is clearly not practical, nor is it wise to attempt to model 23 variables with data from only 93 plots. To further guide the reduction of variables we calculated the importance of each variable for predicting the probability that a site is "self-sustaining" based on the assumption that reference sites are themselves self-sustaining.

We used logistic regression to develop models for estimating differences between reference and rehabilitated sites, with an underlying assumption that the distribution of data for a variable within reference sites reflects the range required for self-sustainability. We also assumed that attributes whose values differed between reference and young (< 10 years old) rehabilitation sites would be useful for monitoring trends towards self-sustainability.

Models were fit using Bayesian generalised linear regression (glm) with binomial response (1= Reference, 0 = Rehabilitation) and with weakly informative priors. All variables were scaled and centred (z-scores) and rehabilitation sites >10 years old were removed. These sites were removed on the assumption that as sites age, they would become increasingly like the reference sites and therefore increasingly self-sustaining. Including them in model fitting could obscure the evaluation of variable importance, especially for monitoring progress towards self-sustainability. The choice of 10 years as the threshold was arbitrary, however only seven sites were excluded - four sites 12 years old and three sites older than 20 years.

We fitted 23 logistic regression models and for each one, used leave-one-out cross validation to estimate the expected log predictive density (ELPD, equivalent to the model log-likelihood). Variables resulting in higher ELPD have greater individual predictive accuracy in differentiating reference and rehabilitated plots. Such variables are likely to be more useful for monitoring progress towards self-sustainability.

Visualising self-sustainability among priority variables

It is likely that some sites will present as self-sustainable for some variables but not others. For example, our box plots are likely to include sites that fall close to the median for some variables and not others. Therefore, it is important to visualise these findings at the site scale. We have done this for 13 high priority variables revealed by the above modelling and present these data as a “heat map”. The values used to generate the heat map are from individual logistic regression model predictions for each of the chosen set of variables, so take values in the range 0, 1. Green cells indicate that a rehabilitated site is similar to the reference sites for that variable (predicted value approaching 1), while red cells indicate that the rehabilitated site is different from the reference sites (predicted value approaching 0).

Benefits and costs of indicator collection, processing and data preparation

The aim of our study was to evaluate a potential suite of variables for use as indicators for monitoring progress of rehabilitated vegetation on mined land towards, and the achievement of, self-sustainability. Our evaluation employed a basic cost-benefit analysis in order to recommend an optimum set of indicators that may provide greatest benefit for the least cost. We calculated the benefit each variable contributed according to its ability to predict the probability that a site is “self-sustaining” based on the assumption that reference sites are themselves self-sustaining. Our benefit variables took a value of 1 for most informative and 0 for the least informative based on the ELPD.

Costs were provided by the various data collectors and providers in person hours (excluding travel time to and between study sites). These costs included the time taken to collect the data or samples in the field, time taken to process the samples in the office or laboratory, and time taken to enter data. Person hours were converted to dollar costs at $100 per hour for Technical Officer level tasks and $180 per hour for more specialised tasks. Dollar costs included salary, on-costs and overheads so are likely to reflect real costs that would be charged to industry for the collection and processing of samples.

All BAM, BBAM and floristic data were collected in the field by Umwelt digitally such that data could be exported in a usable format and no additional office-based data entry time was required. Where digital field data capture is not used, costs would likely be higher.

For laboratory analyses, costs of consumables were added and for specialised laboratory analyses an additional cost was added where specialist support and interpretation would be required. Full details are provided in Table A10.

Probabilistic determination of self-sustainability

Independent analysis of variables identifies high priority variables that should be included in monitoring programs for self-sustainability. This analysis does not however determine an optimum collective set of variables that should be used together for determining when a site might be considered self-sustainable.

We used logistic regression to predict the probability that a site is "self-sustaining" based on the assumption that reference sites are themselves self-sustaining. Models were fit using Bayesian generalised linear regression (glm) with binomial response (1= Reference, 0 = Rehabilitation). The resulting model therefore predicts the probability a site is drawn from the population of reference sites, given the observed values for each of the independent variables (explanatory variables). Our aim was to find a single model with the best predictive power but the fewest variables (most parsimonious model).

Bayesian models require that prior distributions are specified for the relationship between each of the explanatory variables and the binary response variable. In this case we assumed no prior information was available and used uninformative priors with a mean of 0 and standard deviation of 2.5.

Before analysis all potential explanatory variables were scaled and centred (z-scores). The models were fit to a reduced dataset in which rehabilitation sites >10 years old were removed. Inclusion of older rehabilitation sites, that are potentially self-sustaining, could reduce the overall differences between the distribution of reference and rehabilitated sites and limit the ability of the model to discriminate between those rehabilitated sites that are self-sustaining and those that are not.

Initially we fit a reference model with all 13 high priority variables. A Bayesian model selection approach (projection predictive variable selection) was used to identify the most parsimonious model (Piironen & Vehtari 2017; Piironen et al. 2018). We used the package projpred in R to estimate the sum of the expected log predictive densities (ELPD) of models with increasing complexity (i.e. from 1 through to 13 variables) and forward selection using leave one out cross validation to identify the relative importance of individual variables. This enabled us to define an initial set of potential models that maximised model fit (best predictive power) but minimised model complexity (used the smallest number of variables). These models were compared through inspection of model coefficients and using leave one out information criterion (LOOIC). A final model was identified after removal of model terms whose estimated mean coefficient approached 0 (i.e. predicted to have no or little effect) and that minimised LOOIC.

The final model was then used to generate predictions of "self-sustainability" for each rehabilitation site, including rehabilitated sites > 20 yrs old.

RESULTS

Community-level differences among reference and rehabilitation plots

Although not directly related to assessments of self-sustainability, comparisons of community level differences based on plant data and microbial data are important for conveying overall differences in the species (plants) or operational taxonomic units (fungal and bacterial OTUs) and their relative abundances recorded at rehabilitation and reference sites.

Figure 3 reveals very clear separation of rehabilitation and reference plots based on plant composition and cover. It also reveals very clear differentiation of PCTs at reference sites, whereas there is some overlap of PCTs for rehabilitation plots.

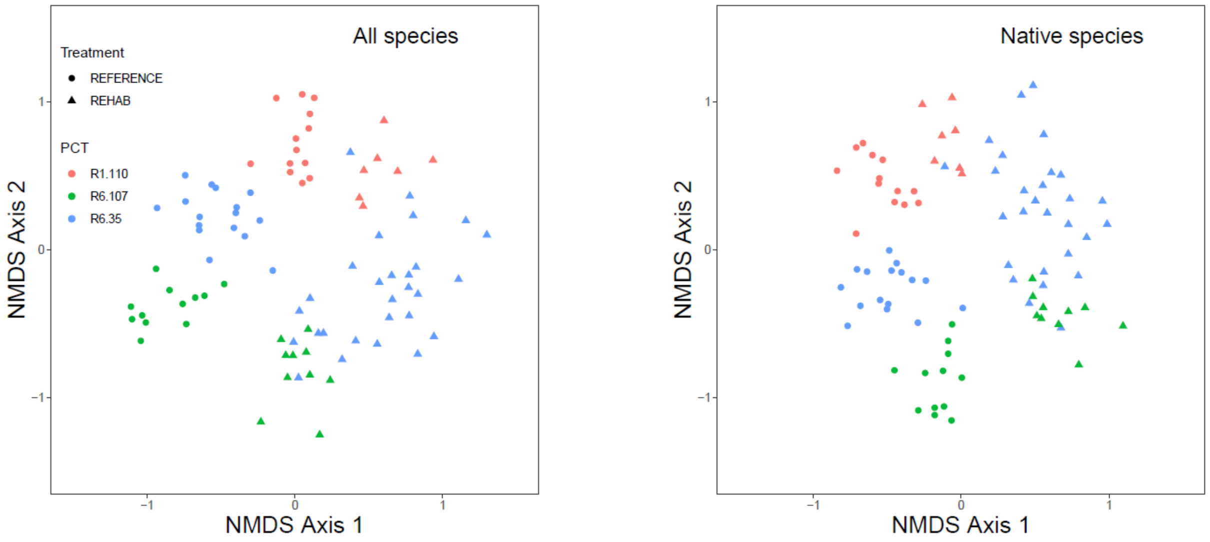


Figure 3. Ordination plots showing the similarity in plant community composition between plots according to distance among points. Points in close proximity have similar species and species abundances (modified Braun-Banquet cover (1-6)).

Results for bacterial communities shown in Figure 4 generally mirror the patterns seen for plants although two tree and two open samples from rehabilitated sites 65 and 66 group with the reference sites in the Spotted gum – Ironbark PCT. Several rehabilitation samples (64O, 64T, 48T) also group with reference sites in the Central Hunter Grey box – Ironbark PCT, and interestingly one reference sample (41T) groups with rehabilitation sites.

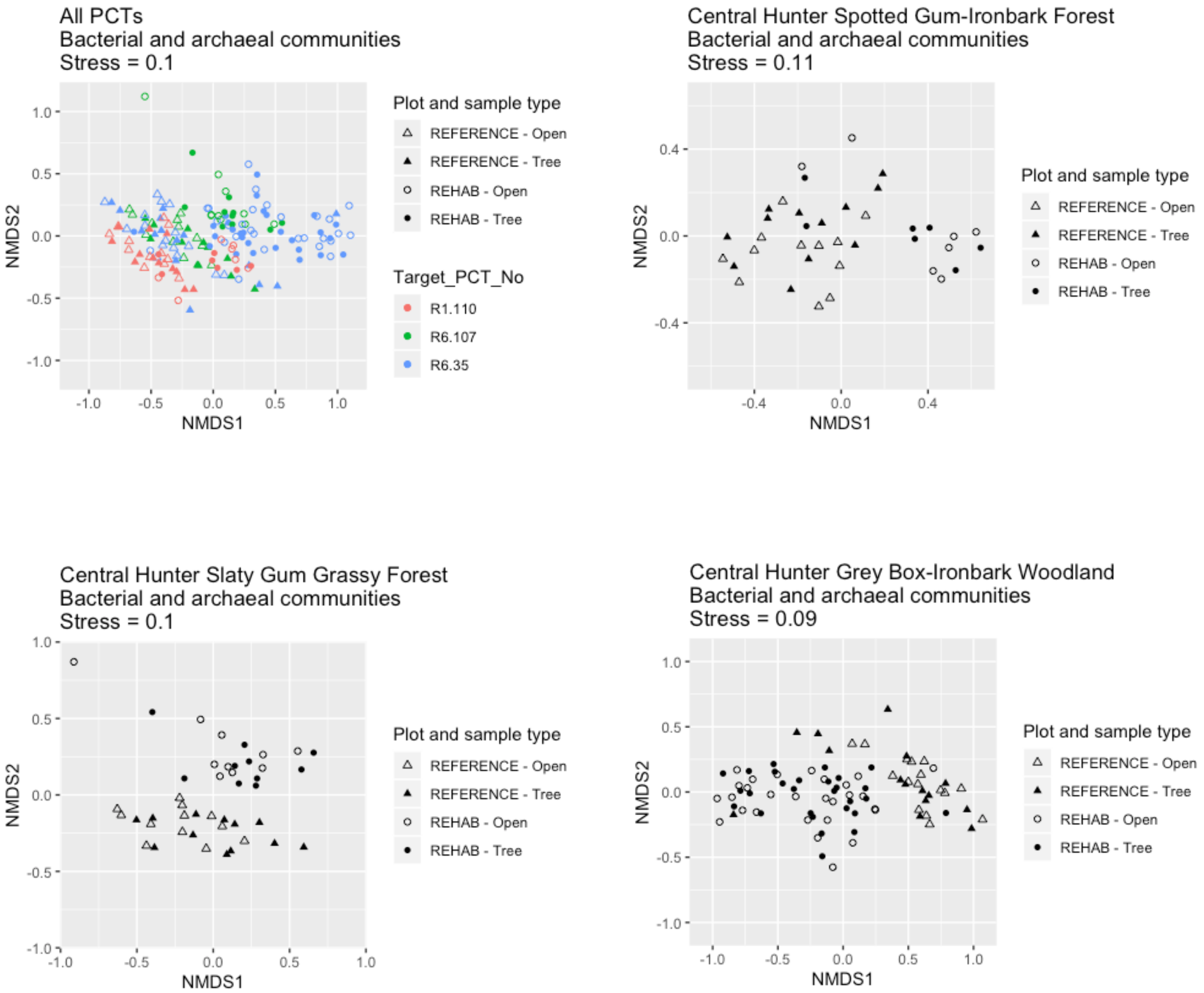


Figure 4. Ordination plots showing the similarity in bacterial community composition between Open and Tree patches from rehabilitation and reference plots in the three target vegetation types. Points in close proximity have similar OTUs and OTU relative abundances

Results for fungal communities again generally mirror the patterns seen for plants (Figure 5). Although overlap among communities in different PCTs appears greater, differences are statistically significant (results not presented). Again, the two open and two tree samples from rehabilitation Sites 65 and 66 group with reference sites in the Spotted gum – Ironbark PCT and rehabilitation Site 64 groups within the range of reference Central Hunter Grey box – Ironbark Woodland.

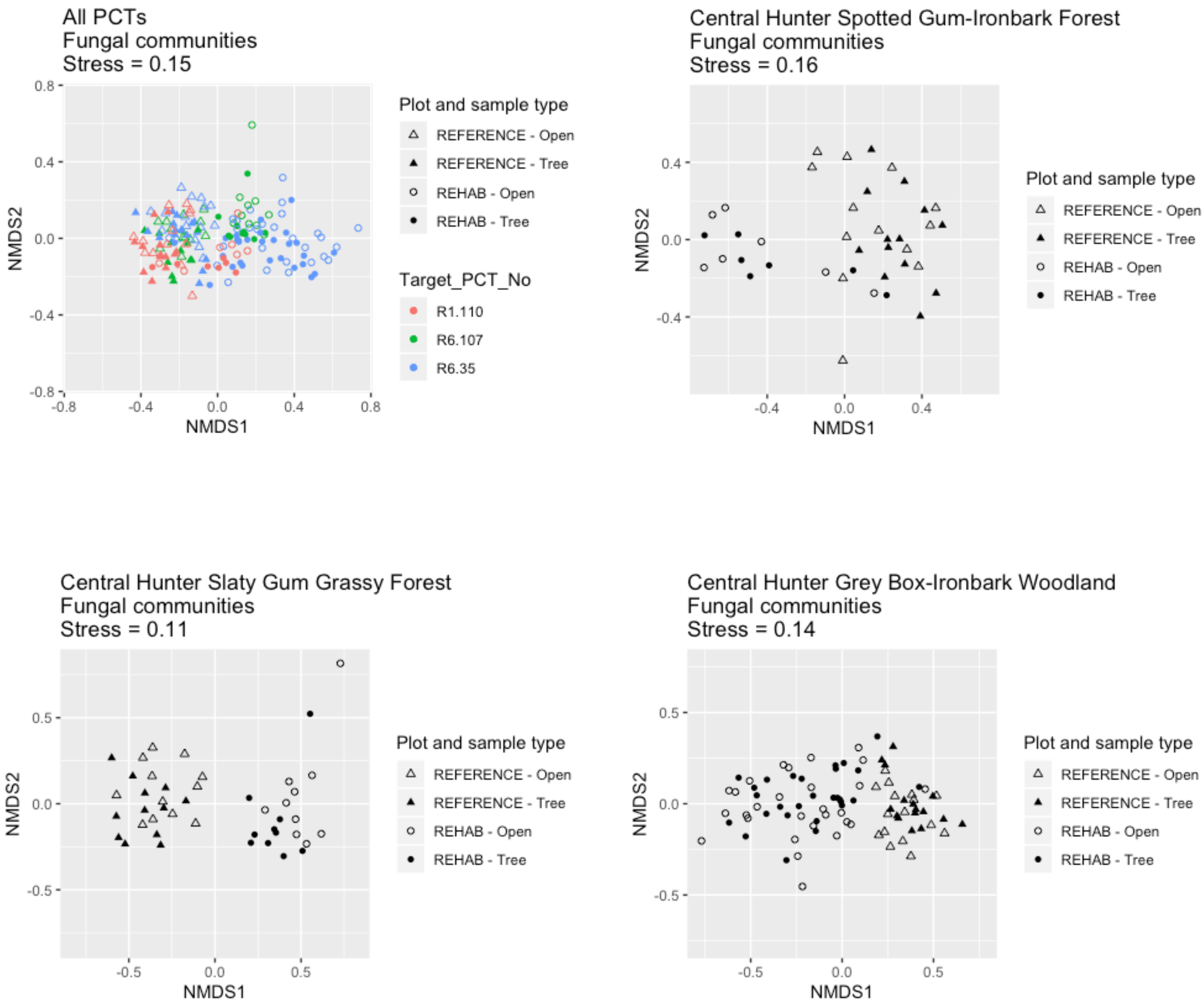


Figure 5. Ordination plots showing the similarity in fungal community composition between Open and Tree patches from rehabilitation and reference plots in the three target vegetation types. Points in close proximity have similar OTUs and OTU relative abundances

Data reduction

Table 2 shows the list of variables remaining after the data reduction process. For substrate regeneration, there were very few correlations > 0.7 for soil surface condition variables (Table A3). We therefore elected to retain the *LFA-stability* and *LFA-infiltration* indices in preference to the individual variables. However, because the *LFA-infiltration* index was highly correlated with the *LFA-nutrient index* (r_s = 0.86) we omitted the former. All soil chemical variables were highly correlated (Table A4) so we retained the commonly used soil health indicator *total organic carbon*.

Within the soil biology performance indicators, microbial respiration following the addition of different substrates was very highly correlated, including with water (basal respiration, Table A5). Therefore, we selected the single substrate *glucose* for inclusion which has been used widely in other studies. A number of enzymes were correlated resulting in the selection of the substrates *CB*, *LAP*, *PHOS* for inclusion in subsequent analyses (Table A6). The biomass of microbial functional groups from PLFA analysis revealed a number of high correlations, particularly between total microbial biomass and other functional groups (Table A7). We therefore selected biomass of the following groups for inclusion in further analyses, *total microbial biomass*, *protist biomass*, and the *ratio of fungal to bacterial biomass*.

We had a wide range of variables related to litter, from the simple assessment of litter cover using the BAM to laboratory intensive measures based on the mass of litter fractions, to a range of litter related soil surface condition variables. We did not pursue those related to LFA and soil surface condition assessment because many of these were already incorporated into the two LFA indices selected above. We included *BAM litter cover* due to its simplicity and familiarity. Most litter fractions were highly correlated with *total litter mass* which we selected for inclusion in subsequent analyses (Table A8).

Although we had measures for 17 leaf nutrients, we selected the *ratio of carbon to nitrogen* as our single leaf nutrient measure due to the known importance of this measure and limited time to explore the full array of leaf nutrients. Similarly, we added *specific leaf area* (*SLA*) due to a vast literature on the role of SLA in plant health and resilience. Neither of these variables were highly correlated with the *number of species flowing/fruiting* or the *mass of fruits* recovered from litter samples, so all were retained for subsequent analyses (Table A9).

Table 2. Reduced variable set identified based on correlations among variables

Ecosystem capacities & attributes	*Performance indicator categories*	*Potential performance indicators*	*No of variables*
A capacity for renewal			
Substrate regeneration	Soil-physical	LFA-stability index	1
	Soil-chemical	LFA-nutrient index Total organic carbon	1 1
	Soil-biological	Microbial biomass (total, protist, and fungi:bacteria) Microbial respiration (glucose) Microbial enzyme substrates (CB, LAP, PHOS)	3 1 3
	Litter biomass	Cover of litter (BAM) Total mass of litter	1 1
Plant regeneration	Second generation plants	Number of species flowering or fruiting Mass of fruits in litter Cover of weeds Plant health (leaf C:N and SLA)	1 1 1 2
Animal regeneration	Invertebrate abundance and diversity	Coarse woody debris	1
A capacity for stability			
Resistance	Species richness	Richness of native plants by site Richness of fungal OTUs by site Richness of bacterial OTUs by site	1 1 1
Resilience	Functional redundancy	Diversity of native plants among growth forms Diversity of fungal OTUs among functional groups	1 1

Box plots for displaying range of variation

Box plots are provided to reveal general differences among reference and rehabilitation sites for BAM and LFA indices (Figure 6) as well as differences between the reduced set of 23 variables contained in Table 2 (Figures 7 - 12).

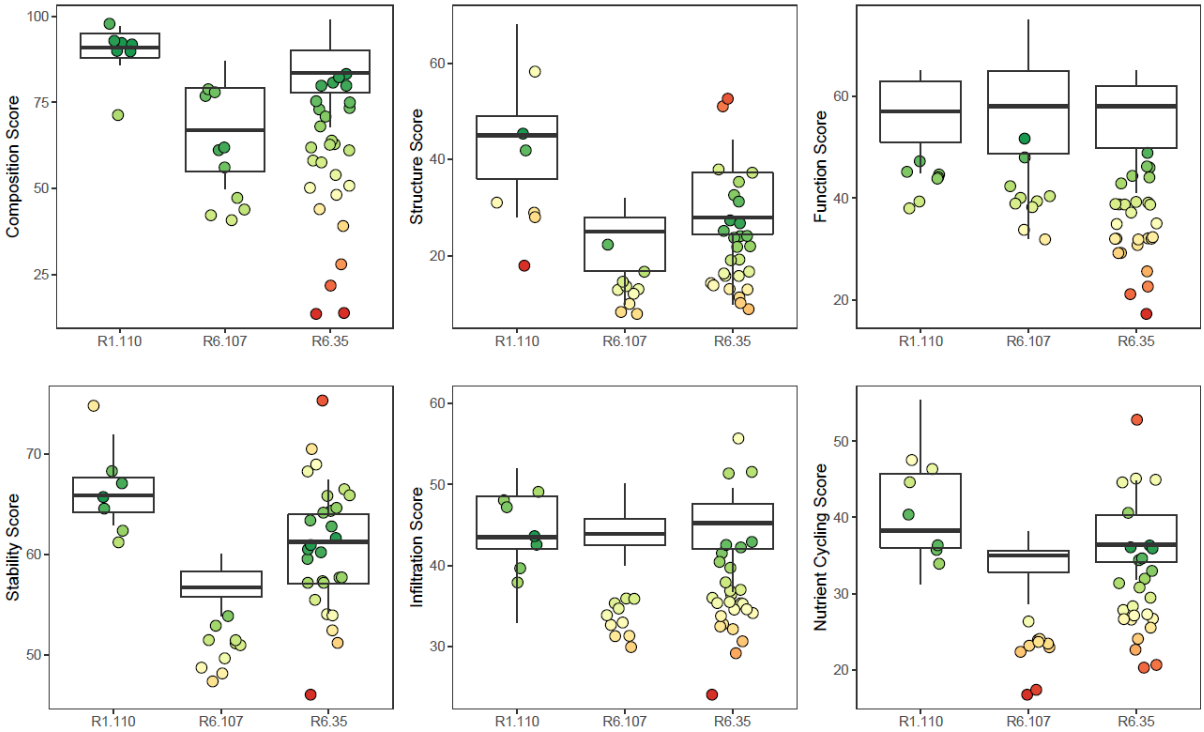


Figure 6. BAM (top row) and LFA (bottom row) index scores for rehabilitation plots (points) compared with the box-and-whisker plots showing the range of variation in index scores for reference sites. Points are coloured according to their distance from the reference median (bold horizontal line) simply to aid visualisation and results are presented by PCT

(R1.110 - Central Hunter Spotted Gum-Ironbark Forest, R6.107 - Central Hunter Slaty Gum Grassy Forest, R6.35 - Central Hunter Grey Box-Ironbark Woodland)

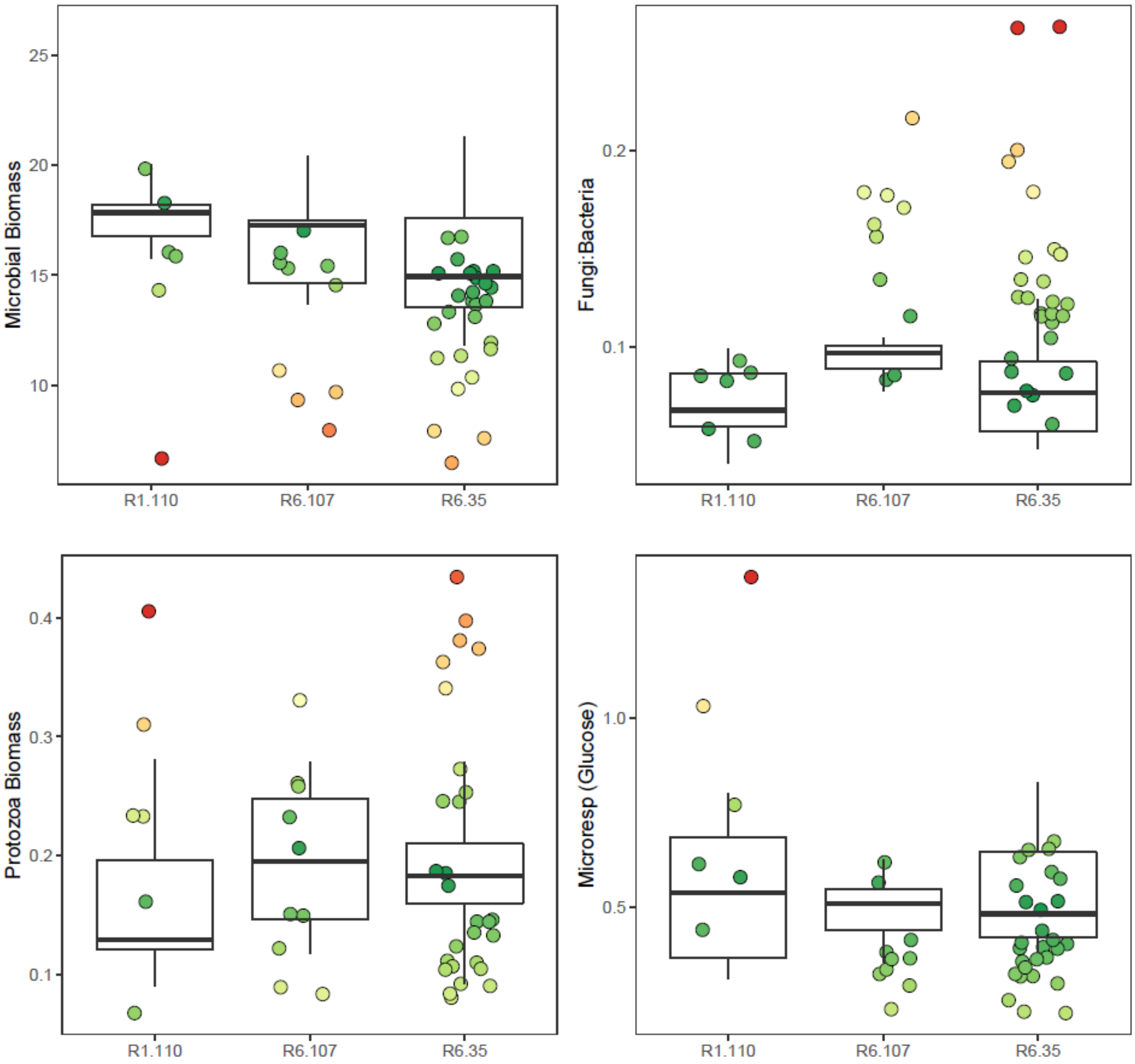


Figure 7. Points show the status at rehabilitation sites for microbial biomass, protozoa biomass, the ratio of fungal to bacterial biomass (from PLFA analyses) and microbial respiration on addition of glucose (from Microresp analyses). Box-and-whisker plots show the range of variation in status for these variables at reference sites. Points are coloured according to their distance from the reference median (bold horizontal line) simply to aid visualisation

(R1.110 - Central Hunter Spotted Gum-Ironbark Forest, R6.107 - Central Hunter Slaty Gum Grassy Forest, R6.35 - Central Hunter Grey Box-Ironbark Woodland)

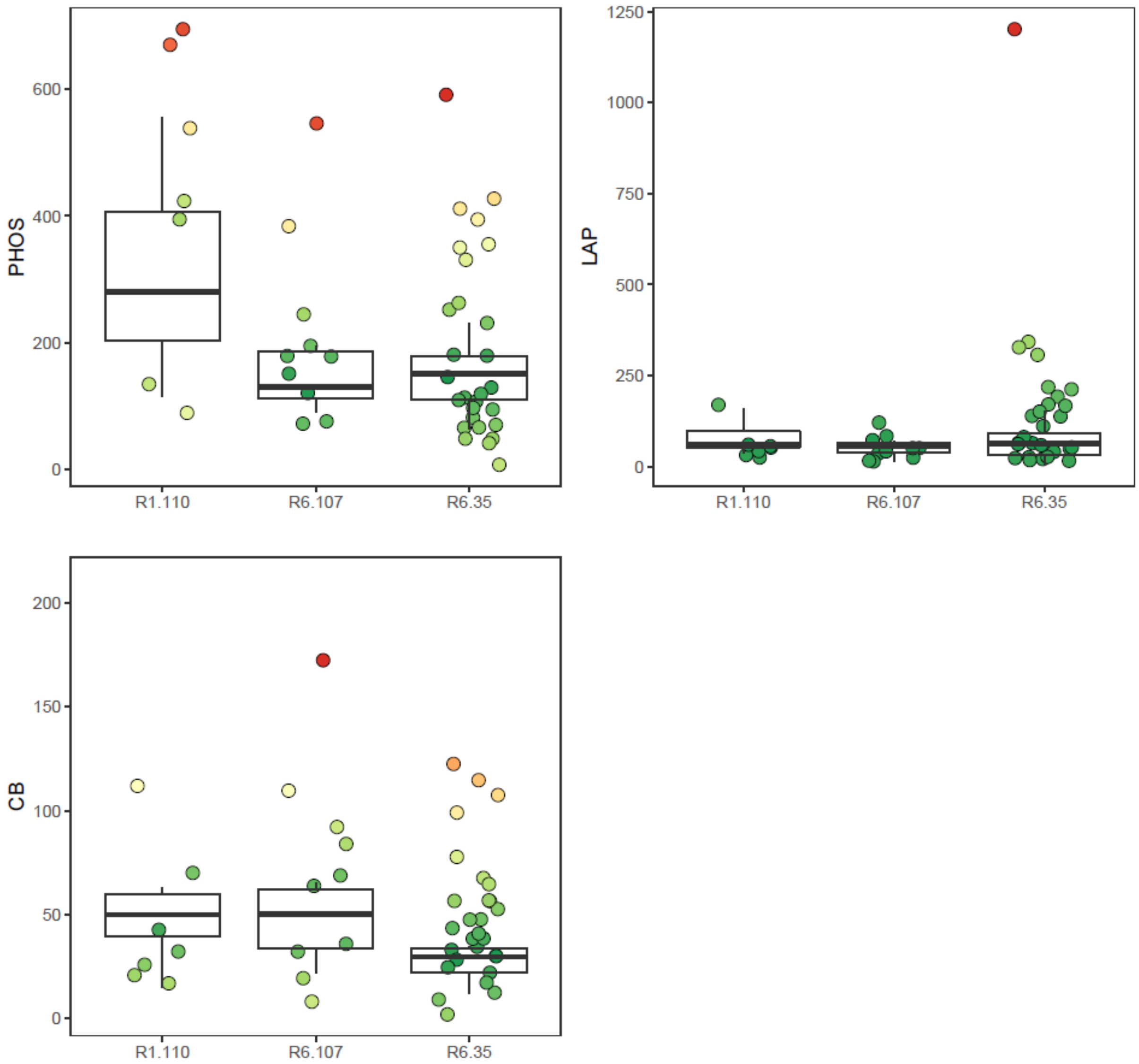


Figure 8. Points show the status at rehabilitation sites for phosphorous mineralisation (PHOS), protein degradation (LAP) and cellulose degradation (CB), from enzyme analyses. Box-and-whisker plots show the range of variation in status for these variables at reference sites. Points are coloured according to their distance from the reference median (bold horizontal line) simply to aid visualisation.

(R1.110 - Central Hunter Spotted Gum-Ironbark Forest, R6.107 - Central Hunter Slaty Gum Grassy Forest, R6.35 - Central Hunter Grey Box-Ironbark Woodland)

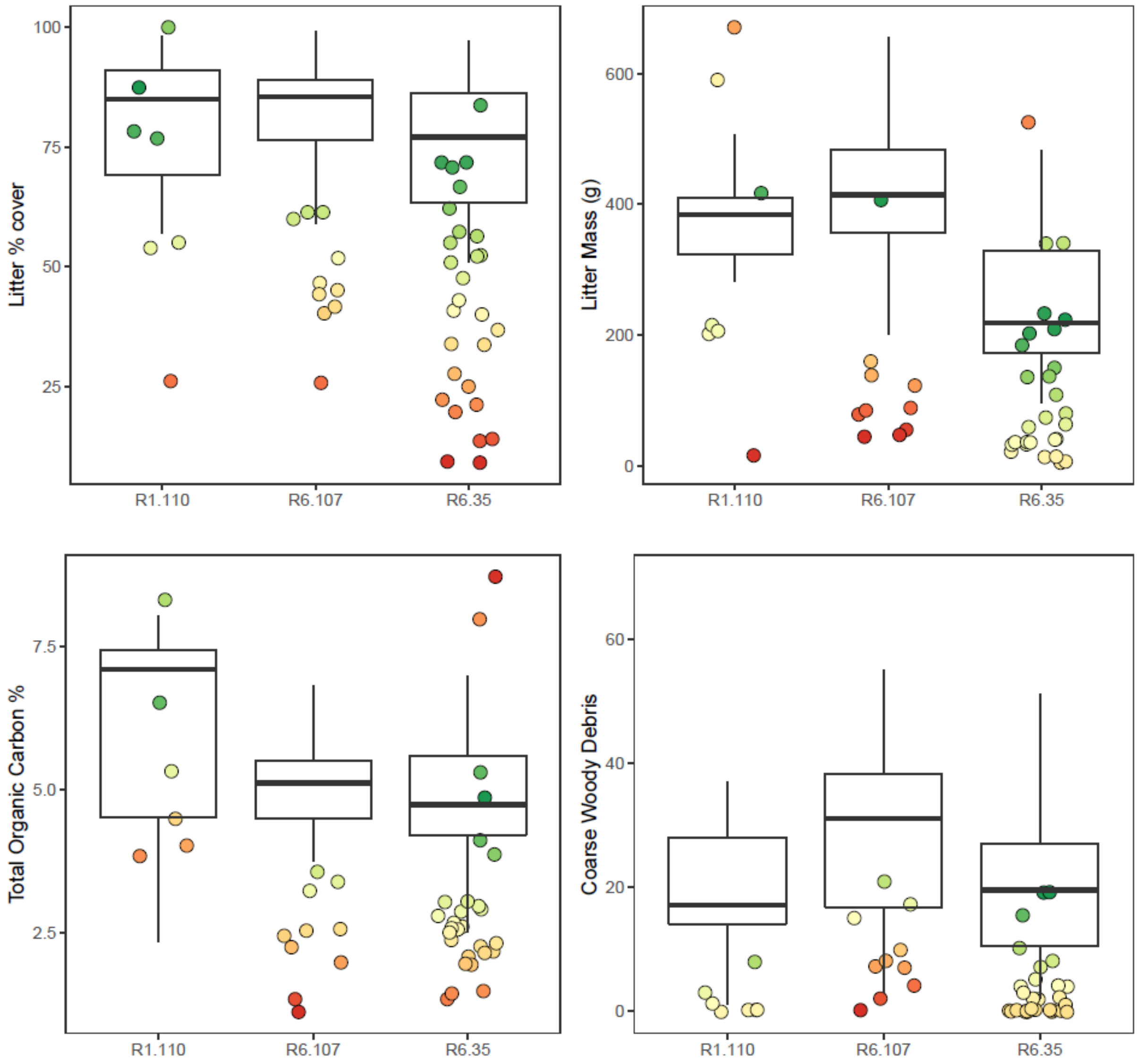


Figure 9. Points show the status at rehabilitation sites for litter cover (from BAM), total litter mass (sum of litter fractions), total organic carbon (from MIR) and the length of coarse woody debris (from BAM). Box-and-whisker plots show the range of variation in status for these variables at reference sites. Points are coloured according to their distance from the reference median (bold horizontal line) simply to aid visualisation.

(R1.110 - Central Hunter Spotted Gum-Ironbark Forest, R6.107 - Central Hunter Slaty Gum Grassy Forest, R6.35 - Central Hunter Grey Box-Ironbark Woodland)

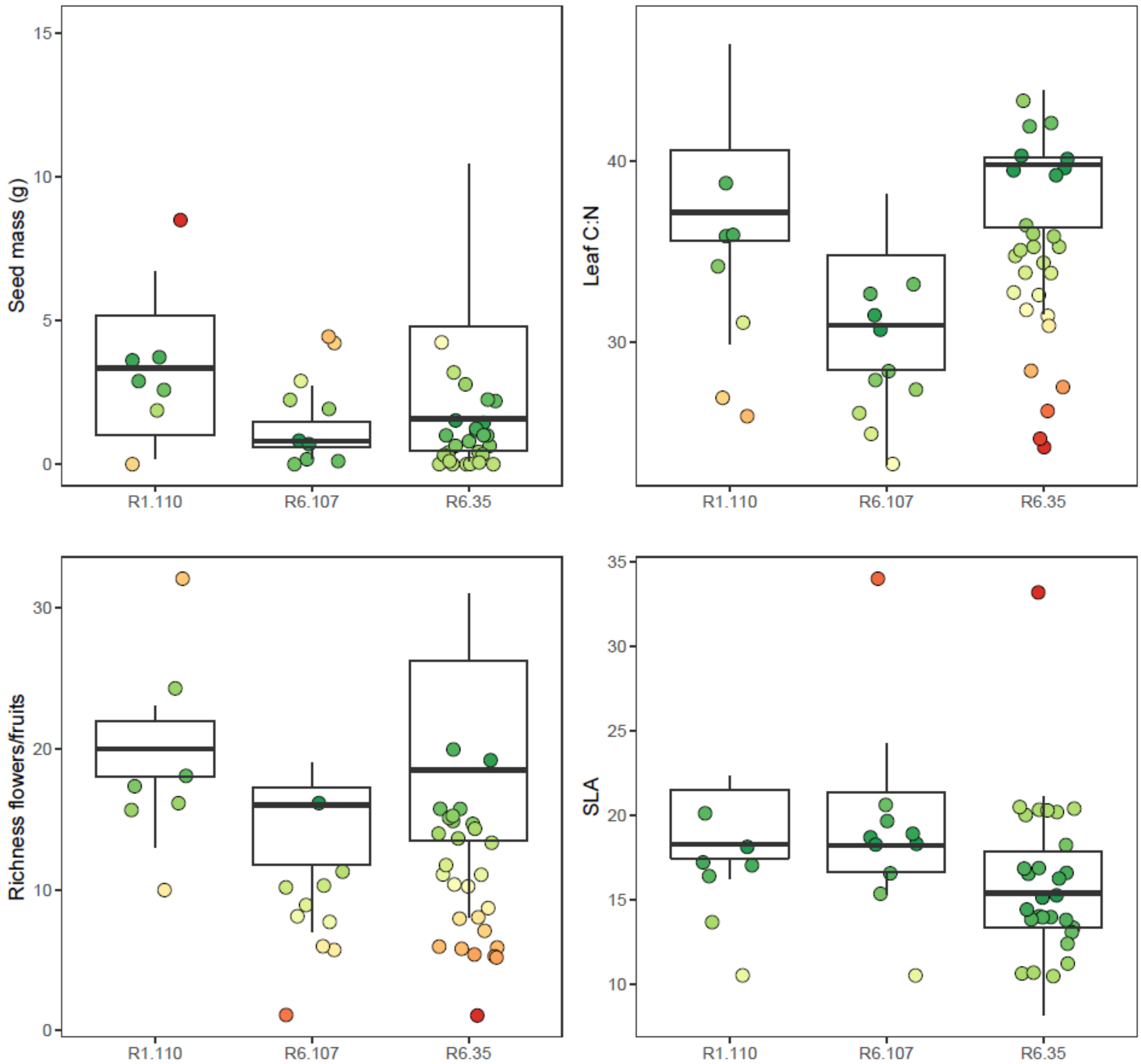


Figure 10. Points show the status at rehabilitation sites for the total mass of fruits/seed capsules recovered from litter samples, the ratio of carbon to nitrogen in the leaves of dominant species, the number of plant species recorded as flowering or fruiting at the time of survey, and specific leaf area (SLA) of dominant species. Box-and-whisker plots show the range of variation in status for these variables at reference sites. Points are coloured according to their distance from the reference median (bold horizontal line) simply to aid visualisation.

(R1.110 - Central Hunter Spotted Gum-Ironbark Forest, R6.107 - Central Hunter Slaty Gum Grassy Forest, R6.35 - Central Hunter Grey Box-Ironbark Woodland)

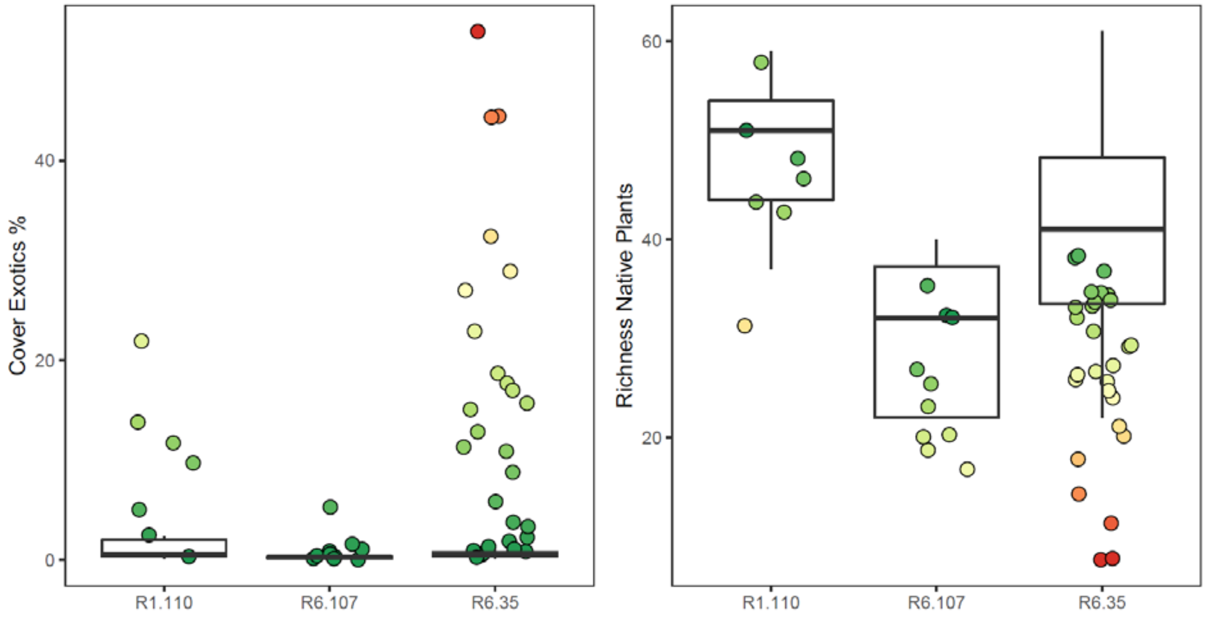


Figure 11. Points show the status at rehabilitation sites for total cover of exotic plant species and the number of native species (richness) recorded at each plot. Box-and-whisker plots show the range of variation in status for these variables at reference sites. Points are coloured according to their distance from the reference median (bold horizontal line) simply to aid visualisation.

(R1.110 - Central Hunter Spotted Gum-Ironbark Forest, R6.107 - Central Hunter Slaty Gum Grassy Forest, R6.35 - Central Hunter Grey Box-Ironbark Woodland)

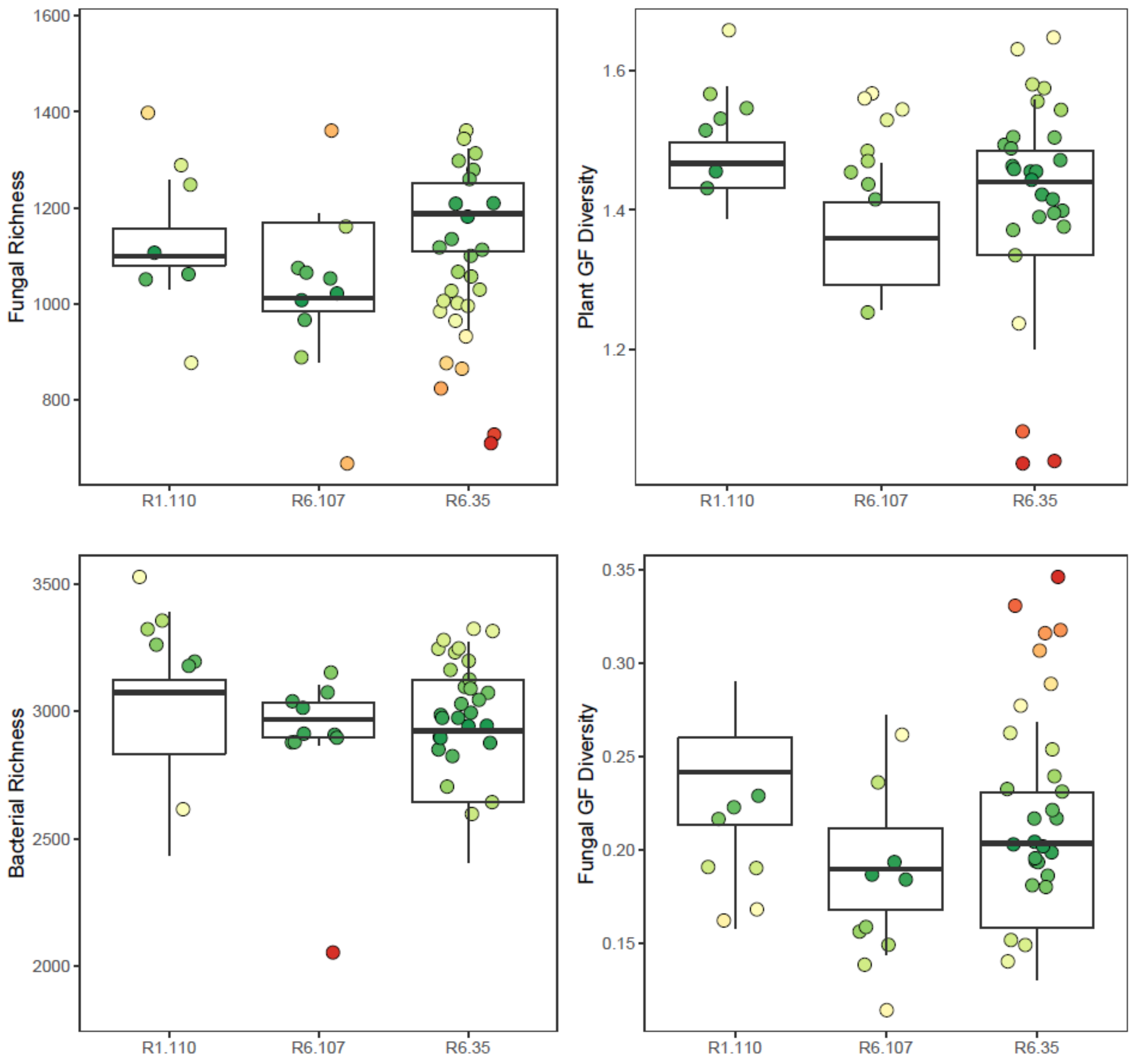


Figure 12. Points show the status at rehabilitation sites for the richness of fungal and bacterial OTUs (from meta-barcoding), the number of plant growth forms and richness of species within growth forms (diversity), and the number of fungal functional groups and the richness of OTUs within functional groups (diversity). Box-and-whisker plots show the range of variation in status for these variables at reference sites. Points are coloured according to their distance from the reference median (bold horizontal line) simply to aid visualisation

(R1.110 - Central Hunter Spotted Gum-Ironbark Forest, R6.107 - Central Hunter Slaty Gum Grassy Forest, R6.35 - Central Hunter Grey Box-Ironbark Woodland)

Estimating individual variable importance

The importance of all 23 variables when considered individually is shown in Table 3 and reveals that a range of BAM generated variables (function and floristics) are ranked highly, as are a number of laboratory-based variables.

Spearman rank correlations between all 23 variables revealed only two coefficients above 0.7 (*litter cover from BAM* with *total mass of litter fractions* $r_s = 0.73$, and *number of species of native plants* with *number of native species flowering or fruiting* $r_s = 0.89$)

Table 3. Importance of each variable (considered separately) for discriminating self-sustaining (reference) from not self-sustaining (rehabilitation < 10 years old). Variables are ranked from most important to least important.

Variable	**Individual importance (ELPD)**	**Normalised importance**
Litter cover (BAM[1])	-24.45	1.000
Total mass of litter fractions	-30.76	0.822
Coarse woody debris (BAM[1])	-38.05	0.616
Exotic species cover (BAM[1])	-41.72	0.512
Total organic carbon (MIR or Leco)	-42.56	0.488
Fungal:Bacterial biomass (PLFA)	-43.25	0.469
Number of plant species flowering/fruiting (BAM[1])	-43.61	0.458
Number of species of native plants (BAM[1])	-43.66	0.457
LFA nutrient cycling index	-47.08	0.360
Total microbial biomass (PLFA)	-48.87	0.310
Microbial respiration (glucose, Microresp)	-53.54	0.178
Total mass of seeds in litter samples	-54.17	0.160
Carbon:nitrogen in leaves of dominant species	-54.21	0.159
Number of fungal OTUs (meta-barcoding)	-57.33	0.071
Protein degradation (LAP enzymes)	-58.10	0.049
LFA stability index	-58.23	0.045
Fungal functional group diversity (meta-barcoding)	-59.06	0.022
Cellulose degradation (CB enzymes)	-59.37	0.013
Number of bacterial OTUs (meta-barcoding)	-59.43	0.011
Native plant growth form diversity (BAM[1])	-59.58	0.007
Phosphorus mineralisation (PHOS enzymes)	-59.69	0.004
Protozoa biomass (PLFA)	-59.76	0.002
Specific leaf area of dominant species	-59.83	0.000

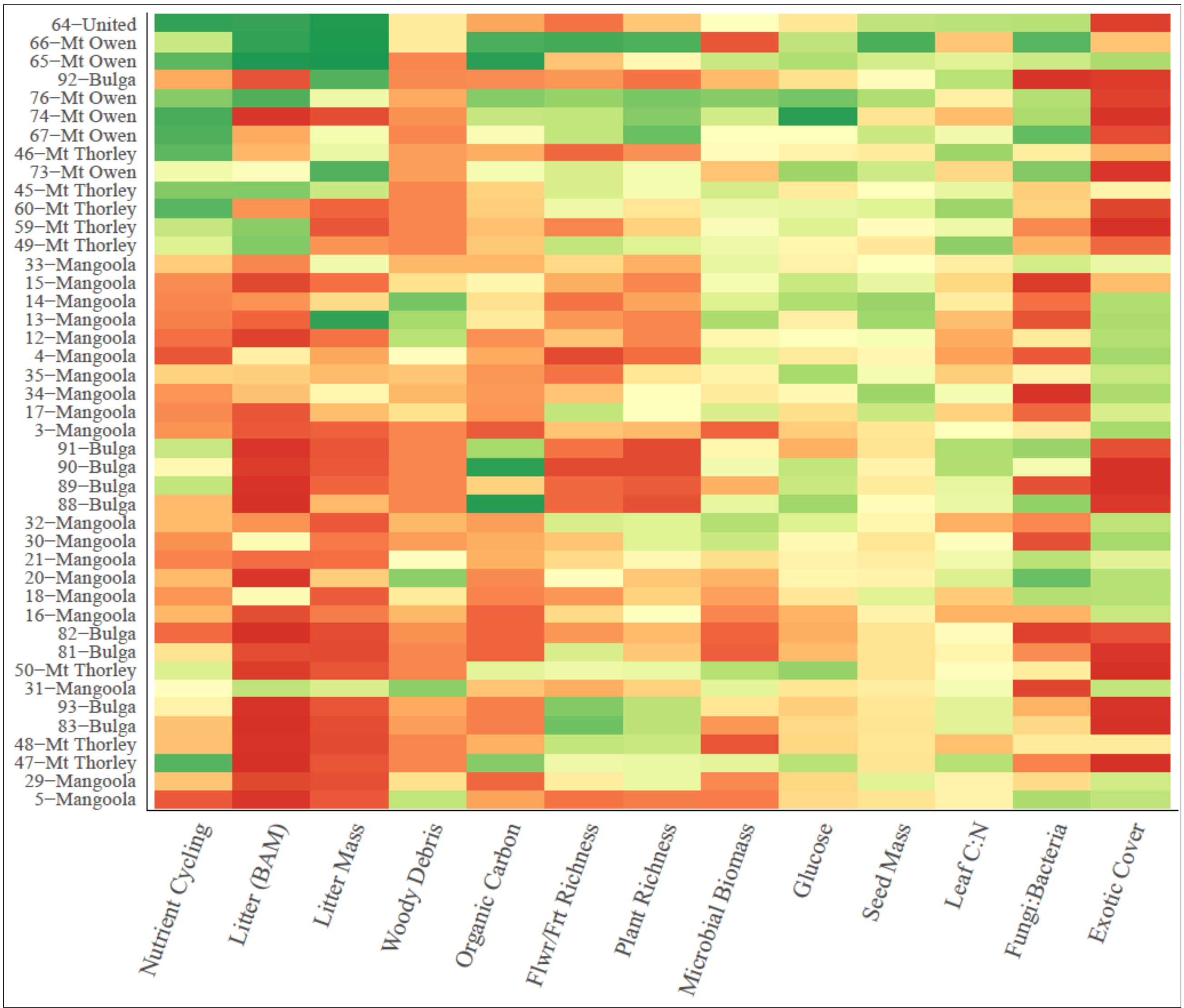
[1] Assumes full-floristic assessment is undertaken and presence of flowering/fruiting is recorded for each species

Visualising self-sustainability among priority variables

Based on the results above we generated a heat map using the top 13 variables. Although the choice of 13 was arbitrary, the 14th was only half as important as the 13th and was based on genetic meta-barcoding so was likely to be more expensive and require significant expertise.

Figure 13 clearly shows a relationship between rehabilitation age and the number of variables that show potential self-sustainability with more green cells towards the top of the figure (especially for *LFA nutrient cycling index* and *litter*). However, the *cover of exotic plants* appears independent of rehabilitation age. The heat-map also reveals those variables with little difference among rehabilitation sites from 3 years to > 20 years of age which are less likely to be useful for routine monitoring (e.g. *glucose*, *seed mass*, *leaf C:N*)

Figure 13. Heat map showing higher and lower potential self-sustainability (dark green thru to dark red cells respectively) for the 13 priority variables for each rehabilitation site[1]. Sites are ranked from oldest (top) to youngest (bottom).



[1] two rehabilitation sites (72 and 75) are not included due to missing data

Cost to Benefit of variables

Table 4 shows the relative costs of different survey or sampling methods along with the normalised marginal benefit ascribed to their constituent variables submitted to modelling. These costs relate to the processing of all variables associated with the method prior to data reduction and modelling. For example, seven enzymes were assayed, however only three were submitted to modelling. Therefore, if fewer enzymes were routinely processed, costs may be slightly lower than the $170 per sample as shown below. Full details of costs are provided in Table A10.

Figure 14 clearly shows that the assessment of BAM function variables is relatively cheap and that the assessment of BAM full-floristics and fungal and bacterial meta-barcoding are relatively expensive. Differences in costs for the remaining methods are small.

The cost benefit analysis reveals that variables related to BAM function (*litter cover*, *coarse woody debris*) and *litter fractions* have high benefit and low cost. Variables generated by PLFA (*microbial biomass*, *fungal:bacterial biomass*), MIR or LECO (*total organic carbon*) and LFA (*nutrient, stability, infiltration indices*) all have relatively high benefit and low cost. Variables generated by BAM floristics (*native plant species richness*, *exotic species cover*) plus the *number of native species flowering/fruiting* also have relatively high benefit but also carry higher cost due, in part, to the assumption that a small number of flora samples will be collected for identification purposes and subsequent editing of data will be required.

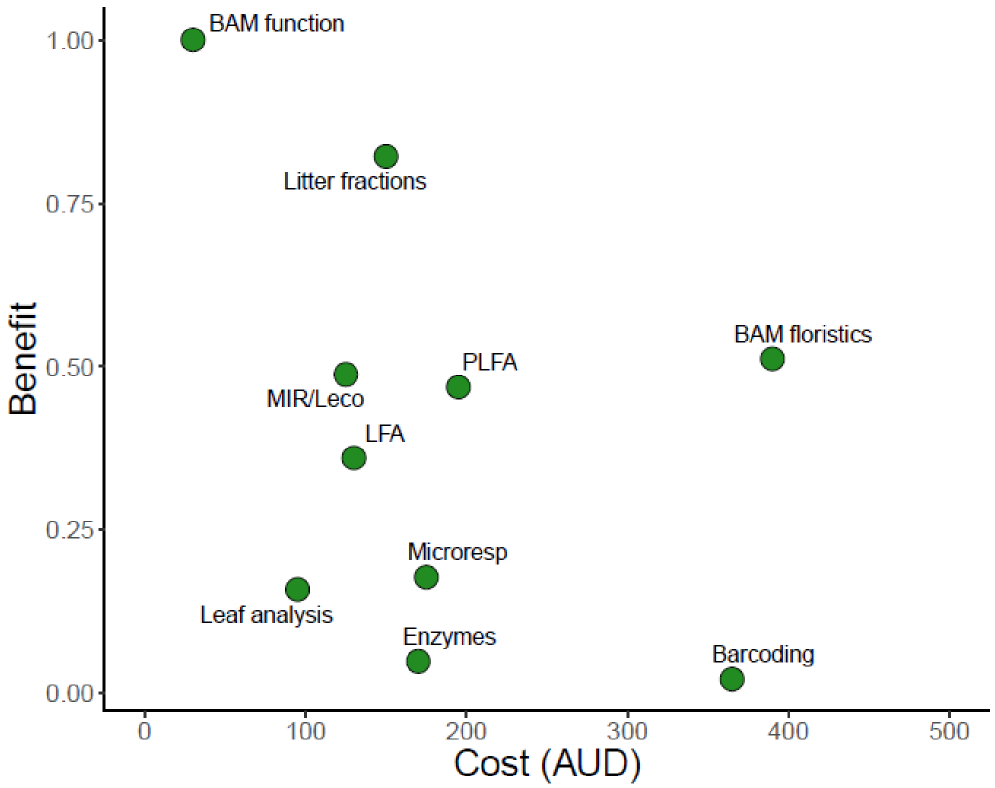


Figure 14. Indicative costs of each method plotted against the highest normalised marginal benefit (variables considered individually) recorded for a variable within each method.

Table 4. Indicative costs[1] for different methods and the relative importance of their constituent variables.

Method	Variable	Normalised importance[3]	Method costs[1]
BAM - function	Litter cover	1.000	$30
	Coarse woody debris	0.616	
MIR or Leco[2]	Total organic carbon	0.488	$125
BAM - floristics	Exotic species cover	0.512	$390
	Number of plant species flowering/fruiting	0.458	
	Number of species of native plants	0.457	
	Native plant growth form diversity	0.007	
PLFA[2]	Fungal:Bacterial biomass	0.469	$195
	Total microbial biomass	0.310	
	Protozoa biomass	0.002	
Meta-barcoding[2]	Fungal functional group diversity	0.022	$365
	Number of fungal OTUs	0.071	
	Number of bacterial OTUs	0.011	
Enzymes[2]	Phosphorus mineralisation (PHOS)	0.004	$170
	Cellulose degradation (CB)	0.013	
	Protein degradation (LAP)	0.049	
Leaf analysis	C:N in leaves of dominant species	0.159	$95
	Specific leaf area of dominant species	0.000	
Litter fractions	Total mass of seeds in litter samples	0.160	$150
	Total mass of litter fractions	0.822	
LFA	Nutrient cycling index	0.360	$130
	Stability index	0.045	
Microresp[2]	Microbial respiration	0.178	$175

[1] Costs relate to one plot (BAM, full-floristics, LFA) or one sample (all other variables). More than one sample per plot will likely be required for any project (for example, 3 leaf samples and 2 soil samples were processed from each plot for this project). The number of samples required will depend on project/monitoring aims.

[2] Costs for each soil sample include sample collection and preparation costs of $90 per sample. Therefore, if multiple soil sample analysis methods were used, this cost would only apply once.

[3.] Normalized importance is based on the estimate of expected log predicted density (ELPD) from models with a single covariate (variable). A larger value suggests that the variable has greater predictive ability when used to independently assess rehabilitated and reference plots.

Probabilistic determination of self-sustainability

Modelling revealed that the most parsimonious model (simplest) contained just six explanatory variables (Table 5): *Litter cover, exotic plant cover, number of species flowering/fruiting, length of coarse woody debris, Fungal:Bacterial biomass* and *total organic carbon*.

The probability of self-sustainability is greater in those rehabilitated sites that have more litter, coarse woody debris, total organic carbon and greater numbers of plant species flowering/fruiting, and less exotic plant cover and a lower Fungal:Bacterial biomass.

Based on the model in Table 5, Figure 15a shows the probability of each rehabilitation plot being grouped with the reference plots and therefore being self-sustainable, and Figure 15b shows the relationship between this probability and rehabilitation age.

Table 5. Six-term model coefficients and confidence intervals. Coefficients with larger absolute values are those with the greatest difference between reference and rehabilitated sites while confidence intervals (5-95%) that include zero (0) suggest greater uncertainty. The intercept is the expected value of the response variable on the logit scale when all of the standardised explanatory variables take a value of 0, which is equivalent to a probability of 0.77.

		Confidence Interval	
Model Terms	Coefficient	5%	95%
Intercept	1.2	-0.8	3.3
Fungal:Bacterial biomass	-1.6	-3.1	-0.4
Litter cover (BAM)	3.3	1.5	5.7
Exotic plant cover	-3.3	-6.5	- 0.7
Plant species flowering/fruiting	2.4	0.8	4.5
Coarse woody debris	2.4	0.5	4.5
Total Organic Carbon	1.1	-1.0	3.4

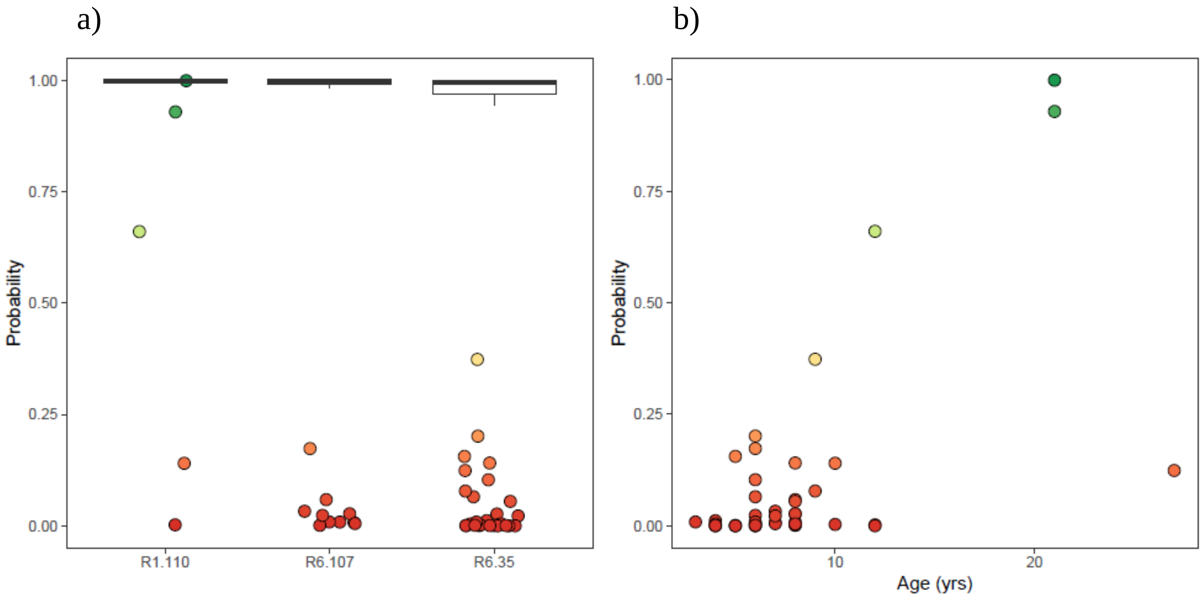


Figure 15. Mean probability of each rehabilitation plot being grouped with the reference plots (a), and the relationship between this probability and rehabilitation site age (b). Points are coloured to aid interpretation and predicted probabilities approaching 1 are green while those approaching 0 are red. Box plots in (a) show the range of predicted values for the reference sites (R1.110 - Central Hunter Spotted Gum-Ironbark Forest, R6.107 - Central Hunter Slaty Gum Grassy Forest, R6.35 - Central Hunter Grey Box-Ironbark Woodland)

The results suggest that two of the older rehabilitated Central Hunter Spotted Gum-Ironbark Forest plots (Sites 65 and 66) have mean predicted values > 0.9 (i.e. > 90% probability of being grouped with the reference sites) and based on the underlying assumptions are highly likely to be self-sustainable. A further rehabilitation plot of the same target PCT (Site 76) has predicted probabilities > 0.5 (> 50% probability) and is likely approaching self-sustainability.

DISCUSSION

How different are plant and microbial communities at rehabilitation and reference sites?

Non-metric multi-dimension plots showed clear differences between rehabilitated and reference sites based on the relative abundance of plant species (using cover data). Plant community types (PCTs) were well separated on the plots for reference sites but there was some overlap at rehabilitation sites. Although more relevant to the concept of “recognisable” PCTs, these findings show that there are still significant differences in species composition and species cover between reference and rehabilitation sites, which is not surprising given the young age of the majority of rehabilitation sites.

Importantly, these findings were also generally observed for microbial communities, although there was evidence that the three oldest rehabilitation sites in Central Hunter Spotted Gum-Ironbark Forest (Sites 64, 65, 66) grouped with the reference communities.

Potential performance indicators for monitoring progress towards self-sustainability

Of the original 84 variables, 23 independent variables from eight performance indicator categories (Tables 1 and 2) were selected for further investigation. Box plots revealed that rehabilitated sites were generally more variable than reference sites, and this variability differed among vegetation communities. That rehabilitated sites are more variable than reference is to be expected, considering the different ages of rehabilitation and different techniques involved in the rehabilitation process. These plots also indicated that for all variables, some rehabilitation sites fell within the reference site inter-quartile range suggesting evidence of self-sustainability for those sites for that variable.

However, the determination of site self-sustainability must include the consideration of multiple variables at a site. Logistic modelling further reduced the 23 variables to a set of 13 high priority variables potentially useful for discriminating early rehabilitation sites (<10 years old) from reference sites. The heat map revealed, however, that no rehabilitation site could be considered self-sustainable on the basis of all 13 variables, but some older sites scored well for multiple variables.

Of the top 13 variables shown in Table 3 and Figure 13, *total mass of litter fractions* was shown to be highly correlated with *BAM litter cover* and more expensive to process. In addition, *glucose*, *seed mass*, and *leaf C:N* revealed little variation among rehabilitation sites and limited difference between reference and rehabilitated sites less than 10 years old.

Our collective analyses therefore suggested the following nine variables as potential performance indicators for monitoring progress towards self-sustainability:

- Litter cover (BAM function)
- Coarse woody debris (BAM function)
- Exotic species cover (BAM function)
- Number of plant species flowering/fruiting (addition to BAM floristics)
- Number of native plants species (BAM floristics)
- Total organic carbon (MIR or Leco)
- Total microbial biomass (PLFA)
- Fungal:Bacterial biomass (PLFA)
- Nutrient cycling index (LFA)

Although our analyses revealed that the *number of native plant species* and the *number of native plant species flowering or fruiting* were significantly correlated, we suggest retaining both due to their potential use as indicators of resistance and renewal (Table 1). It should also be noted that the variable *tree regeneration* was not analysed due to miscommunication about data availability. BAM recruitment assessment of stems < 5cm dbh is not a measure of true regeneration on rehabilitation sites given the majority of these stems were seeded/planted. True second generation tree recruitment was however assessed by Umwelt at all rehabilitation sites but was only recorded at site 76 (established in 2007). At the time of analysis we were unaware of these true recruitment data. Given that regeneration was recorded at all except one reference site (stems < 5 cm dbh) but only at one rehabilitation site (separate specific data) it would undoubtedly have been included as a high priority attribute in our model. We would therefore strongly recommend the inclusion of evidence of true second generation plant recruitment in any self-sustainability monitoring program of ecological rehabilitation.

Towards a cost-benefit assessment of performance indicators of self-sustainability

It is critical that the suite of performance indicators for assessing progress towards self-sustainability consider both the relative benefit and the unit cost of obtaining data on the indicators. Based on a rudimentary benefit cost analysis of the nine variables suggested above, the BAM function attributes provide the highest benefit to cost and the variables derived from BAM floristics the least. However, floristics data are likely to be a monitoring requirement for other purposes with a likely spread of costs among multiple objectives. Importantly, the suggested laboratory-derived indicators (MIR / LECO and PLFA) perform well on the basis of benefit to cost.

Although the cost figures are at best rough approximations, nonetheless they indicate the relative utility of different attributes for assessing progress to self-sustainability.

To what extent do rehabilitated sites meet the criterion of self-sustainability?

While we have suggested a list of nine potential variables for monitoring (plus second generation recruitment), our results suggest that a site’s overall progress can be estimated from a smaller suite of complementary variables. In this case we have developed a logistic regression model that predicts the probability that a rehabilitated site is self-sustainable to a similar extent to that of the sampled reference sites. This model, based on six variables, indicates that, of the sampled rehabilitated sites, two are expected to be self-sustainable (Sites 65 and 66 established in 1998) while a third (Site 76 established in 2007) is approaching self-sustainability. As far as we are aware, this is the first time that an attempt has been made to develop a rigorous scientifically-based procedure for determining the extent to which rehabilitated sites are self-sustaining.

The results suggest that while sites generally become more self-sustainable as they age (Figure 15b), not all older sites are performing well. For example, Figure 13 shows that the oldest site (Site 64), established in 1992, is predicted to not be self-sustaining (predicted probability ~ 0.2). It did, however, group with the reference sites based on fungal and bacterial community composition. Visual presentation of the data using the heat map, can assist in identifying those attributes which may be contributing to a site’s overall performance. In this case, the heat map reveals that Site 64 scored poorly for four of the six variables used in the predictive model of self-sustainability (*coarse woody debris*, *exotic plant cover*, *total organic carbon* and the *number of native species flowering or fruiting*).

Visual identification of attributes scoring poorly can also provide guidance for management actions aimed at improving self-sustainability into the future. For example, *Eucalyptus cladocalyx* (sugar gum) which is indigenous to South Australia was a co-dominant tree at site 64 with 15% foliage cover. Consequently, it was treated as exotic in our analyses. Thinning or removal of this species and the retention of felled trees on site would **in time** improve measures of *coarse woody debris*, *exotic plant cover* and *total organic carbon*. The same would apply to the *Acacia saligna* where it is present. It is however important to recognise that any such management changes would take a number of years to yield benefits to ecological processes and therefore self-sustainability, and also for groundcover vegetation to adapt to changes in light and heat. The same would apply to the addition of *coarse woody debris* to sites where it is lacking. Ideally *coarse woody debris* should be distributed on site at the commencement of ecosystem establishment. Where management actions are undertaken within existing rehabilitation to address self-sustainability, reassessment against self-sustainability completion criteria would need to be undertaken several years post management actions.

It must be emphasised however, that these results are drawn from a single case-study with a limited set of reference and rehabilitated sites. The model coefficients and the relative importance of different variables may vary by vegetation type and study region. Expanding this work to further plant community types would be valuable. The approach taken here using Bayesian logistic models provides a structured formal framework for updating model coefficients and associated uncertainty.

Functional changes in relation to self-sustainability

We found some evidence of logical responses of attributes to changes in self-sustainability while others did not respond in a predicted manner. For example, microbial biomass of the rehabilitation sites was consistently below the median values for the reference sites, particularly in Slaty gum grassy forest and Grey box - Ironbark woodland. Microbial biomass is a measure of microbial activity, and lower values reflect younger soils undergoing soil development, and generally associated with reductions in soil pH with soil age (Zemunik et al. 2015). Young soils have lower levels of organic matter, and lose cations with age, thereby declining in soil pH. Although we did not examine the distribution of pH values at rehabilitated sites, the lower level of microbial biomass at rehabilitation sites is consistent with processes occurring during plant succession and ecosystem development in natural ecosystems (Chadwick *et al.* 1999).

We also found that the fungal to bacterial ratio for rehabilitated sites was substantially greater than that for reference sites, particularly for the Slaty gum grassy forest and Grey box-Ironbark woodland communities, suggesting that fungal biomass is more abundant in degraded or recovering systems. Fungi play multiple key roles in terrestrial environments, are involved in the mineralization of organic matter (organic phosphorus and nitrogen) and the release of CO_2, contribute large amount of microbial biomass to soils (Joergensen and Emmerling 2006), and form mycorrhizal associations with some plants that increase phosphorus uptake (Treseder and Lennon 2015). Despite the greater ratio in rehabilitated sites, we found a significant negative correlation between the fungal to bacterial ratio and both total (upper-, mid- and ground-storey) plant cover and the LFA nutrient index, consistent with our understanding that fungal biomass is relatively greater than bacterial biomass in more degraded systems. This may be due to differences in the fungal requirement for carbon, which is greater than that of bacteria. We also found that the fungal to bacterial ratio was correlated with the LFA nutrient index, and specifically, was positively associated with soil integrity (stability) and negatively associated with litter cover. Notwithstanding the relationships with other site attributes, the higher fungal to bacterial ratio is likely an artefact of the lower bacterial biomass under rehabilitation, hence the greater ratio of fungal biomass to bacterial biomass under rehabilitation.

It is clear from our study that coarse woody debris is generally lacking on rehabilitation sites. Fallen logs and timber or coarse woody debris have been shown to provide critical habitat for a range of surface-active vertebrates and invertebrates (Tongway et al. 1989; MacNally et al. 2001, 2002; Bowman and Facelli 2013) and provide a measure of the extent of animal regeneration (invertebrate abundance and diversity). However, as discussed above the additional of coarse woody debris will take a number of years to yield improvements in ecological processes and therefore self-sustainability. This will need to be taken into consideration when sites are assessed for self-sustainability against completion criteria.

Concluding remarks

We have demonstrated that a potential suite of high priority performance indicators of self-sustainability vary markedly among rehabilitated and reference sites depending on the indicator and the particular plant community type. Our approach to assess self-sustainability has several benefits. From an analytical perspective, it is objective in terms of both model selection and the relative importance provided to each attribute within the predictive model. The system also allows explicit monitoring of progress towards self-sustainability and it can allow managers to rapidly identify those features that are performing well and those that are not. Any comparison of rehabilitated sites against the variability in reference sites for a particular attribute is not restricted to particular seasonal conditions (e.g. good condition years compared with droughts) but allows for conditions to change over time. This allows for a stochastic system in which both reference and rehabilitated sites vary over time and space.

We emphasise, however, that there are a number of caveats of our approach. First, the extent to which rehabilitated sites meet the criteria of self-sustainability is highly dependent upon the status and variability in the reference sites and therefore, the number of reference sites sampled. A larger number of reference sites would likely alter the magnitude of the model coefficients and result in more rigorous assessment of self-sustainability. Second, the variables used in these analyses are generally not direct measures of ecological processes, but rather field- or laboratory-based proxies. Finally, the results are drawn from a single case study with a limited set of reference and rehabilitated sites and a limited set of plant community types. Expanding this work to further plant community types is critical, so that restoration can be assessed against an appropriate set of reference plant communities.

Acknowledgements

The Umwelt team for project support, site selection, data collection and collaboration – Trish Robinson, Belinda Howe, Travis Peake

Nigel Charnock (Glencore) and Bill Baxter (Yancoal) for project support and facilitating mine access

Dr Carmen Castor, CSER Research PL – quadrat cover assessment, leaf collection

Dr David Eldridge, DPIE – data analysis, report preparation

Laura Kuginis, DPIE – leaf, litter, soil collection and project planning

Dr Brian Wilson, UNE – soil chemistry and microbial respiration

Christine Fyfe, UNE – soil chemistry and microbial respiration

Apsara Pubudu Kumari Amarasinghe Kapugahamula Waththe Gedara, UNE – microbial respiration

Dr Jeff Powell, WSU – Meta-barcoding and Bioinformatics

Dr Uffe Nielsen, WSU – Enzyme assays

Dr Yolima Carrillo Espanol, WSU – PLFA analyses

Laura Castaneda Gomez, WSU – PLFA analyses

Chathu Daulagala, WSU – frozen soil sample processing, DNA preparation

Giles Ross, WSU – Enzyme assays

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APPENDICES

Microbial analyses

Microbial enzyme activity (coordinated by Dr Uffe Nielsen, Western Sydney University)

Potential enzyme activities were estimated by measuring enzyme-catalyzed degradation of a substrate bound with a fluorescent dye (Table A1). During incubation, enzymes break the bond between the fluorescent dye and the substrate to acquire C, N or P and the activity of the enzyme in question can then be estimated by comparing the resulting fluorescence using a spectrophotometer microplate reader to that of a standard dilution curve of fluorescence intensities for the specific fluorescent dye of the substrate used in the assay (i.e. 4-methylumbelliferone (MUB) or 7-amino-4-methylcoumarin (MUC)). The following substrates were used for C-rich substrates: β-1,4-glucosidase, β-d-cellubiosidase, α-glucosidase, and β-xylosidase; N-rich substrates β-1,4-N-acetylglucosaminidase and leucine aminopeptidase, and P phosphatase for P-rich substrates. Enzyme assays were performed using a 800uL soil slurry in H_2O buffer following 3 hours incubation at 25 °C, with enzyme activities calculated as nmol activity g^{-1} dry soil hr^{-1}.

Table A1. Enzymes and their potential roles in nutrient cycling

Enzymes	Substrate	Related to potential cycling of	
α-glucosidase	AG	4-Methylumbelliferyl α-D-glucopyranoside	C - Sugar degradation
β-1,4-glucosidase	BG	4-Methylumbelliferyl β-D-glucopyranoside	C - Sugar degradation
β-d-cellubiosidase	CB	4-Methylumbelliferyl β-D-cellobioside	C - Cellulose degradation
β-1,4-N-acetylglucosaminidase	NAG	4-Methylumbelliferyl N-acetyl-β-D-glucosaminide	N - Chitin degradation
phosphatase	PHO	4-Methylumbelliferyl phosphate	P - Phosphorus mineralization
β-xylosidase	XYL	4-Methylumbelliferyl-β-D-xylopyranoside	C - Hemicellulose degradation
leucine aminopeptidase	LAP	L-Leucine-7-amido-4-methylcoumarin hydrochloride	N - Protein degradation

Microbial respiration (coordinated by Dr Brian Wilson, University of New England)

Sample preparation: Soil samples were sieved through a 2.0 mm stainless steel sieve and then stored at 4 ºC until analysis. The gravimetric water content of all the samples were measured by placing a sub sample (5-10 g) in the 105 ºC oven until constant weight was achieved (overnight).

Preparation of deep-well plates: Soil samples were added into wells using a filling device (Sassi et al. 2012). An example of the layout of a deep-well plate demonstrating the positioning of the soil sample and 23 nutrient substrates plus water is shown in Figure A1a and A1b. One sample from each field sample was used for the initial 23 substrate respiration measurement, and two replicate samples used for the seven substrates subsequently selected for further analysis (increasing degrees of freedom for statistical analysis; see PCA analysis below). An average weight of soil added to each cell was calculated on a sample basis. Typically, an average weight for soil across all cells in each plate is used for calculation of soil water addition and respiration rate (Campbell et al. 2003, Sassi et al. 2012), however, in this instance, as four different samples were added in each plate, and to increase confidence, an average weight was calculated on a sample basis.

Moisture content of the soils in the deep-well plates were adjusted to 30% of its maximum water holding capacity by adding water accordingly. Deep-well plates with moisture adjusted soils were incubated at 25 °C for 3-5 days in sealed containers containing a dish of self-indicating soda lime and lined with wet paper towels prior to carrying out MicroResp™ method.

	1	2	3	4	5	6	7	8	9	10	11	12
A	4-O	4-O	4-O	26-O	26-O	26-O	26-T	26-T	26-T	27-O	27-O	27-O
B	4-O	4-O	4-O	26-O	26-O	26-O	26-T	26-T	26-T	27-O	27-O	27-O
C	4-O	4-O	4-O	26-O	26-O	26-O	26-T	26-T	26-T	27-O	27-O	27-O
D	4-O	4-O	4-O	26-O	26-O	26-O	26-T	26-T	26-T	27-O	27-O	27-O
E	4-O	4-O	4-O	26-O	26-O	26-O	26-T	26-T	26-T	27-O	27-O	27-O
F	4-O	4-O	4-O	26-O	26-O	26-O	26-T	26-T	26-T	27-O	27-O	27-O
G	4-O	4-O	4-O	26-O	26-O	26-O	26-T	26-T	26-T	27-O	27-O	27-O
H	4-O	4-O	4-O	26-O	26-O	26-O	26-T	26-T	26-T	27-O	27-O	27-O

a

	1	2	3	4	5	6	7	8	9	10	11	12
A	w	gly	phe	w	gly	phe	w	gly	phe	w	gly	phe
B	ala	his	raf	ala	his	raf	ala	his	raf	ala	his	raf
C	ara	hyp	ser	ara	hyp	ser	ara	hyp	ser	ara	hyp	ser
D	arg	leu	suc	arg	leu	suc	arg	leu	suc	arg	leu	suc
E	asp	lig	thre	asp	lig	thre	asp	lig	thre	asp	lig	thre
F	fru	lys	try	fru	lys	try	fru	lys	try	fru	lys	try
G	gluc	mal	val	gluc	mal	val	gluc	mal	val	gluc	mal	val
H	glut	meth	xyl	glut	meth	xyl	glut	meth	xyl	glut	meth	xyl

b

Figure A1. The layout of sample arrangement (a) and nutrient substrate location (b)

Preparation of detection plates: The colorimetric method depends on the change in the pH of a solution of bicarbonate in quasi-equilibrium with the well headspace in MicroResp. Detection plates were prepared by combining the indicator dye, cresol red (12.5 ppm, wt/wt), potassium chloride (150 mM), and sodium bicarbonate (2.5 mM) in 150 µl of Noble agar (1%) in each well of the detection plate. The agar and indicator solutions were prepared separately and combined in a 1:2 ratio (agar:indicator) prior to use. These plates were stored in sealed plastic boxes with wet paper towels and soda lime to ensure they did not desiccate or react with atmospheric CO_2 until used.

Preparation of substrates: Carbon and amino acids substrate solutions were prepared based on their solubility in water (Table A2). Once the required volume was prepared, the solution was filter sterilized and stored in sterile tubes at 4 °C.

Table A2. Nutrient substrates and their solubility

No	Chemical	Solubility
1	Alanine	H_2O soluble 50 mg/mL, clear, colourless
2	Arabinose	H_2O soluble 100 mg/mL, clear, colourless
3	Arginine	H_2O soluble 50 mg/mL, clear, colourless
4	Aspartic acid	H_2O soluble 50 mg/mL (with heat), clear, colourless
5	Fructose	H_2O soluble 50 mg/mL, clear, colourless
6	Glucose	H_2O soluble 130mg/mL, clear, colourless
7	Glutamine	H_2O soluble 50 mg/mL, clear, slightly hazy
8	Glycine	H_2O soluble 100 mg/mL, clear, colourless
9	Histidine	H_2O soluble 50 mg/mL, clear, colourless
10	Hydroxy-L-proline	H_2O soluble 50 mg/mL, clear, colourless
11	Leucine	H_2O soluble 20 mg/mL, clear, colourless
12	Lignin	H_2O soluble
13	Lysine	H_2O soluble 50 mg/mL, clear, colourless
14	Maltose	H_2O soluble 50 mg/mL, clear, colourless
15	Methionine	H_2O soluble 50 mg/mL, clear, colourless
16	Phenylalanine	H_2O soluble 25 mg/mL, clear, colourless
17	Raffinose	H_2O soluble 50 mg/mL, clear, colourless
18	Serine	H_2O soluble 50 mg/mL, clear, colourless
19	Sucrose	H_2O soluble 342 mg/mL, clear, colourless
20	Threonine	H_2O soluble 50 mg/mL, clear, colourless
21	Tryptophan	H_2O soluble 13.4 mg/mL (with heat), clear, colourless
22	Valine	H_2O soluble 50 mg/mL, clear, colourless
23	Xylose	H_2O soluble 150 mg/mL, clear, colourless

Detection of substrate utilization: Thirty microliters (30 µl) of each prepared substrate and water was added to the pre-incubated soil in the deep-well plates. In order to calculate C utilization, the detection plate colour was measured as absorbance at 570 nm immediately before and after the 24 hr incubation using a microplate reader (Campbell et al. 2003, Burton et al. 2010).

Initially, all 23 substrates and water were tested for a subset of 34 soil samples (17 sites for both Open and Tree samples). Based on the MicroResp data generated, PCA analysis was performed using PRIMER-e software to select the most influenced substrates and the variability of the microbial respiration rates.

Principal Component Analysis (PCA): In PCA, the cumulative proportion was used to determine the amount of variance that the principal components (PCs) explained, and the principal components that explain an acceptable level of variance were retained. Usually, if we want to perform other analyses on the data, we may want to have at least 90% of the variance explained by the PCs. For descriptive purposes, you may only need 80% of the variance explained. In this analysis, the first two PCs explained 90% of the variability in both sites. Therefore the first two components were retained.

Then, to interpret each of the principal components, the magnitude and direction of the coefficients for the original variables were observed. The larger the absolute value of the coefficient, the more important the corresponding variable is in calculating the component. How large the absolute value of a coefficient has to be in order to consider it important is subjective. Based on this, the substrates that show larger coefficients were selected for further testing (Figure 1). Accordingly, out of 23 nutrient substrates, seven (fructose, glucose, maltose, raffinose, sucrose, threonine and xylose) substrates were selected for substrate induced respiration for the Hunter samples (Figure A2), and water utilised for basal respiration rate.

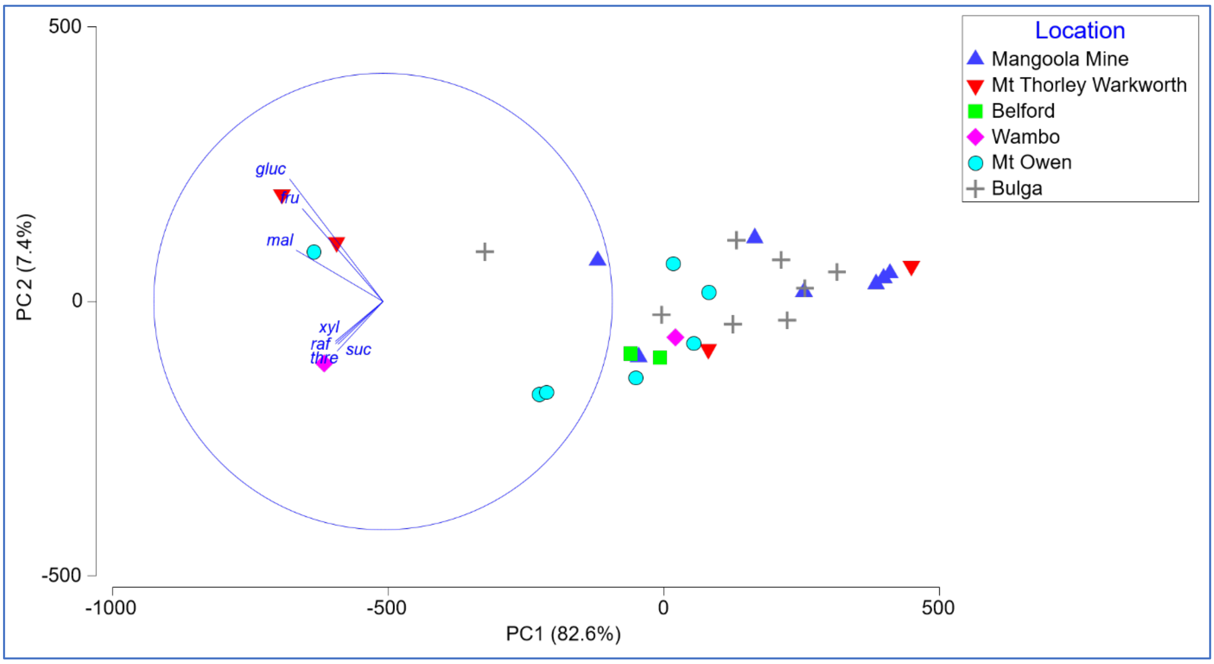

Figure A2. Principal Component Analysis for Hunter samples and selected substrates

PLFA (coordinated by Dr Yolima Carrillo Espanol, Western Sydney University)

Microbial phospholipid-derived fatty acids (PLFA) in soils were extracted from 2 g of homogenized and freeze dried soil following the high throughput method developed by Buyer and Sasser (2012). Soil was extracted with methanol-chloroform-phosphate buffer (2:1:0.8 in volume), then fractionated into lipid types with a silica gel column followed by mild alkaline methanolysis to produce phospholipid fatty acid methyl esters (PLFAME). PLFAME were dried and analysed for composition and quantification of concentration relative to an internal standard via gas chromatography. Gas chromatography was performed on an Agilent 7890A GC (Agilent Technologies, Wilmington, DE, USA) and FAME profiles were identified using the MIDI PLFAD1 calibration mix and the software SHERLOCK version 6.2 (MIDI, Inc., DE, USA). The abundance of individual PLFA was calculated as µg PLFA g^{-1} dry soil and as percentages of total µg PLFA g^{-1} dry soil.

Meta-barcoding (coordinated by Dr Jeff Powell, Western Sydney University)

DNA was extracted from 0.25 g of sieved soil using the DNeasy PowerSoil Kit (Qiagen, Hilden, Germany). DNA concentrations were determined using a NanoDrop 2000 Micro-Volume UV-Vis spectrophotometer (Thermo Scientific, Wilmington, Delaware, USA). DNA samples were diluted to 10 ng/uL prior to PCR amplification. DNA samples were submitted to the Ramaciotti Centre for Genomics (University of New South Wales, Sydney, NSW, Australia). Amplicons of the V4 region of the bacterial rRNA gene were generated using 515f (5'-GTGCCAGCMGCCGCGGTAA-3'; Caporaso et al. 2011) and 806r (5'-GGACTACHVGGGTWTCTAAT-3'; Caporaso et al. 2011). Amplicons to identify fungal taxa were generated using fITS7 (5'-GTGARTCATCGAATCTTTG-3'; Ihrmark et al. 2012) and ITS4 (5'-TCCTCCGCTTATTGATATGC-3'; White et al. 1990). All amplicons purified using the Agencourt AMpure XP system (Beckman Coulter, Lane Cove, NSW, Australia) and genomic libraries were prepared using the Nextera XT Index Kit (Illumina, San Diego, CA, USA). Paired-end (2 x 251 bases) sequencing was performed on the Illumina MiSeq platform.

To process the DNA sequencing data, we used the approach described by Bissett et al. (2016) with a few modifications. Contigs were generated from paired-end reads using the 'make.contigs' command in mothur (version 1.39.5) (Schloss et al. 2009). Initial quality filtering removed DNA sequences containing ambiguous bases and/or homopolymers greater than eight bases in length. De novo operational taxonomic units (OTUs) at 97% sequence similarity were initially picked using numerically dominant sequences (observed at least four times) using the '-cluster_otus' command in USEARCH (version v8.1.1803; Edgar 2010). All quality-filtered sequences were mapped at 97% sequence similarity against representative sequences of these OTUs using the '-usearch_global' command in VSEARCH (version v2.3.4; Rognes et al. 2016). Non-mapped sequences were subjected to a second round of de novo OTU picking, as above but only using sequences observed at least two times. All initially non-mapped sequences were then mapped against these newly picked OTUs, as above. Non-mapped sequences at this step represent singleton OTUs and were excluded from further analysis. Putative taxonomic identities for fungal and bacterial OTUs were generated using BLAST (v.2.6.0, Altschul et al. 1990) to compare representative sequences for each OTU to a reference database of bacterial 16S rRNA gene sequences and taxonomic annotations (bacterial 16S rRNA: greengenes version 13_8, DeSantis et al. 2006; fungal ITS: UNITE version 7.0, Abarenkov et al. 2010). Trophic mode of fungal OTUs that were assigned to taxa were then inferred using FUNGuild (version 1.0; Nguyen et al. 2016).

Soil chemistry *(coordinated by Dr Brian Wilson, University of New England)*

MIR spectra were acquired from neat fine-ground (<100 µm) samples using the PerkinElmer (Shelton, CT, USA) Spectrum One mid-Fourier transform infrared (FTIR) laboratory bench spectrometer equipped with a deuterated triglycine sulphate (DTGS) detector (PerkinElmer, Shelton, CT, USA) and extended-range KBr beam splitter, scanning at a resolution of 8 cm^{-1} to give a spectrum range of 7800–400 cm^{-1} at a 2 cm^{-1} point spacing and with a 0.5 cm s^{-1}

scan speed. Spectrum One CO2/H2O compensation software (PerkinElmer) was used for correction of atmospheric water vapour and CO_2 absorption bands. Subsamples of the powder samples were individually transferred to an autofocusing Perkin-Elmer diffuse reflectance Fourier transform (mid)-infrared (DRIFT) accessory sample cup holder, and the surface of the powder levelled, without compaction, before it was scanned for 1 min.

Samples from the national Soil Carbon Research Program (SCaRP) and the NSW State-wide Land and Soil Condition Monitoring Program (SLSCMP 2016) were used to build partial least squares regression (PLSR) models for TOC, POC, HOC and ROC. Separate calibration (for full cross-validation) and validation (for an independent test set) sample sets were selected randomly from the full dataset. The PLSR calibrations of total organic carbon (TOC%) and the organic carbon fractions POC, HOC and ROC were performed using full leave-one-out cross-validation using the GRAMS PLSplus/IQ software package (Thermo Fisher Scientific, Waltham, MA, USA). The spectra were mean centred and pre-processed with a GRAMS automatic baseline correction function (linear Detrend algorithm) for the optimum spectral range from 4000 to 450 cm^{-1}. All carbon fraction reference data were transformed to a square root of the data before calibration in order to minimise non-linearity in the calibration (Janik et al. 2007; Baldock et al. 2013). The resulting cross-validation and test sample predictions were back-transformed by squaring the PLSR predicted data.

The development of carbon fractionation methodology and MIR calibration has been described in detail by Baldock et al. (2013) but is summarised here briefly. Calibrations for SOC%, POC, HOC and ROC were developed from 258 SCaRP samples collected across Australia. During the measurement of samples to create calibration models, POC was defined as labile carbon in the >50-µm soil fraction that was not ROC (charcoal-like carbon). HOC was defined as humified carbon in the <50- µm soil fraction that was not ROC, and ROC was defined as char-like carbon. Measured values and spectral data from SOC%, POC, HOC and ROC analyses were then used to develop prediction models using PLSR. All spectral analyses were completed using the GRAMS PLSplus (Thermo FisherScientific, Waltham, MA, USA) application.

The robustness of the derived PLSR models for the SOC%, POC, HUM and ROC was evaluated with the 80 independent external validation samples that were analysed for TOC, POC, HOC and ROC by traditional methods at CSIRO Land and Water laboratories (Glen Osmond, SA, Australia). For 80 random validation samples from varying depths, soil types and land uses, there were linear relationships between the fractions estimated using MIR spectra and the actual measurements in an approach outlined in Baldock et al. (2013): R^2= 0.99, 0.79, 0.96 and 0.91 for SOC%, POC, HOC and ROC respectively.

The N calibration procedure was the same as the carbon fraction calibration procedure but used a different calibration data set covering a wide range of soil types and nitrogen values. The Total Nitrogen value for the calibration was obtained by dry combustion analysis by Leco Truemac CN analyser.

Leaf sampling and leaf area and nutrient analysis

(Coordinated by Dr Jennifer Fern, Queensland University of Technology, QUT)

The leaf nitrogen and carbon content were determined using a LECO TruMac, which is based on a combustion technique that uses thermal conductivity relative to pure gas and is considered accurate to within 1%. All other leaf nutrient contents were determined using laser ablation ICPMS after Duodu et al. (2015) with the following exceptions: the internal standard was not added but was the measured C from the combustion analyses, the most abundant naturally occurring element was used, and no extra pulverizing was performed beyond that required for C and N analysis, which consisted of placing a sample and a 2-mm-diameter tungsten carbide ball inside 2-mm plastic centrifuge vials, followed by grinding for 15 min using a TissueLyser©.

Leaves (approximately 0.2 g) were compressed in a hydraulic dye, which produced a pellet approximately 5 mm across and 2 mm tall. These pellets were glued to a plastic tray in groups of ~100 and were placed inside the laser chamber. A New Wave 193-nm excimer laser with a True-line cell was connected to an Agilent 8800 ICPMS. The laser beam was 65 microns in diameter and was rastered across a length of approximately 500 microns for approximately 50 seconds, five times per sample with a 30-second washout or background between rasters. The laser fluence at the laser exit was approximately 2 J/cm^2, and the repetition rate was 7 Hz.

The reference material was NIST NBS peach leaves (USA National Institute of Standards and Technology 2017), and NIST NBS spinach (USA National Institute of Standards and Technology 2014) was used as a monitoring standard; these were analysed every three samples (15 rasters) for moderately close sample-standard bracketing. The average and standard deviation of each element in each sample were calculated and reported after the method presented by (Longerich et al. 1996) using Iloite data reduction software (Paton et al. 2010).

Data reduction - correlation coefficients > 0.7 are highlighted

Table A3. Spearman rank correlations among soil surface condition variables

	Foliage	Basal	LitterCov	LitterOrig	LitterIncorp	Biocrust	Brokenness	Erosion	Deposited	Roughness	Resistance	Slaking
Basal	0.63											
LitterCov	-0.37	0.09										
LitterOrig	-0.16	0.26	0.71									
LitterIncorp	0.06	0.42	0.74	0.70								
Biocrust	0.09	0.33	0.08	0.18	0.26							
Brokenness	0.33	0.24	0.04	-0.03	0.34	-0.05						
Erosion	-0.25	0.23	0.77	0.82	0.69	0.27	0.01					
Deposited	-0.05	0.21	0.47	0.79	0.48	0.03	0.08	0.65				
Roughness	0.49	0.04	-0.58	-0.62	-0.40	-0.15	0.19	-0.63	-0.51			
ResistAdj	-0.49	-0.32	0.23	0.20	-0.05	0.06	-0.54	0.17	0.06	-0.43		
Slake	0.26	0.24	-0.02	0.03	0.22	-0.08	0.48	0.05	0.07	0.15	-0.61	
Texture	0.16	0.09	-0.18	-0.04	0.00	0.02	0.19	-0.03	-0.04	0.15	-0.11	0.12

Table A4. Spearman rank correlations among soil chemistry variables

	HUM%	POC%	ROC%	TOC%	N%	P	pH
POC%	0.98						
ROC%	0.99	0.98					
TOC%	1.00	0.99	1.00				
N%	0.99	0.99	0.99	0.99			
P	0.88	0.90	0.88	0.89	0.90		
pH	0.84	0.83	0.85	0.84	0.86	0.84	
EC	0.76	0.74	0.76	0.76	0.77	0.78	0.85

Table A5. Spearman rank correlations among soil biology (respiration) variables

	Fruc	Gluc	Mal	Raf	Suc	Thre	W
Gluc	0.967						
Mal	0.938	0.944					
Raf	0.935	0.943	0.951				
Suc	0.929	0.943	0.955	0.965			
Thre	0.89	0.908	0.93	0.933	0.938		
W	0.858	0.856	0.872	0.879	0.856	0.925	
Xyl	0.843	0.849	0.86	0.861	0.865	0.901	0.863

Table A6. Spearman rank correlations among soil biology (enzyme) variables

	AB	BG	CB	NAG	PHOS	XYL
BG	0.809					
CB	0.790	0.896				
NAG	0.612	0.723	0.669			
PHOS	0.555	0.723	0.627	0.826		
XYL	0.874	0.839	0.849	0.700	0.632	
LAB	0.395	0.421	0.335	0.282	0.195	0.42

Table A7. Spearman rank correlations among soil biology (biomass) variables

	MicrBiom	G+Biom	G-Biom	BacterBiom	ActinoBiom	FungalBiom	ProtoBiom	AMFBiom
G+Biom	0.96							
G-Biom	0.95	0.91						
BacterBiom	0.96	0.92	0.91					
ActinoBiom	0.76	0.78	0.63	0.70				
FungalBiom	0.47	0.35	0.40	0.51	0.23			
ProtoBiom	0.24	0.14	0.20	0.20	0.04	0.33		
AMFBiom	0.72	0.63	0.58	0.60	0.73	0.35	0.24	
FungitoBact	-0.21	-0.33	-0.29	-0.16	-0.29	0.69	0.17	-0.07

Table A8. Spearman rank correlations among litter fraction variables

	Sticks&Bark	Leaf-Tree	Leaf-Groundstorey	Frass-Coarse	Frass-Fine
Leaf-Tree	0.716				
Leaf-groundstorey	-0.306	-0.169			
Frass-Coarse	0.831	0.799	-0.164		
Frass-Fine	0.731	0.673	-0.074	0.825	
Woodies	0.129	0.16	-0.068	0.214	0.163
Total mass	0.903	0.785	-0.188	0.944	0.887

Table A9. Spearman rank correlations among plant recruitment/health variables

	No species flowering/fruiting	Exotic cover	Leaf C:N	SLA
Exotic cover	-0.033			
Leaf C:N	0.160	0.009		
SLA	-0.033	-0.263	-0.412	
Fruit mass in litter	0.260	-0.121	0.236	0.062

Table A10. Breakdown of costs for different methods (time is in hours)

	Technical Officer	**$100**	**per hour**			**Specialist**	**$180**	**per hour**					
Method-dataset-indicator	**Mean field time / sample**	**Mean office time / sample**	**Mean lab time / sample**	**TOTAL Technical Officer time**	**TOTAL Technical Officer Cost**	**Mean time per sample - hr**	**TOTAL specialist cost**	**Lab All-inclusive cost / sample OR consumables, instrument time**	**Summed cost / sample**	**Summed cost / 100 samples**	**Plus specialist support and interpretation**	**Soil collection / preparation for each indicator**	**TOTAL PROJECT RELATED COST 100 samples**
Leaf nutrients	0.5			**0.5**	**50**			$45	$95	$9,500			**$9,500**
Floristics		0.3		**0.3**	**30**	2	$360		$390	$39,000			**$39,000**
BBAM	0.3	0.2		**0.5**	**50**				$50	$5,000			**$5,000**
BAM	0.3			**0.3**	**30**				$30	$3,000			**$3,000**
LFA	1.0	0.3		**1.3**	**130**				$130	$13,000			**$13,000**
Litter (mean of 500g)	0.5		1.00	**1.5**	**150**				$150	$15,000			**$15,000**
soil collection	0.5			**0.5**	**50**				**$50**	**$5,000**			
soil prep-sieving, drying, sub-sampling			0.40	**0.4**	**40**				**$40**	**$4,000**			
N & C fractions (MIR+20%Leco)								$35	$35	$3,500		$9,000	**$12,500**
P			0.25	**0.25**	**25**			$3	$28	$2,800		$9,000	**$11,800**
EC & pH			0.10	**0.1**	**10**				$10	$1,000		$9,000	**$10,000**
Microresp (7 substrates+water)			0.40	**0.4**	**40**				$40	$4,000	$4,500	$9,000	**$17,500**
Enzymes (7 enzymes)			0.20	**0.2**	**20**			$15	$35	$3,500	$4,500	$9,000	**$17,000**
PLFA			0.40	**0.4**	**40**			$20	$60	$6,000	$4,500	$9,000	**$19,500**
Meta-barcoding (fungi&bacteria)			0.30	**0.3**	**30**			$200	$230	$23,000	$4,500	$9,000	**$36,500**

APPENDIX 2

Rainfall Data

Appendix 2 – Rainfall Data

Table A2.1 – Rainfall data for twelve months preceding field surveys at weather stations closest to mine sites

Mine	Weather Station	Data type	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	12 Month Cumulative	Annual
Mangoola	Mangoola Mine Meteorological Data	Actual Rainfall*	45.4	27.8	6.2	19.8	0.2	40.4	12.6	35.6	57.6	74.6	24.8	22			**367**	
	Mangoola (Lindisfarne)	Actual Rainfall	66	13	7	22	0	31	24.5	*85*	58.5	*92*	-	14			**413**	
		Mean (all years)	60	36.5	40.7	37.8	29.6	30.1	38.9	50.3	57.7	64.4	77.9	60.2				**593**
		10th percentile (all years)	7.9	0	4.3	3.8	0	0	4.3	7	12.1	19.8	9.6	8.5				**415.2**
		20th percentile (all years)	15.8	1.1	10.4	9.0	4.9	5.4	15.5	16.8	30.2	34.7	29.0	15.4				**480.9**
		90th percentile (all years)	128.4	81.9	97	73.7	58.4	70.8	71.8	84.8	106.8	121.9	175	128.1				**765.2**
MTW	Bulga (Down Town)	Actual Rainfall	62.2	10.8	7.8	30.6	2.6	14.4	32.2	74.4	51.2	*50.4*	56.4	30.6			**423.6**	
		Mean (all years)	75.9	46.1	45.6	45.1	26	34.3	38.1	55.4	67.5	77.9	86	85.3				**682.4**
		10th percentile (all years)	19.2	4.7	7.9	6.4	5	5.3	8.8	7.8	13.1	22.4	21	18				**455.9**
		20th percentile (all years)	32.8	10.1	10.7	14.6	7.6	9.0	17.4	22.6	28.5	36.9	35.2	22.8				**539.3**
		90th percentile (all years)	159.5	96.3	104.5	86.3	55.7	72.9	75.4	105.3	135.6	138.3	189.8	169.4				**893.1**

Mine	Weather Station	Data type	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	12 Month Cumulative	Annual
United	Bulga (South Wambo)	Actual Rainfall		11.5	6.7	32.8	2.1	*19.9*	28.6	*96.7*	49.5	*45.2*	59.6	21	*145.6*		**519.2**	
		Mean (all years)		45.9	40.3	44.1	30	34.2	38.5	54.3	62.3	72.8	86.6	84.2	66.7			**662.5**
		10th percentile (all years)		3.4	6.7	7	3.8	4.8	11.2	9.1	11.3	18.7	21.5	17.9	15.2			**478.2**
		20th percentile (all years)		10.9	14.5	14.7	8.1	8.9	15.2	21.0	22.6	33.8	32.6	26.6	26.3			**565.3**
		90th percentile (all years)		98.2	91.9	89.8	63.9	67.8	79	101.8	130.6	131	195.7	170.2	147.7			**844.9**
MTO	Bowmans Creek (Grenell)	Actual Rainfall			8.6	52.6	3.4	*44*	*29.4*	*81.8*	*86.2*	*92.8*	53.2	*60.8*	*187.2*	*2.4*	**702.4**	
		Mean (all years)			57.5	67.6	45.5	46.7	54.5	66	84.9	84.6	104.6	90.5	98.4	58		**859.3**
		10th percentile (all years)			14.4	25.8	14.4	9.8	17.5	14.5	22.7	26.8	25.8	17.5	28.2	4.6		**623.7**
		20th percentile (all years)			19.5	33.0	21.4	15.9	20.8	24.0	33.2	36.6	51.4	30.8	37.8	14.9		**683.9**
		90th percentile (all years)			120	120.5	82.2	88.2	104.8	104.4	146.5	177.4	201.2	175.2	187.6	129.6		**1098**
Bulga	Bulga (Down Town)	Actual Rainfall			7.8	30.6	2.6	14.4	32.2	74.4	51.2	*50.4*	56.4	30.6	*138.8*	*3.6*	**493**	
		Mean (all years)			45.6	45.1	26	34.3	38.1	55.4	67.5	77.9	86	85.3	75.9	46.1		**682.4**
		10th percentile (all years)			7.9	6.4	5	5.3	8.8	7.8	13.1	22.4	21	18	19.2	4.7		**455.9**
		20th percentile (all years)			10.7	14.6	7.6	9.0	17.4	22.6	28.5	36.9	35.2	22.8	33.5	9.9		**539.3**
		90th percentile (all years)			104.5	86.3	55.7	72.9	75.4	105.3	135.6	138.3	189.8	169.4	159.5	96.3		**893.1**

Notes:

Data sourced from Bureau of Meteorology (2019), except where otherwise indicated

*Data sourced from Mangoola Mine (2019)

Data within the table which are in italics represent observations which have not been fully quality controlled, a process which may take a number of months to complete. While these data may be correct, one should exercise caution in their use (Bureau of Meteorology 2019).

Gaps occur in the table where there are missing valid daily observations within the month. This is frequently associated with the observer being unavailable (where observations are undertaken manually), a failure in the observing equipment, or when an event has produced suspect data (Bureau of Meteorology 2019).

APPENDIX 3

Mine rehabilitation establishment, management and monitoring information

The following information, which supplements Section 6.1 of the main report, was compiled during the desktop review of mine documentation such as MOPs, management plans and monitoring reports from the target coal mines.

A3.1 Mangoola

Mangoola Coal has used similar rehabilitation establishment techniques throughout the life of their rehabilitation program. The following information is relevant for all the Mangoola rehabilitation sites discussed in the report.

Targeted Plant Communities (from Department of Planning and Environment 2017a)

- Ironbark Woodland Complex
- Bulloak Woodland
- Paperbark Woodland
- Slaty Box Woodland
- Forest Red Gum Riparian Woodland
- Rough Barked Apple Woodland
- Swamp Oak Riparian Forest and
- Weeping Myall Woodland.

Treatment of substrate for the plantings

The following information is extracted from the Mangoola Annual Rehabilitation and Closure Plan (Mangoola Coal 2019)*:*

> *<u>Topsoil</u>*
>
> *Topsoil is loaded and hauled from the stockpiles and spread over specified area at 100mm depth. Wherever possible, direct placement of topsoil is carried out, and this is preferable to topsoil stockpiling.*
>
> *<u>Gypsum Application</u>*
>
> *Gypsum application is undertaken immediately following topsoil spreading. Gypsum is applied at 5 tonnes per hectare.*
>
> *<u>Ripping</u>*
>
> *Double ripping is undertaken immediately following gypsum application. Double ripping is carried out in order to incorporate the gypsum, topsoil and overburden adequately. The ripping depth varies dependent upon the area, however is generally in accordance with **Table A3.1**.*

Table A3.1 - Rehabilitation ripping depth (Table 9.1 in Mangoola Coal 2019)

Slope (Degrees)	Land Use	Ripping Depth
>5	Woodland	600mm
0-5	Woodland	400mm
0-5	Grassland	100mm

Ripping may be required in an area prior to topsoil spreading. This will be a single pass and will occur if a medium to high rainfall event is predicted and topsoil/gypsum application has not been completed or if topsoil/gypsum application is on hold (Mangoola Coal 2019).

Planting method

Direct seeding is used to establish the vegetation on the rehabilitation areas. Infill planting has been used in some areas of the rehabilitation if a deficiency in certain species is detected (D. Ryba pers. comm. 2018)

Planting mix used

The planting mixed used varies depending on the target vegetation community Mangoola is attempting to establish. **Table A3.2** describes the typical seeding mixes used (Mangoola Coal 2016). It should be noted that seeding mixes vary due to availability.

Table A3.2 - Typical seed mix for Slaty Box and Ironbark Woodland (Table 7.4 in Mangoola Coal 2016**)**

Slaty Box		Ironbark Woodland	
Species	Sowing rate kg/ha)	Species	Sowing rate (kg/ha)
Eucalyptus dawsonii	0.2	*Eucalyptus moluccana*	0.4
Eucalyptus moluccana	0.1	*Eucalyptus crebra*	0.4
Eucalyptus crebra	0.1	*Allocasuarina littoralis*	0.2
Eucalyptus blakelyi	0.1	*Allocasuarina gymnanthera*	0.1
Cassinia arcuata	0.2	*Acacia parvipinnula*	0.2
Allocasuarina gymnanthera	0.2	*Acacia salicina*	0.3
Acacia parvipinnula	0.2	*Acacia falcata*	0.2
Acacia salicina	0.3	*Acacia decora*	0.3
Acacia falcata	0.3	*Dodonaea viscosa*	0.3
Acacia decora	0.5	*Bothriochloa macra*- mix	1
Dodonaea viscosa	0.5	*Cynodon dactylon*	1
Bothriochloa macra-mix	1	Oats/Jap Millet	5
Cynodon dactylon	1		
Oats/Jap Millet	5		
Total	**9.4**	**Total**	**9.4**

Management treatments occurring on site

Table A3.3 summarises the management treatments used by the Mangoola in the rehabilitation areas.

Table A3.3 - Summary of management actions that have occurred in Mangoola rehabilitation areas (D. Ryba pers. comm. 2018)

Management Action	Notes
Supplementary planting	Infill planting has occurred in areas identified as being deficient in certain species
Thinning of vegetation	Where required
Erosion control	Where required
Weed management	Autumn to Spring
Controlled burning	No
Feral animal control	Yes, in the wider area (i.e. remnant vegetation owned by the mine)

Rehabilitation Monitoring

Monitoring has been conducted by several different companies. From 2014 onwards, there was a change from surveying in every season to surveying annually in spring (Forest Fauna Surveys Pty Ltd and Eastcoast Flora Survey 2016).

Monitoring methods used to date include:

- 400 m^2 floristic plot (actual cover and actual abundance).
- Landscape Function Analysis.
- Transect monitoring consistent with BioBanking method (2016-2017).
- Comparison to reference sites in adjoining bushland
- Fauna surveys (birds, bats, herpetofauna, molluscs (Umwelt 2018a),
- Soil monitoring includes:
    - pH
    - Cation exchange capacity (Mangoola Coal 2016).

Mangoola Mine introduced a revised monitoring approach in 2020 which is aligned with the BAM. The new monitoring approach supersedes the methods described above.

A3.2 Mount Thorley Warkworth

Mount Thorley Warkworth (MTW) have trialled a range of different establishment techniques. These have been summarised in **Table A3.4**.

Table A3.4 - Rehabilitation establishment summary for MTW target sites (Niche 2017)

Rehabilitation area	ACARP site number	Area (ha)	Establishment date	Soil and seeding information
MTWNPN2009	46	21.8	2010	Topsoil, native seed broadcasted in 2010
MTWCDD2011	49	8.1	2011	Topsoil, native seed hydroseeded
MTWNPN2011	59, 60	43.3	2011	Topsoil, natives hydroseeded 2011
MTWWDL2014	50	4.7	2014	Compost (with topsoil), natives drilled 2015
MTWCDD2015	48	6.4	2015	Compost (with spoil), natives drilled
MTWTD12015	47	20.6	2015	Compost (with spoil), natives drilled

Targeted Plant Community

MTW are operating under two Development Consent conditions, both require post mined lands be rehabilitated to conform to the Central Hunter Grey Box – Ironbark Woodland EEC (Niche 2018).

Treatment of substrate for the plantings

Refer to **Table A3.4**.

Planting method

Refer to **Table A3.4**.

Planting mix used

A variety of seeding mixes have been used by MTW at each of the rehabilitated areas listed in **Table A3.4**. See **Tables A3.5** to **A3.8** for seeding lists**.**

Table A3.5 - Seed mix used at MTWCDD201101 (B. Baxter pers. comm. 2019)

Species	Rate kg/ha	Species	Rate kg/ha
Acacia amblygona	0.018	*Dichondra repens*	0.007
Acacia buxifolia	0.267	*Digitaria brownii*	0.060
Acacia deanei	0.200	*Dodonaea viscosa* subsp. *cuneata*	0.400
Acacia decora	0.367	*Einadia nutans*	0.067
Acacia decurrens	0.175	*Einadia trigonos*	0.017
Acacia falcata	0.300	*Enchylaena tomentosa*	0.087
Acacia implexa	0.367	*Eragrostis elongata*	0.050
Acacia longifolia	0.082	*Eremophila debilis*	0.100
Acacia paradoxa	0.017	*Eragrostis leptostachya*	0.033
Acacia salicina	0.100	*Eucalyptus crebra*	0.140
Allocasuarina littoralis	0.075	*Eucalyptus fibrosa*	0.175

Species	Rate kg/ha	Species	Rate kg/ha
Allocasuarina luehmannii	0.035	*Eucalyptus moluccana*	0.197
Angophora floribunda	0.045	*Eucalyptus punctata*	0.030
Austrodanthonia setacea	0.333	*Gahnia aspera*	0.133
Austrostipa densiflora	0.067	*Geijera parvifolia*	0.100
Austrostipa ramosissima	0.047	*Hardenbergia violacea* climbing	0.200
Austrostipa scabra	1.333	*Indigofera australis*	0.053
Bothriochloa macra	2.000	*Linum marginale*	0.019
Brachychiton populneus	0.100	*Microlaena stipoides*	2.000
Bursaria spinosa	0.107	*Myoporum montanum*	0.047
Calotis lappulacea	0.001	*Notelaea microcarpa*	0.018
Capillipedium spicigerum	0.050	*Olearia elliptica*	0.042
Carex incomitata	0.010	*Ozothamnus diosmifolius*	0.027
Cassinia arcuata	0.100	*Podolepis neglecta*	0.033
Chloris truncata	1.667	*Eragrostis brownii*	0.005
Chrysocephalum apiculatum	0.001	*Rhagodia spinescens*	0.022
Cymbopogon refractus	0.067	*Sporobolus creber*	0.021
Daviesia genistifolia	0.038	*Themeda triandra*	5.000
Dianella caerulea	0.100	*Vittadinia muelleri*	0.011
Dichanthium sericeum	0.667		
Total			**17.82887**

Table A3.6 - Seed mix used at MTWNPN201101 (B. Baxter pers. comm. 2019)

Species	Rate kg/ha	*Species*	Rate kg/ha
Acacia amblygona	0.013	*Eragrostis leptostachya*	0.029
Acacia cultriformis	0.040	*Eucalyptus crebra*	0.085
Acacia deanei	0.161	*Eucalyptus fibrosa*	0.175
Acacia decora	0.308	*Eucalyptus moluccana*	0.092
Acacia falcata	0.167	*Eucalyptus punctata*	0.030
Acacia filicifolia	0.283	*Gahnia aspera*	0.104
Acacia hakeoides	0.213	*Geijera parviflora*	0.094
Acacia implexa	0.259	*Hardenbergia violacea* climbing	0.258
Acacia longifolia	0.111	*Hardenbergia violacea* shrub	0.137
Acacia salicina	0.118	*Ozothamnus diosmifolius*	0.045
Allocasuarina littoralis	0.165	*Swainsona galegifolia*	0.094
Angophora floribunda	0.045	*Wahlenbergia stricta*	0.002

Species	Rate kg/ha	Species	Rate kg/ha
Brachychiton populneus	0.094	*Austrostipa densiflora*	0.19
Callistemon pinifolius	0.006	*Austrostipa scabra*	1.42
Carex incomitata	0.022	*Bothriochloa macra*	1.89
Chrysocephalum semipapposum	0.024	*Capillipedium spicigerum*	0.23
Corymbia maculata	0.175	*Chloris truncata*	1
Daviesia ulicifolia subsp. *ulicifolia*	0.085	*Dichanthium sericeum*	1.46
Dianella revoluta	0.008	*Dichelachne crinita*	0.03
Dodonaea viscosa subsp. *cuneata*	0.377	*Joycea pallida*	0.47
Einadia nutans	0.047	*Microlaena stipoides*	1.51
Eragrostis elongata	0.042	*Podolepis neglecta*	0.05
Eremophila debilis	0.094	*Themeda triandra*	5.33
Total			**17.58448**

Table A3.7 - **Seed mix used at MTWWLD201401** (B. Baxter pers. comm. 2019)

Species	Rate kg/ha	Species	Rate kg/ha
Eucalyptus crebra	0.200	*Einadia nutans*	0.071
Eucalyptus fibrosa	0.057	*Einadia polygonoides*	0.014
Eucalyptus moluccana	0.071	*Einadia trigonos*	0.014
Corymbia maculata	0.071	*Enchylaena tomentosa*	0.129
Eucalyptus dawsonii	0.014	*Eremophila debilis*	0.029
Eucalyptus glaucina	0.014	*Hibbertia obtusifolia*	0.014
Eucalyptus punctata	0.007	*Solanum cinereum*	0.043
Eucalyptus tereticornis	0.050	*Ajuga australis*	0.043
Jacksonia scoparia	0.029	*Glycine clandestina*	0.014
Kunzea ambigua	0.021	*Pomax umbellata*	0.014
Melaleuca decora	0.021	*Swainsona galegifolia*	0.143
Melaleuca nodosa	0.029	*Paspalidium distans*	0.571
Mentha satureioides	0.014	*Carex fascicularis*	0.071
Panicum effusum	0.143	*Dianella caerulea*	0.071
Sporobolus creber	0.071	*Gahnia aspera*	0.143
Imperata cylindrica	0.214	*Lomandra longifolia*	0.186
Fimbristylis dichotoma	0.029	*Callitris endlicheri*	0.029
Angophora floribunda	0.014	*Cassinia arcuata*	0.143
Acacia implexa	0.100	*Cassinia quinquefaria*	0.071

Species	Rate kg/ha	Species	Rate kg/ha
Acacia parvipinnula	0.107	*Hakea sericea*	0.014
Acacia salicina	0.014	*Olearia elliptica*	0.043
Allocasuarina luehmannii	0.029	*Ozothamnus diosmifolius*	0.143
Brachychiton populneus	0.114	*Pandorea pandorana*	0.014
Bursaria spinosa	0.086	*Calocephalus citreus*	0.043
Notelaea microcarpa	0.021	*Calotis* spp.	0.100
Acacia cultriformis	0.086	*Chrysocephalum apiculatum*	0.071
Acacia falcata	0.286	*Desmodium brachypodum*	0.014
Acacia spectabilis	0.129	*Podolepis neglecta*	0.014
Acacia amblygona	0.071	*Vittadinia sulcata*	0.029
Acacia brownii	0.029	*Austrostipa scabra*	1.429
Acacia decora	0.286	*Bothriochloa macra*	2.000
Acacia paradoxa	0.114	*Chloris truncata*	1.429
Daviesia genistifolia	0.036	*Aristida ramosa*	0.429
Daviesia ulicifolia	0.114	*Austrodanthonia setacea*	0.571
Hardenbergia violacea	0.200	*Austrostipa bigeniculata*	0.143
Indigofera australis	0.314	*Capillipedium spicigerum*	0.143
Podolobium ilicifolium	0.029	*Dichanthium sericeum*	0.357
Pultenaea spinosa	0.029	*Eulalia aurea*	0.143
Dodonaea viscosa subsp. *cuneata*	0.100	*Themeda avenacea*	0.214
Eremophila deserti	0.029	*Themeda triandra*	2.857
Myoporum montanum	0.043	*Austrostipa verticillata*	0.214
Senna artemisioides subsp. *zygophylla*	0.079	*Cymbopogon refractus*	0.214
Atriplex semibaccata	0.171	*Microlaena stipoides*	0.571
Einadia hastata	0.014	*Poa labillardierei*	0.286
Total			**17.000**

Table A3.8 - Seed mix used at MTWCDD201501 (B. Baxter pers. comm. 2019)

Species	Rate kg/ha	Species	Rate kg/ha
Eucalyptus crebra	0.143	*Pultenaea spinosa*	0.029
Eucalyptus fibrosa	0.071	*Dodonaea viscosa* subsp. *cuneata*	0.143
Eucalyptus moluccana	0.114	*Hakea sericea*	0.007
Corymbia maculata	0.071	*Myoporum montanum*	0.007
Eucalyptus dawsonii	0.007	*Senna artemisioides* subsp. *zygophylla*	0.114

Species	Rate kg/ha	Species	Rate kg/ha
Eucalyptus glaucina	0.029	*Atriplex semibaccata*	0.143
Eucalyptus punctata	0.029	*Einadia nutans*	0.043
Eucalyptus tereticornis	0.014	*Einadia polygonoides*	0.029
Kunzea ambigua	0.014	*Einadia trigonos*	0.043
Melaleuca decora	0.029	*Enchylaena tomentosa*	0.129
Melaleuca nodosa	0.021	*Solanum cinereum*	0.114
Imperata cylindrica	0.006	*Swainsona galegifolia*	0.100
Angophora floribunda	0.007	*Dianella caerulea*	0.121
Acacia implexa	0.043	*Gahnia aspera*	0.214
Acacia parvipinnula	0.143	*Carex fascicularis*	0.021
Acacia salicina	0.029	*Lomandra longifolia*	0.143
Allocasuarina luehmannii	0.036	*Cassinia arcuata*	0.114
Brachychiton populneus	0.143	*Cassinia quinquefaria*	0.114
Bursaria spinosa	0.064	*Olearia elliptica*	0.071
Notelaea microcarpa	0.043	*Ozothamnus diosmifolius*	0.114
Acacia cultriformis	0.157	*Ajuga australis*	0.043
Acacia falcata	0.171	*Calocephalus citreus*	0.029
Acacia spectabilis	0.171	*Calotis lappulacea*	0.071
Acacia amblygona	0.071	*Chrysocephalum apiculatum*	0.071
Acacia brownii	0.029	*Podolepis neglecta*	0.043
Acacia decora	0.286	*Pomax umbellata*	0.071
Acacia paradoxa	0.114	*Vittadinia sulcata*	0.071
Daviesia genistifolia	0.057	*Capillipedium spicigerum*	0.259
Daviesia ulicifolia	0.171	*Themeda avenacea*	0.081
Hardenbergia violacea	0.257	*Themeda triandra*	0.134
Indigofera australis	0.179	*Austrostipa verticillata*	0.100
Jacksonia scoparia	0.029	*Microlaena stipoides*	0.500
Podolobium ilicifolium	0.029	*Berryman Mix	8.642
Total			**11.83693**

**Note: Berryman Mix is a mixed species harvest from paddocks at Mt Pleasant near Muswellbrook. It is mainly composed of seed from the following species: Aristida spp., Austrodanthonia spp., Austrostipa spp., Bothriochloa decipiens, Bothriochloa macra, Chloris truncata, Chloris ventricosa, Cymbopogon refractus, Dichanthium sericeum, Digitaria brownii, Enteropogon acicularis, Eragrostis spp., Sporobolus, Eulalia aurea and Panicum spp.*

Management treatments occurring on site

Table A3.9 summarises the management treatments used by MTW in the rehabilitation areas.

Table A3.9 - Summary of management actions that have occurred in MTW rehabilitation areas (MTW 2016)

Management Action	Notes
Supplementary planting	No supplementary plantings have occurred
Thinning of vegetation	Where required
Erosion control	Where required
Weed management	Yes
Controlled burning	No
Feral animal control	Yes

Rehabilitation Monitoring

MTW monitoring methods (as of 2017) (Mount Thorley Warkworth Operations 2016; Niche 2017):

- Landscape Function Analysis
- BioBanking method (OEH 2014)
- 400 m^2 floristic plot (abundance method species richness).
- Soil Analysis, assessing: pH, EC, Available Ca, Mg, K, Ammonia, sulphur, organic matter, exchangeable Na, Ca, Mg, K, H, Al, cation exchange capacity, available and extractable phosphorus, micronutrients (Zn, Mn, Fe, Cu, B), Total Carbon and Nitrogen.
- Photo monitoring
- For the past two years monitoring has been conducted in February
- The reference site BVTs are either:
    - HU701 Central Hunter Grey Box-Ironbark Woodland, or
    - HU632 Central Hunter Ironbark-Spotted Gum-Grey Box Forest.

A3.3 Mount Owen

Mount Owen has been establishing rehabilitation since 1998. Differing rehabilitation establishment methods have been trialled. **Table A3.10** summarises the rehabilitation establishment methods for each study site.

Table A3.10 - Rehabilitation establishment summary for Mount Owen target sites

Monitoring Site Number	ACARP Site Number	Establishment Year	Soil treatment and Seed List
14	65	1998	Seeded on 10cm forest topsoil, over spoil, using components of **Table A3.11** and **Table A3.12**. Soil either direct transfer or stockpiled for a short time.
16	66	1998	Seeded on 10cm forest topsoil, over spoil, using components of **Table A3.11** and **Table A3.12**. Soil either direct transfer or stockpiled for a short time.
18	76	2007	Seeded on forest topsoil 10cm direct transferred (or very short storage in stockpiles) and seeded only with canopy species (**Table A3.11**).
28	75	2007	Seeded on forest topsoil 10cm direct transferred (or very short storage in stockpiles) and seeded only with canopy species (**Table A3.11**).
30	74	2007	Seeded on forest topsoil 10cm direct transferred (or very short storage in stockpiles) and seeded only with canopy species (**Table A3.11**).
37	67	2009	Seeded on 5cm forest topsoil that was a direct transferred or had short stockpile storage. Seed mixes variable (some additions to lists **Table A3.11** and **Table A3.12**).
38	72	2009	Seeded on 10cm forest topsoil that was a direct transferred or had short stockpile storage. Seed mixes variable (some additions to lists **Table A3.11** and **Table A3.12**).
39	73	2010	Seeded on 10cm forest topsoil that was a direct transferred or had short stockpile storage. Seed mixes variable (some additions to lists **Table A3.11** and **Table A3.12**).

Targeted plant community

The overall objectives of the current Mount Owen Complex Mining Operations Plan January 2017 – December 2021 (SLR 2017) of the proposed post-mining land use design are:

- *Establish a vegetation community consistent with the Central Hunter Ironbark – Spotted Gum – Grey Box Forest on the post mining landform;*
- *Contribute to effective regional native corridors that promote fauna movements between the MOC, Ravensworth Surface Operations, Liddell Coal Operations, Lake Liddell and the Liddell and Ravensworth Operations Hillcrest Offset Area;*

- *Maintain and provide additional suitable habitat for a range of threatened fauna species including the spotted-tailed quoll (Dasyurus maculatus maculatus);*
- *Provide opportunities for future agricultural activities such as sustainable grazing;*
- *Improve the visual amenity of the area; and*
- *Not preclude other potential post mining land use should they be determined to be viable and preferable as part of the detailed mine closure planning process that will commence at least five years prior to the planned cessation of mining.*

Treatment of substrate for the plantings

Refer to **Table A3.10**.

Planting method

Refer to **Table A3.10**.

Planting mix used

Table A3.11 and **Table A3.12** list three separate planting mixes used by Mount Owen. See **Table A3.10** for the composition of the seed mix used for each rehabilitation area.

Table A3.11 - A planting mix used in 1998/99 rehabilitation (C. Castor pers. comm. 2019). Please note, this was the proposed planting list, and the actual planting mix used may have changed due to seed availability.

Species	Rate (kg/ha)
Casuarina glauca	0.3
Eucalyptus tereticornis	0.5
Corymbia maculata	0.6
Eucalyptus moluccana	0.3
Eucalyptus crebra	0.5
Eucalyptus punctata	0.3
Acacia decurrens	0.3
Acacia myrtifolia	0.4
Acacia suaveolens	0.3
Acacia longifolia	0.3
Acacia implexa	0.3
Acacia decora	0.3
Acacia falcata	0.3
Acacia parvipinnula	0.2

Table A3.12 - A planting mix used in 1998/99 rehabilitation (C. Castor pers. comm. 2019). Please note, this was the proposed planting list, and the actual planting mix used may have changed due to seed availability.

Species	Rate (kg/ha)
Hardenbergia violacea	0.1
Daviesia ulicifolia	0.1
Dodonaea viscosa	0.1
Indigofera australis	0.1
Bursaria spinosa	0.1
Jacksonia scoparia	0.1
Kennedia prostrata	0.1
Breynia oblongifolia	0.05
Swainsona galegifolia	0.05
Dianella caerulea	0.05
Clematis glycinoides	0.05
Desmodium varians (if not any others)	0.05
Eremophila debilis	0.05
Glycine clandestina	0.05
Glycine tabacina	0.05
Calotis lappulacea	0.05
Wahlenbergia sp.	0.05
Pultenaea cunninghamii	0.1

Management treatments occurring on site

Table A3.13 summarises the management treatments used by Mount Owen in the rehabilitation areas.

Table A3.13 - Summary of management actions that have occurred in Mount Owen rehabilitation areas (Mount Owen Pty Limited 2017)

Management Action	Notes
Supplementary planting	Supplementary planting has occurred in areas that were rehabilitated with pasture topsoil.
Thinning of vegetation	No
Erosion control	Yes, where needed
Weed management	Yes
Controlled burning	No
Feral animal control	Yes

Rehabilitation Monitoring

Methods include:

- Biobanking
- 400 m^2 floristics
- Comparison to reference sites
- Research has been completed by CSER in the past that examined the effect of different soil media/inoculations on plant growth.
- Soil monitoring includes:
  - pH
  - electrical conductivity
  - Soil carbon, nitrogen, potassium, and phosphorus (SLR Consulting Australia 2017)

Mount Owen Mine introduced a revised monitoring approach in 2020 which is aligned with the BAM. The new monitoring approach supersedes the methods described above.

A3.4 United

The rehabilitation areas surveyed at United were established in the early 1990s, and information recorded at the time did not meet the standard that is expected today. (S. Pigott pers. comm. 2019)

Targeted plant community

The target final land use for sites 1, 2, and 3 is native woodland, however there is no specific vegetation community targeted. (S. Pigott pers. comm. 2019)

Treatment of substrate for the plantings

Topsoil was spread onto rehabilitation sites unless no topsoil was available. (S. Pigott pers. comm. 2019)

Planting method

Vegetation was established on rehabilitation areas via direct broadcast seeding. If required, some areas had secondary planting events. (S. Pigott pers. comm. 2019)

Planting mix used

No data available. (S. Pigott pers. comm. 2019)

Management treatments occurring on site

Table A3.14 summarises the management actions that have occurred at United. No site-specific information was available at the time of writing.

Table A3.14 - **Summary of management actions that have occurred in United rehabilitation areas** (S. Pigott pers. comm. 2019)

Management Action	Notes
Supplementary planting	Supplementary planting has occurred in areas identified as being deficient in certain species.
Thinning of vegetation	No
Erosion control	Yes
Weed management	Yes
Controlled burning	No
Feral animal control	Yes

Rehabilitation Monitoring

Rehabilitation monitoring includes:

- Walk over inspections
- Flora
- Fauna surveys
- Habitat surveys
- Photo monitoring.

United Mine introduced a revised monitoring approach in 2020 which is aligned with the BAM. The new monitoring approach supersedes the methods described above.

A3.5 Bulga Coal

Targeted plant community

Bulga Coal are required to rehabilitate:

- 2,200 ha of Central Hunter Grey Box-Ironbark Woodland EEC
- 250 ha of Central Hunter Ironbark-Spotted Gum-Grey Box Forest EEC
- 50 ha of Central Hunter Swamp Oak Forest (Department of Planning and Environment 2017b)

Treatment of substrate for the plantings and planting method

Table A3.15 lists the planting method used by Bulga.

Table A3.15 - Planting method at Bulga Coal Rehabilitation Sites (T. Scott pers. comm 2019)

Rehabilitation Establishment date	ACARP site number(s)	Initial Weed Treatment	Fertiliser	Soil Preparation	Plant mix
2013	88, 89, 90, 91	Topsoil stockpiles sprayed and scalped prior to spreading.	None used	Deep rip (450mm) Rock rake into piles Spread compost (25mm) Spread topsoil (75mm) Re-rip (300mm)	Cover crop: Millet (5kg/ha), Couch (2kg/ha), Wimmera rye (1kg/ha). See **Table A3.16** for final landform seed mix.
2014	81	None required	None used	Deep rip (450mm) Rock rake and push off rehab area Spread topsoil (100mm) Spread gypsum (7t/ha) Re-rip (300mm)	Cover crop: Millet (5kg/ha), Couch (2kg/ha), Wimmera rye (1kg/ha). Kitty litter used as bulking agent (62.5kg/ha) See **Table A3.17** for final landform seed mix
2015	82, 83, 93	None required	None used	Deep rip (450mm) Rock rake and push off rehab area Spread topsoil (100mm) on batters and compost (100t/ha) on contour banks Spread gypsum (10t/ha) Re-rip (450mm)	Cover crop: Millet (5kg/ha), Couch (2kg/ha), Wimmera rye (1kg/ha). Kitty litter used as bulking agent (62.5kg/ha) See **Table A3.17** for final landform seed mix

Planting mix used

See **Table A3.16** and **A3.17** for the composition of the seed mix used for each rehabilitation area.

Table A3.16 - **Seeding mix used at Bulga Coal for rehabilitation of Central Hunter Grey Box – Ironbark Woodland** (T. Scott pers. comm. 2019)

Central Hunter Grey Box – Ironbark Woodland		
Species	Rate (kg/ha)	Type
Acacia amblygona (fan wattle)	0.3	Shrub
Acacia decora (western silver wattle)	0.4	Shrub
Acacia falcata (sickle wattle)	0.4	Shrub
Acacia implexa (hickory wattle)	0.3	Shrub
Acacia paradoxa (kangaroo thorn)	0.1	Shrub
Allocasuarina littoralis (black she-oak)	0.1	Low tree
Allocasuarina luehmannii (bulloak)	0.1	Low tree
Angophora floribunda (rough-barked apple)	0.2	Tree
Bothriochloa decipiens (red grass)	0.1	Groundcover
Brachychiton populneus (kurrajong)	0.2	Low tree
Bursaria spinosa (blackthorn)	0.1	Shrub
Chloris ventricosa (windmill grass)	0.1	Groundcover
Corymbia maculata (spotted gum)	0.4	Tree
Dodonaea viscosa (sticky hop-bush)	0.3	Shrub
Eremophila debilis (amulla)	0.1	Groundcover
Eucalyptus blakelyi (Blakely's red gum)	0.4	Tree
Eucalyptus crebra (narrow-leaved ironbark)	1.2	Tree
Eucalyptus moluccana (grey box)	1.2	Tree
Eucalyptus tereticornis (forest red gum)	0.2	Tree
Hardenbergia violacea (false sarsaparilla)	0.1	Groundcover
Lomandra filiformis or *L. multiflora* (many-flowered mat rush)	0.1	Groundcover
Microlaena stipoides (weeping grass)	0.1	Groundcover
Total	**6.5**	

Table A3.17 - Seeding mix used at Bulga Coal for rehabilitation of Central Hunter Grey Box – Ironbark Woodland (T. Scott pers. comm. 2019)

Central Hunter Grey Box – Ironbark Woodland		
Species	Rate (kg/ha)	Type
Acacia amblygona (fan wattle)	0.3	Shrub
Acacia decora (western silver wattle)	0.4	Shrub
Acacia decurrens	0.5	Shrub
Acacia falcata (sickle wattle)	0.4	Shrub
Acacia implexa (hickory wattle)	0.3	Low tree

Central Hunter Grey Box – Ironbark Woodland		
Acacia paradoxa (kangaroo thorn)	0.1	Shrub
Allocasuarina littoralis (black she-oak)	0.1	Low tree
Allocasuarina luehmannii (bulloak)	0.1	Low tree
Angophora floribunda (rough-barked apple)	0.2	Tree
Bothriochloa decipiens (red grass)	0.1	Native grass
Brachychiton populneus (kurrajong)	0.2	Tree
Bursaria spinosa (blackthorn)	0.1	Shrub
Chloris ventricosa (windmill grass)	0.1	Native grass
Corymbia maculata (spotted gum)	0.4	Tree
Dodonaea viscosa (sticky hopbush)	0.3	Shrub
Einadia hastata (saltbush)	0.1	Groundcover
Eremophila debilis (amulla)	0.1	Groundcover
Eucalyptus blakelyi (Blakely's red gum)	0.4	Tree
Eucalyptus crebra (narrow-leaved ironbark)	1.2	Tree
Eucalyptus moluccana (grey box)	1.2	Tree
Eucalyptus tereticornis (forest red gum)	0.2	Tree
Hardenbergia violacea (false sarsaparilla)	0.1	Groundcover
Lomandra filiformis or *L. multiflora* (many-flowered mat rush)	0.1	Rush
Microlaena stipoides (weeping grass)	0.1	Native grass
Total	**7.1**	

Table A3.18- Seeding mix used at Bulga Coal for rehabilitation of Central Hunter Ironbark– Spotted Gum-Grey Box Woodland (T. Scott pers. comm. 2019)

Central Hunter Ironbark– Spotted Gum – Grey Box Forest		
Species	**Rate (kg/ha)**	**Type**
Acacia decurrens (green wattle)	0.5	Low tree
Acacia falcata (sickle wattle)	0.5	Shrub
Acacia implexa (hickory wattle)	0.2	Low tree
Acacia parvipinnula (silver-stemmed wattle)	0.3	Shrub
Acacia salicina (sally wattle)	0.3	Shrub
Allocasuarina luehmannii (bull oak)	0.1	Low tree
Dodonaea viscosa (sticky hopbush)	0.1	Shrub
Bursaria spinosa (blackthorn)	0.2	Shrub
Corymbia maculata (spotted gum)	1.3	Tree
Daviesia ulicifolia (gorse bitter pea)	0.1	Shrub

Central Hunter Ironbark– Spotted Gum – Grey Box Forest		
Dianella caerulea (blue flax lily)	0.1	Groundcover
Eremophila debilis (winter apple)	0.1	Groundcover
Eucalyptus blakelyi (Blakely's red gum)	0.4	Tree
Eucalyptus crebra (narrow-leaved ironbark)	1.0	Tree
Eucalyptus fibrosa (broad-leaved ironbark)	0.5	Tree
Eucalyptus moluccana (grey box)	0.8	Tree
Eucalyptus tereticornis (forest red gum)	0.3	Tree
Hardenbergia violacea (false sarsaparilla)	0.1	Groundcover
Lomandra filiformis or *multiflora* (many-flowered mat rush)	0.1	Rush
Microlaena stipoides (weeping grass)	0.1	Native grass
Pultenaea spinosa (grey bush-pea)	0.1	Shrub
Themeda australis (kangaroo grass)	0.1	Native grass
Total	**7.3**	

Management treatments occurring on site

Table A3.19 summarises the management actions that occurring the rehabilitation areas. No site-specific information was available at the time of writing.

Table A3.19 - **Summary of management actions that have occurred in Bulga Coal rehabilitation areas** (T. Scott pers. comm.)

Management Action	Notes
Supplementary planting	No
Thinning of vegetation	No
Erosion control	Yes
Weed management	Yes
Controlled burning	No
Feral animal control	Yes

Rehabilitation Monitoring

Monitoring methods included:

- 2018 monitoring collected LFA and BAM data (Emergent Ecology 2018).
- 2017 monitoring collected LFA and BBAM data (Emergent Ecology 2017).
- 2013 to 2016 monitoring collected LFA data, completed a soil analysis, and collected Biometric data as per Gibbons *et al.* (2008) however this data seems very similar to BBAM (DnA Environmental 2013, 2014, 2015, 2016)

Bulga Coal introduced a revised monitoring approach in 2020 which is aligned with the BAM. The new monitoring approach supersedes the methods described above.

APPENDIX 4

PCT Assignment Tool Outputs

Appendix 4 – PCT Assignment Tool Outputs

Table A4.1 – Outputs from PCT Assignment Tool for all sites

Site Number	Type	Age (yrs)	Match 1			Match 2			Match 3			Match 4			Match 5			Match 6			Match 7			Match 8			Match 9			Match 10		
			PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env
1	Ref	n/a	R6.136p	0.718		R6.107	0.719	#	R6.189	0.723	#	R1.110	0.741		R6.35	0.745	#	R1.32p	0.753		R1.55	0.769		R6.15p	0.77		R6.12	0.777	#	R10.277	0.782	
2	Ref	n/a	R6.107	0.664	#	R6.35	0.714	#	R6.136p	0.732		R6.189	0.735	#	R1.110	0.763		R6.58	0.783	#	R6.15p	0.791		R6.12	0.794	#	R6.184	0.803	#	R1.32p	0.806	
3	Reh	7	R6.107	0.655	#	R6.35	0.659	#	R6.58	0.692	#	R6.140p	0.705		R6.189	0.709	#	R6.12	0.744	#	R6.15p	0.749		R1.55	0.762		R6.184	0.762	#	R6.81	0.764	#
4	Reh	8	R6.107	0.824	#	R6.189	0.824	#	R6.35	0.836	#	R6.58	0.858	#	R6.122	0.878	#	R6.61	0.88		R6.113	0.882		R6.41	0.882	#	R1.55	0.884		R6.46	0.884	
5	Reh	3	R6.12	0.803	#	R6.107	0.805	#	R6.189	0.816	#	R6.35	0.838	#	R6.81	0.838	#	R6.15p	0.842		R6.140p	0.843		R6.58	0.847	#	R2.18	0.848		R6.73	0.854	
7	Ref	n/a	R6.107	0.59	#	R6.35	0.635	#	R6.136p	0.663		R6.58	0.663	#	R6.136	0.688		R6.189	0.694	#	R1.32p	0.713		R1.110	0.714		R6.140p	0.716		R6.184	0.734	#
8	Ref	n/a	R6.107	0.637	#	R6.35	0.701	#	R6.58	0.702	#	R6.189	0.712	#	R6.84	0.734		R6.171	0.737		R6.136	0.75		R6.140p	0.769		R6.42	0.771		R6.29	0.773	
9	Ref	n/a	R6.107	0.615	#	R6.35	0.646	#	R6.189	0.657	#	R6.58	0.667	#	R1.110	0.705		R6.136	0.718		R1.45p	0.728		R6.8	0.728		R1.55	0.733		R1.45	0.735	
10	Ref	n/a	R6.107	0.627	#	R6.35	0.636	#	R6.58	0.656	#	R6.171	0.669		R6.136	0.692		R6.140p	0.7		R6.81	0.711	#	R6.8	0.713		R6.42	0.718		R6.84	0.726	
11	Ref	n/a	R6.107	0.64	#	R6.189	0.67	#	R6.35	0.691	#	R6.15p	0.711		R6.58	0.719	#	R6.140p	0.723		R6.171	0.723		R6.8	0.743		R6.136	0.744		R6.84	0.744	
12	Reh	8	R6.35	0.771	#	R6.140p	0.778		R6.107	0.782	#	R6.113	0.792		R6.171	0.802		R6.58	0.806	#	R6.81	0.807	#	R6.105	0.809		R6.189	0.813	#	R6.180	0.824	
13	Reh	8	R6.107	0.793	#	R6.189	0.8	#	R6.58	0.822	#	R6.35	0.826	#	R11.107	0.827		R6.12	0.86	#	R2.18	0.864		R1.45p	0.873		R6.84	0.875		R1.39	0.876	
14	Reh	8	R6.107	0.742	#	R6.35	0.751	#	R6.140p	0.773		R6.58	0.775	#	R6.189	0.792	#	R6.81	0.813	#	R6.171	0.815		R6.17	0.816		R6.113	0.823		R6.180	0.823	
15	Reh	8	R6.107	0.732	#	R6.35	0.745	#	R6.140p	0.751		R6.58	0.764	#	R6.180	0.777		R6.122	0.782	#	R6.171	0.782		R6.81	0.782	#	R6.189	0.788	#	R6.105	0.814	
16	Reh	6	R6.140p	0.732		R6.107	0.742	#	R6.35	0.746	#	R6.58	0.759	#	R6.189	0.777	#	R6.12	0.789	#	R6.52	0.792		R6.15p	0.796		R6.140	0.8		R6.17	0.803	
17	Reh	7	R6.107	0.686	#	R6.35	0.69	#	R6.58	0.732	#	R6.140p	0.733		R6.81	0.74	#	R6.189	0.755	#	R6.161	0.767	#	R6.171	0.769		R6.46	0.772		R1.56	0.773	#
18	Reh	6	R6.107	0.703	#	R6.58	0.746	#	R6.140p	0.752		R6.35	0.757	#	R6.189	0.764	#	R6.15p	0.766		R6.12	0.786	#	R6.180	0.801		R6.184	0.808	#	R6.171	0.814	
19	Ref	n/a	R6.107	0.599	#	R6.35	0.662	#	R6.58	0.672	#	R6.136p	0.688		R6.189	0.698	#	R6.136	0.707		R1.32p	0.735		R1.45p	0.739		R6.140p	0.739		R1.110	0.742	
20	Reh	6	R6.35	0.714	#	R6.58	0.714	#	R6.140p	0.722		R6.107	0.747	#	R6.189	0.77	#	R6.84	0.781		R6.15p	0.782		R6.75	0.785	#	R6.140	0.789		R6.17	0.792	
21	Reh	6	R6.35	0.644	#	R6.140p	0.673		R6.58	0.674	#	R6.107	0.706	#	R6.189	0.723	#	R1.55	0.728		R6.180	0.737		R6.15p	0.743		R6.46	0.746		R6.81	0.749	#
22	Ref	n/a	R6.35	0.62	#	R6.58	0.669	#	R6.140p	0.687		R6.8	0.695		R6.107	0.697	#	R6.134	0.703		R6.162	0.703	#	R1.32p	0.707		R1.55	0.71		R6.189	0.711	#
23	Ref	n/a	R6.35	0.617	#	R6.58	0.664	#	R1.56	0.665	#	R6.112p	0.669		R6.140p	0.691		R1.55	0.694		R6.11	0.696		R6.134	0.696		R6.8	0.696		R1.32p	0.698	
24	Ref	n/a	R6.189	0.719	#	R6.107	0.728	#	R6.84	0.747		R6.35	0.76	#	R6.130q	0.765		R6.188	0.771	#	R1.55	0.775		R6.12	0.782	#	R6.58	0.783	#	R10.277	0.785	
25	Ref	n/a	R6.35	0.693	#	R6.142	0.712	#	R1.56	0.718	#	R6.79	0.75		R1.55	0.754		R6.161	0.755	#	R1.32p	0.76		R10.119	0.762		R10.23	0.765		R6.119	0.767	
26	Ref	n/a	R6.189	0.662	#	R6.107	0.703	#	R6.58	0.724	#	R6.35	0.727	#	R1.32p	0.73		R6.12	0.73	#	R6.130q	0.735		R1.56	0.74	#	R6.157	0.743		R6.42	0.743	
27	Ref	n/a	R1.56	0.614	#	R1.82	0.654	#	R1.32p	0.672		R1.55	0.672		R6.48	0.678		R2.125	0.699	#	R6.25	0.704		R6.35	0.705	#	R6.112	0.707		R6.130q	0.718	
28	Ref	n/a	R1.56	0.636	#	R1.55	0.65		R6.35	0.665	#	R6.22	0.678		R6.48	0.679		R6.25	0.68		R6.112	0.689		R2.125	0.695		R1.82	0.697	#	R6.11	0.706	
29	Reh	4	R6.35	0.739	#	R6.107	0.751	#	R6.58	0.751	#	R6.140p	0.77		R6.52	0.775		R6.189	0.778	#	R6.81	0.782	#	R6.136p	0.794		R6.184	0.795	#	R1.55	0.799	
30	Reh	6	R6.107	0.66	#	R6.35	0.676	#	R6.58	0.68	#	R6.140p	0.711		R6.81	0.726	#	R6.189	0.736	#	R6.171	0.739		R6.15p	0.757		R6.180	0.762		R6.136	0.763	
31	Reh	5	R6.35	0.748	#	R6.58	0.771	#	R6.140p	0.78		R6.113	0.799		R6.107	0.807	#	R6.17	0.813		R9.101b	0.814		R6.171	0.815		R6.189	0.816	#	R6.84	0.817	
32	Reh	6	R6.140p	0.665		R6.35	0.665	#	R6.107	0.725	#	R6.15p	0.729		R6.58	0.733	#	R6.140	0.746		R6.171	0.749		R1.56	0.755	#	R6.184	0.758	#	R6.81	0.759	#

Site Number	Type	Age (yrs)	Match 1			Match 2			Match 3			Match 4			Match 5			Match 6			Match 7			Match 8			Match 9			Match 10		
			PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env
33	Reh	8	R6.35	0.704	#	R6.140p	0.744		R6.81	0.746	#	R6.107	0.751	#	R6.171	0.759		R6.58	0.76	#	R6.61	0.783		R1.56	0.789	#	R6.184	0.796	#	R6.52	0.796	
34	Reh	7	R6.35	0.639	#	R6.140p	0.669		R6.107	0.701	#	R6.58	0.706	#	R1.56	0.711	#	R6.171	0.716		R6.189	0.723	#	R6.46	0.729		R1.55	0.731		R6.81	0.731	#
35	Reh	7	R6.140p	0.683		R6.35	0.685	#	R6.58	0.72	#	R6.107	0.723	#	R6.15p	0.728		R6.171	0.744		R6.189	0.752	#	R6.180	0.754		R6.81	0.76	#	R6.140	0.763	
36	Ref	n/a	R6.107	0.569	#	R6.35	0.606	#	R6.58	0.633	#	R6.189	0.678	#	R6.140p	0.684		R6.136	0.695		R6.171	0.7	#	R6.42	0.72		R1.110	0.729		R6.8	0.737	
37	Ref	n/a	R6.35	0.611	#	R6.58	0.658	#	R6.107	0.681	#	R6.189	0.686	#	R6.15p	0.69		R1.55	0.693		R1.110	0.712		R6.8	0.712		R6.161	0.72	#	R1.32p	0.724	
38	Ref	n/a	R6.35	0.637	#	R6.58	0.65	#	R6.140p	0.681		R6.189	0.703	#	R1.55	0.71		R6.107	0.71	#	R6.110	0.716		R6.171	0.718	#	R1.32p	0.723		R6.8	0.731	
39	Ref	n/a	R6.35	0.593	#	R6.58	0.602	#	R6.107	0.621	#	R6.140p	0.621		R6.136	0.661		R6.15p	0.673		R6.189	0.674	#	R6.171	0.682		R6.8	0.689		R6.42	0.713	
40	Ref	n/a	R6.35	0.655	#	R6.161	0.701		R1.110	0.713		R6.142	0.717	#	R6.79	0.717		R1.55	0.722	#	R2.82	0.735		R2.93	0.738		R2.193	0.745		R10.23	0.75	
41	Ref	n/a	R1.110	0.633		R1.55	0.635	#	R6.35	0.646	#	R6.136p	0.686		R1.45	0.703		R9.101b	0.706		R6.161	0.721		R1.32p	0.726		R1.75	0.742		R6.142	0.742	#
42	Ref	n/a	R6.35	0.545	#	R1.55	0.613	#	R6.58	0.621		R1.110	0.649		R6.189	0.658		R6.161	0.66		R6.140p	0.662		R6.107	0.665		R1.56	0.667	#	R6.8	0.678	
43	Ref	n/a	R6.35	0.574	#	R6.58	0.67		R6.107	0.677		R1.110	0.68		R1.55	0.68	#	R1.45p	0.702		R11.107	0.705		R1.45	0.707		R1.32p	0.714		R6.140p	0.719	
44	Ref	n/a	R6.35	0.549	#	R6.58	0.606	#	R6.140p	0.638		R6.107	0.64		R6.189	0.674	#	R6.8	0.683		R1.56	0.691	#	R1.55	0.693	#	R6.110	0.696		R6.184	0.699	#
45	Reh	9	R6.35	0.657	#	R6.107	0.688		R6.58	0.688		R1.110	0.729		R1.55	0.749	#	R6.184	0.749		R6.140p	0.75		R1.75	0.752		R1.45	0.758		R9.107c	0.761	
46	Reh	10	R6.35	0.729	#	R1.110	0.741	#	R6.58	0.755		R1.45p	0.773		R1.55	0.775	#	R1.45	0.779		R6.107	0.783		R1.75	0.793		R6.140p	0.794		R9.107c	0.807	
47	Reh	4	R6.58	0.77		R6.140p	0.791		R6.35	0.792	#	R6.107	0.794		R6.81	0.81		R1.55	0.821	#	R6.189	0.822		R6.84	0.823		R1.45p	0.833		R6.105	0.834	
48	Reh	4	R6.35	0.756		R6.107	0.757		R6.58	0.777		R1.110	0.785		R1.55	0.785		R6.140p	0.785		R6.180	0.792		R1.32q	0.797		R6.81	0.797		R6.52	0.802	
49	Reh	8	R6.107	0.759		R6.35	0.768	#	R1.39	0.776		R6.58	0.783		R6.140p	0.79		R1.45	0.798		R9.107c	0.799		R1.75	0.806		R1.110	0.811		R1.39p	0.819	
50	Reh	5	R6.107	0.73		R6.35	0.752	#	R6.58	0.759		R6.140p	0.776		R6.105	0.781		R6.180	0.781		R6.81	0.786		R6.122	0.796		R6.52	0.797		R6.136p	0.804	
51	Ref	n/a	R1.110	0.559	#	R1.45	0.626		R1.75	0.637	#	R1.55	0.638	#	R1.45p	0.647		R6.35	0.647	#	R6.58	0.65		R1.20	0.665		R1.32p	0.675		R1.40	0.684	#
52	Ref	n/a	R1.110	0.598	#	R1.75	0.65	#	R1.98p	0.652		R1.53	0.671	#	R6.112p	0.672		R1.1	0.677		R1.55	0.682	#	R1.20	0.697		R1.40	0.703	#	R1.62	0.704	
53	Ref	n/a	R1.110	0.571	#	R1.53	0.616	#	R1.1	0.628		R1.74	0.631	#	R1.98p	0.66		R1.75	0.676	#	R1.45	0.68		R1.55	0.682	#	R6.112p	0.683		R1.45p	0.693	
54	Ref	n/a	R6.58	0.569		R6.35	0.574	#	R6.107	0.586	#	R6.189	0.65	#	R6.136	0.673		R6.134	0.675		R6.140p	0.677		R6.8	0.677		R6.42	0.687		R6.15p	0.7	
55	Ref	n/a	R1.55	0.588	#	R1.82	0.624	#	R1.60	0.635	#	R1.40	0.658	#	R6.35	0.66	#	R6.189	0.664	#	R1.110	0.665		R1.20	0.669		R1.83	0.677	#	R6.58	0.679	#
56	Ref	n/a	R1.55	0.595	#	R1.60	0.633	#	R1.82	0.638	#	R1.40	0.665	#	R6.189	0.666	#	R1.110	0.671		R1.32p	0.679		R1.20	0.682		R6.35	0.682	#	R1.83	0.693	#
57	Ref	n/a	R6.189	0.603	#	R6.58	0.611	#	R1.55	0.612	#	R6.112p	0.671		R1.83	0.674	#	R1.110	0.68		R6.35	0.681	#	R1.45	0.692		R6.172	0.697		R1.28	0.711	#
58	Ref	n/a	R6.35	0.58	#	R1.55	0.633	#	R6.58	0.653	#	R6.189	0.656	#	R6.107	0.66	#	R6.84	0.683		R6.134	0.692		R6.136p	0.696		R6.112p	0.701		R6.142	0.703	#
59	Reh	8	R6.58	0.792		R6.35	0.793	#	R1.45	0.798		R6.107	0.813		R1.39	0.815		R9.107c	0.82		R1.55	0.821	#	R1.45p	0.824		R6.184	0.826	#	R6.189	0.826	#
60	Reh	8	R6.136p	0.758		R6.35	0.768	#	R6.107	0.769		R1.39	0.79		R6.58	0.793		R1.45	0.798		R6.184	0.81	#	R1.55	0.812	#	R9.107c	0.815		R6.113	0.817	
61	Ref	n/a	R6.35	0.579	#	R6.107	0.658		R1.110	0.675		R1.55	0.681	#	R6.58	0.693		R6.161	0.695		R6.162	0.706	#	R6.140p	0.712		R6.184	0.712		R1.45	0.717	
62	Ref	n/a	R6.58	0.59	#	R6.35	0.619	#	R6.107	0.62	#	R6.140p	0.653		R6.136	0.668		R6.8	0.677		R6.171	0.678		R6.189	0.693	#	R6.184	0.699	#	R6.42	0.703	
63	Ref	n/a	R6.107	0.628	#	R6.189	0.691	#	R6.35	0.693	#	R6.58	0.699	#	R6.136p	0.741		R6.84	0.741		R1.45p	0.747		R6.136	0.761		R6.162	0.765		R6.140p	0.766	
64	Reh	27	R1.55	0.643	#	R1.110	0.66		R6.35	0.682	#	R6.136p	0.738		R1.53	0.739		R2.82	0.747		R6.161	0.75		R1.45	0.751		R6.142	0.751	#	R6.189	0.753	
65	Reh	21	R1.110	0.68	#	R1.53	0.709		R1.98q	0.714		R1.62	0.718		R1.75	0.718	#	R6.112p	0.726		R1.55	0.73	#	R1.12	0.734		R1.40	0.735	#	R1.45	0.739	
66	Reh	21	R6.35	0.636	#	R6.58	0.664		R6.140p	0.675		R1.75	0.677	#	R6.107	0.68		R9.107c	0.685		R1.110	0.691	#	R1.40	0.71	#	R1.45	0.714		R6.184	0.717	#

Site Number	Type	Age (yrs)	Match 1			Match 2			Match 3			Match 4			Match 5			Match 6			Match 7			Match 8			Match 9			Match 10		
			PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env	PCT	DtC	Env
67	Reh	10	R1.110	0.685		R6.58	0.694		R6.35	0.702	#	R1.55	0.713		R6.140p	0.735		R6.107	0.738		R1.75	0.754		R1.45	0.768		R1.40	0.77	#	R6.189	0.77	#
68	Ref	n/a	R1.110	0.576	#	R6.35	0.65	#	R1.55	0.656	#	R1.75	0.687	#	R1.20	0.688		R1.45	0.694		R1.1	0.712		R1.32p	0.712		R6.58	0.713		R1.53	0.716	#
69	Ref	n/a	R1.110	0.58	#	R1.75	0.617	#	R1.40	0.638	#	R1.45	0.654		R1.20	0.655		R1.55	0.662		R6.35	0.683	#	R1.98p	0.687		R1.53	0.688	#	R9.107c	0.689	
70	Ref	n/a	R6.35	0.59	#	R1.110	0.641	#	R6.58	0.672		R6.140p	0.678		R6.184	0.679	#	R6.15p	0.696		R9.107c	0.696		R1.40	0.7	#	R1.55	0.701		R6.107	0.703	
71	Ref	n/a	R1.110	0.579	#	R6.35	0.627	#	R1.45	0.64		R1.75	0.643	#	R6.58	0.658	#	R1.55	0.666	#	R1.40	0.686	#	R1.20	0.697		R1.45p	0.698		R1.82	0.699	#
72	Reh	10	R6.35	0.605	#	R1.110	0.644	#	R6.140p	0.659		R6.107	0.667		R6.58	0.677		R6.15p	0.7		R6.52	0.707		R9.107c	0.71		R6.184	0.714		R1.45	0.716	
73	Reh	9	R6.140p	0.688		R6.58	0.721	#	R6.107	0.722		R6.35	0.724	#	R6.140	0.756		R10.125	0.766		R6.2	0.767		R6.136	0.771		R6.184	0.771	#	R6.171	0.775	
74	Reh	12	R6.184	0.668	#	R6.140p	0.683		R6.35	0.688	#	R6.58	0.719		R6.107	0.726		R6.15p	0.728		R1.110	0.73	#	R6.17	0.742		R6.140	0.75		R6.52	0.754	
75	Reh	12	R1.110	0.596	#	R6.35	0.616	#	R6.140p	0.662		R6.58	0.662		R6.107	0.665		R1.75	0.668	#	R6.112p	0.669		R1.45	0.683		R9.107c	0.689		R1.40	0.691	#
76	Reh	12	R1.110	0.677	#	R6.35	0.714	#	R1.75	0.739	#	R1.55	0.744	#	R6.58	0.744		R6.140p	0.746		R1.40	0.757	#	R6.107	0.76		R6.112p	0.762		R1.45	0.77	
77	Ref	n/a	R1.110	0.54	#	R1.75	0.645	#	R1.45	0.646		R1.1	0.648		R6.35	0.648	#	R1.53	0.651	#	R1.55	0.655	#	R1.20	0.657		R1.74	0.692		R6.112p	0.694	
78	Ref	n/a	R1.110	0.587	#	R1.75	0.642	#	R1.45	0.66		R1.1	0.666		R1.53	0.667	#	R6.35	0.674	#	R6.58	0.683	#	R1.40	0.687	#	R1.20	0.691		R1.55	0.696	#
79	Ref	n/a	R1.110	0.6	#	R6.35	0.66	#	R6.58	0.663		R1.75	0.667	#	R1.45	0.674		R1.55	0.678	#	R1.40	0.698	#	R6.112p	0.701		R1.1	0.704		R1.20	0.705	
80	Ref	n/a	R1.110	0.553	#	R6.35	0.604	#	R1.55	0.633	#	R1.75	0.643	#	R1.45	0.647		R6.58	0.658	#	R1.20	0.681		R1.40	0.691	#	R6.140p	0.691		R9.107c	0.698	
81	Reh	5	R1.55	0.787	#	R1.39	0.788		R6.113	0.79		R6.35	0.793	#	R6.107	0.794		R1.110	0.796	#	R6.58	0.807		R1.75	0.82		R1.45	0.822		R6.136p	0.822	
82	Reh	4	R1.55	0.792	#	R1.39	0.807		R6.35	0.813	#	R6.38	0.821		R1.110	0.822		R6.58	0.822		R1.45	0.825		R1.75	0.829		R6.110	0.838		R1.39p	0.839	
83	Reh	4	R6.107	0.719		R6.35	0.728	#	R6.58	0.744		R6.140p	0.753		R1.55	0.765	#	R6.184	0.774	#	R1.110	0.775	#	R6.189	0.778	#	R6.110	0.802		R1.45	0.804	
84	Ref	n/a	R6.35	0.53	#	R6.58	0.615		R6.107	0.618		R6.140p	0.633		R6.184	0.644	#	R6.136	0.649		R6.17	0.651		R6.15p	0.66		R1.110	0.675	#	R9.107c	0.675	
85	Ref	n/a	R1.110	0.586	#	R1.55	0.593	#	R6.35	0.626	#	R6.136p	0.703		R1.56	0.704	#	R1.45	0.705		R6.161	0.711	#	R1.1	0.712		R1.20	0.721		R1.75	0.723	#
86	Ref	n/a	R6.58	0.597	#	R6.35	0.627	#	R1.55	0.648	#	R6.189	0.66	#	R1.82	0.666	#	R1.60	0.671	#	R6.140p	0.672		R1.40	0.677	#	R6.140	0.685		R1.83	0.691	#
87	Ref	n/a	R1.110	0.587	#	R6.35	0.607	#	R1.55	0.64	#	R1.45	0.658		R6.58	0.685		R6.107	0.689		R1.75	0.69	#	R6.15p	0.702		R6.140p	0.722		R6.189	0.725	#
88	Reh	6	R1.55	0.838		R6.113	0.848		R6.110	0.856		R6.61	0.859		R6.35	0.865	#	R11.107	0.868		R6.58	0.868		R6.184	0.869		R6.19	0.873		R1.110	0.875	
89	Reh	6	R6.35	0.816	#	R1.39	0.822		R6.58	0.827		R1.110	0.841		R1.4	0.843		R6.171	0.843		R1.55	0.848		R6.113	0.85		R1.75	0.854		R11.107	0.857	
90	Reh	6	R1.55	0.874	#	R6.35	0.879	#	R1.110	0.881	#	R10.46	0.883		R10.180	0.884		R6.113	0.888		R1.105	0.89		R6.19	0.89		R6.110	0.894		R6.61	0.895	
91	Reh	6	R6.73	0.842		R6.61	0.849		R6.164	0.867		R1.55	0.874	#	R6.95	0.877		R6.145	0.882		R6.29	0.882		R10.125	0.883		R6.35	0.886	#	R6.38	0.888	
92	Reh	12	R6.35	0.771	#	R6.107	0.791		R1.110	0.803	#	R6.184	0.808	#	R1.55	0.812	#	R6.140p	0.829		R6.122	0.83	#	R6.58	0.834		R6.189	0.852	#	R1.45	0.853	
93	Reh	4	R6.35	0.718	#	R6.107	0.748		R6.58	0.777		R1.110	0.779	#	R1.45	0.785		R1.55	0.789	#	R1.39	0.793	#	R6.140p	0.793		R1.75	0.799		R6.184	0.803	#
94	Ref	n/a	R6.107	0.599		R6.35	0.643	#	R6.58	0.656		R6.140p	0.657		R6.171	0.684		R6.136	0.701		R6.15p	0.701		R6.135	0.72		R6.184	0.73	#	R6.84	0.733	

Notes:

PCT – plant community type
DtC – distance to PCT centroid
Env – environmental variables including elevation, rainfall and temperature.
Ref – reference site
Rehab – rehabilitation site
- the location of the site falls within the range of all three environmental variables (elevation, rainfall and temperature) for the PCT, as indicated by the PCT Assignment Tool

APPENDIX 5

Rehabilitation Composition, Structure and Function Data

Table 5.1 Raw composition, structure and function data for rehabilitation sites and similarity to reference site values

				Composition	Structure										Function					Overall Performance			
						Foliage Cover				TG Stem Counts													
Site Name	PCT	Site Type	Age	Distance to PCT Centroid	BAM Structure Condition Score	TG	SG	GG	FG	30-49cm DBH	20-29cm DBH	10-19cm DBH	5-9cm DBH	<5cm DBH	TOC%	Microbial biomass	Fungi:bacteria biomass	Litter cover (%)	HTE cover (%)	"very strong"	"strong"	"moderate"	"weak"
MAN1655R03	3485	Rehab	7	0.655	17.8	8	8.2	1.2	1.1	0	0	22	26	18	1.1266	7.9663	0.1156	45	0.1	3	2	3	8
MAN1655R04	3485	Rehab	8	0.824	9.3	4.1	30.6	0	0.8	0	0	79	39	28	2.5426	15.3162	0.1709	60	0.1	2	1	3	10
MAN1655R05	3485	Rehab	3	0.805	11.7	5.6	29	0.7	0.2	0	0	0	21	48	2.4524	9.3384	0.0831	26	0.2	0	2	4	10
MAN1655R12	3431	Rehab	8	0.771	5.8	6	5.3	0.8	6.5	0	0	15	55	15	2.1809	13.8165	0.1169	37	0.2	3	4	4	5
MAN1655R13	3485	Rehab	8	0.793	30.3	13.1	7.8	0.3	2.4	0	0	24	56	65	3.3936	17.0251	0.1772	47	0.2	3	2	0	11
MAN1655R14	3485	Rehab	8	0.742	28.9	13.2	5.5	0.6	1.6	0	0	21	60	30	3.2360	15.4224	0.1561	52	0.2	3	2	2	9
MAN1655R15	3485	Rehab	8	0.732	31.4	15	5.4	1.8	2	0	0	11	62	49	3.5675	14.5500	0.2166	40	5	3	4	1	8
MAN1655R16	3485	Rehab	6	0.742	21.5	9.1	14.4	4.2	1.2	0	0	1	29	14	1.3500	9.6984	0.1342	42	0.3	2	2	4	8
MAN1655R17	3485	Rehab	7	0.686	29.3	13.1	14.3	1	1.9	0	0	3	51	46	2.2550	15.5619	0.1623	44	1.1	4	1	2	9
MAN1655R18	3485	Rehab	6	0.703	20.6	8	16.2	1	2.8	0	0	0	24	44	1.9898	10.6766	0.0855	61	0.2	1	3	6	6
MAN1691R20	3431	Rehab	6	0.714	26.5	32.1	11.3	1	0.6	0	0	10	60	24	2.0906	11.3439	0.0604	28	0.3	6	2	4	4
MAN1691R21	3431	Rehab	6	0.644	17.5	13.5	15.2	7.4	6.1	0	0	0	25	60	2.6139	12.8043	0.0872	48	0.7	4	5	6	1
MAN1691R29	3431	Rehab	4	0.739	17.4	8.6	21	9.3	1.4	0	0	0	0	41	1.4908	9.8411	0.1217	40	0.4	3	3	5	5
MAN1691R30	3485	Rehab	6	0.66	33.7	17.4	12.8	5.3	1.9	0	0	0	25	130	2.5704	16.0146	0.1787	61	0.1	5	3	3	5
MAN1691R31	3431	Rehab	5	0.748	15	18	14.2	1.4	0.9	0	0	0	5	105	2.8754	15.1834	0.1944	67	0.3	3	2	8	3
MAN1691R32	3431	Rehab	6	0.665	11.1	15.7	11.6	1.8	2.2	0	0	1	26	54	2.3800	16.7430	0.1472	52	0.5	4	3	8	1
MAN1691R33	3431	Rehab	8	0.704	15	19.1	7.5	0.9	7.7	0	0	3	51	112	2.6800	15.0850	0.0941	51	2	1	6	7	2
MAN1691R34	3431	Rehab	7	0.639	11.2	18.1	9.2	1.1	2.3	0	0	4	40	73	2.3250	13.3375	0.2626	56	0.1	3	4	7	2
MAN1691R35	3431	Rehab	7	0.685	13.4	13.1	16.1	1	1.3	0	0	2	28	76	2.2695	13.6691	0.1123	57	1	3	4	7	2
MTW1601R45	3431	Rehab	9	0.657	25.6	35	5.5	4.1	1.2	0	0	6	97	94	3.0419	15.7218	0.1253	72	1.5	4	4	6	2
MTW1601R46	3431	Rehab	10	0.729	30.7	45.1	1.7	0.5	0.6	0	0	0	28	960	2.5645	14.0753	0.1155	55	5.1	3	3	5	5
MTW1601R47	3431	Rehab	4	0.792	18.3	4.8	8	24.4	5.3	0	0	0	0	31	5.3000	15.1822	0.1496	14	51.2	6	1	3	6
MTW1601R48	3431	Rehab	4	0.756	23.1	10.7	18.5	18	4	0	0	0	11	95	2.5863	6.4875	0.1168	22	3.5	3	2	7	4
MTW1601R49	3431	Rehab	8	0.768	38.6	20	15.6	32	1	0	0	0	36	86	2.9156	14.7725	0.1333	72	1.3	4	2	7	3
MTW1601R50	3431	Rehab	5	0.752	42.8	9	15.1	43	4.1	0	0	0	1	49	4.1168	16.6918	0.1156	34	5	3	3	5	5
MTW1601R59	3431	Rehab	8	0.793	20.4	5.3	31.2	1.3	0.7	0	0	0	4	77	2.8000	14.4409	0.1471	71	22.5	3	1	5	7
MTW1601R60	3431	Rehab	8	0.768	27.8	14	28.1	15.8	0.7	0	0	0	13	119	2.9700	14.8803	0.1249	52	11.3	3	2	7	4
UNI1601R64	3431	Rehab	27	0.682	17.8	27.8	1	1.3	0.3	0	1	20	65	253	2.5109	14.2302	0.0864	84	0	8	3	2	3
MTO1604R65	3315	Rehab	21	0.68	45.4	43.6	11.1	8.7	0.7	1	26	38	65	127	8.3038	16.0472	0.0928	100	0.3	5	2	4	5

Site Name	PCT	Site Type	Age	Composition	Structure										Function					Overall Performance			
						Foliage Cover				TG Stem Counts													
				Distance to PCT Centroid	BAM Structure Condition Score	TG	SG	GG	FG	30-49cm DBH	20-29cm DBH	10-19cm DBH	5-9cm DBH	<5cm DBH	TOC%	Microbial biomass	Fungi:bacteria biomass	Litter cover (%)	HTE cover (%)	"very strong"	"strong"	"moderate"	"weak"
MTO1604R66	3315	Rehab	21	0.691	58.2	43.5	9	19.4	7.9	6	12	12	28	4	6.5130	6.6825	0.0518	87	3.2	5	6	2	3
MTO1604R67	3315	Rehab	10	0.685	31.2	17	12.9	19.3	2	0	5	19	23	16	3.8422	14.3188	0.0581	54	1	6	4	4	2
MTO1601R72	3315	Rehab	10	0.644	41.9	38.5	7.7	11.8	2.2	0	0	28	106	183	no data	19.8292	0.0867	55	0.7	4	5	2	4
MTO1601R73	3431	Rehab	9	0.724	7.5	10.5	10.2	5.4	2.8	0	1	21	35	19	3.8700	11.9392	0.0699	62	1.5	5	5	5	1
MTO1601R74	3315	Rehab	12	0.73	29	5	6.7	27.3	4.4	0	0	1	1	6	4.4900	15.8628	0.0825	26	4.4	5	2	3	6
MTO1601R75	3315	Rehab	12	0.596	18.1	21.8	3.3	5.5	2.2	0	4	13	17	19	4.0248	no data	no data	77	2.3	5	3	3	3
MTO1601R76	3315	Rehab	12	0.677	27.7	10.5	9	23.9	2.4	1	2	5	2	17	5.3192	18.2739	0.0851	78	0.2	9	1	2	4
BUL1603R81	3431	Rehab	5	0.793	7.2	10.3	11.3	6.2	0.7	0	0	0	5	44	1.3508	7.6036	0.1456	41	6.2	1	1	6	8
BUL1603R82	3431	Rehab	5	0.813	27.7	19.7	3.1	30.4	0.7	0	0	0	1	70	1.4479	7.9325	0.2003	14	0.9	3	1	5	7
BUL1603R83	3431	Rehab	4	0.728	9.5	12.7	12	7	1.4	0	0	0	0	57	1.9490	10.3663	0.1229	9	0.9	0	4	9	3
BUL1603R88	3431	Rehab	6	0.865	11.5	22.3	0.8	1.2	0	0	0	14	24	58	8.7083	15.0852	0.0752	9	7.3	4	4	2	6
BUL1603R89	3431	Rehab	6	0.816	9.5	20	0.8	5.1	0.5	0	0	2	35	49	3.0516	11.2425	0.1790	20	22.5	2	4	4	6
BUL1603R90	3431	Rehab	6	0.879	7.6	18	0.4	5.1	0	0	0	1	50	45	7.9670	14.6288	0.1044	34	30.3	2	4	4	6
BUL1603R91	3431	Rehab	6	0.886	22.3	20	0.4	25.3	0	0	0	4	65	51	4.8600	13.8237	0.0775	25	10.2	5	5	2	4
BUL1604R92	3431	Rehab	12	0.771	6.6	17.1	0.2	0.8	0.4	0	4	14	66	222	2.1550	11.6505	0.2632	43	0	3	1	4	8
BUL1603R93	3431	Rehab	4	0.718	14.3	16.6	13.1	9.4	1.7	0	0	0	2	154	1.9656	13.1128	0.1343	21	0.9	1	4	8	3

Legend:

Category	Description (Composition - distance to PCT centroid)	Description (Stucture and Function)
very strong	≤ 0.695	Rehabilitation site value for an attribute falls within IQR (between 25^{th} and 75^{th} percentiles) of all reference site values for the given PCT
strong	> 0.695 but ≤ mean distance to PCT centroid of all secondary plots	Rehabilitation site value for an attribute falls between the 10^{th} and 90^{th} percentiles of reference site values for the given PCT, but outside of the IQR
moderate	> mean distance to centroid of all secondary PCT to their target PCT but ≤ 1 standard deviation from the mean distance to PCT centroid of secondary plots	Rehabilitation site falls below the 10^{th} percentile or above the 90^{th} percentile, but is within the observed range of reference site values for the given PCT
weak	> 1 standard deviation from the mean distance to PCT centroid of secondary plots	Rehabilitation site falls below the minimum or above the maximum observed reference site values for the given PCT

APPENDIX 6

Influence of Age and Mine Site on Rehabilitation Results

Influence of Age and Mine Site on Rehabilitation Results

Five mine sites were the subject of this research project. Among these mine sites the rehabilitation areas ranged in age from 3 years to 27 years post initial vegetation establishment. A GLM was performed to examine which mine site was contributing significantly to the model.

Table A6.1 shows the results of the Logistic GLM analyses of the rehabilitation species richness. The results are variable, however they indicate that both mine site and age of rehabilitation have a significant effect on the development of species richness on the rehabilitation sites.

Table A6.1 Species Richness Logistic GLM Analysis Results
For each species richness variable the p-value, estimate, standard error, and t-value is reported.

Species Richness	Pr(>|t|)	Estimate	Standard Error	t value
Tree				
Mine Site				
Mangoola	>0.05	-0.20656	0.126269	-1.636
Mt Owen	>0.05	-0.09146	0.200541	-0.456
Mount Thorley Warkworth	>0.05	0.065898	0.220013	0.456
United	>0.05	0.426042	0.456785	0.933
Rehabilitation Age	>0.05	0.004261	0.018134	0.235
Shrub				
Mine Site				
Mangoola	**<0.01**	0.38802	0.13771	2.818
Mt Owen	**<0.001**	1.35719	0.22177	6.12
Mount Thorley Warkworth	**<0.01**	0.63688	0.16609	3.834
United	**<0.01**	1.81812	0.55344	3.285
Rehabilitation Age	**<0.001**	-0.09134	0.02011	-4.542
Total Ground Cover				
Mine Site				
Mangoola	**<0.001**	0.45023	0.1174	3.835
Mt Owen	**<0.001**	1.17918	0.15003	7.859
Mount Thorley Warkworth	**<0.001**	0.54889	0.13276	4.134
United	>0.05	0.60093	0.38827	1.548
Rehabilitation Age	>0.05	-0.01514	0.01245	-1.217

Table A6.2 shows the results of the Logistic GLM analyses of the rehabilitation species foliage cover. The results are variable, however they indicate that both mine site and age of rehabilitation have a significant effect on the development of plant foliage cover on the rehabilitation sites.

Table A6.2 Foliage Cover Logistic GLM Analysis Results
For each species foliage cover variable the p-value, estimate, standard error, and t-value is reported.

Foliage Cover	Pr(>|t|)	Estimate	Standard Error	t value
Tree				
Mine Site				
Mangoola	>0.05	1.8996	1.3377	1.42
Mt Owen	>0.05	1.7804	1.8474	0.964
Mount Thorley Warkworth	>0.05	0.1346	1.4167	0.095
United	>0.05	5.3422	3.3161	1.611
Rehabilitation Age	**<0.01**	-0.365	0.128	-2.851
Shrub				
Mine Site				
Mangoola	**<0.001**	-0.00859	0.178147	-0.048
Mt Owen	>0.05	-0.19276	0.286903	-0.672
Mount Thorley Warkworth	>0.05	-0.00997	0.21487	-0.046
United	>0.05	-1.14977	0.715978	-1.606
Rehabilitation Age	>0.05	0.003367	0.026019	0.129
Total Ground Cover				
Mine Site				
Mangoola	**0.01**	12.4696	4.7435	2.629
Mt Owen	>0.05	-6.4986	3.5351	-1.838
Mount Thorley Warkworth	>0.05	-4.6975	2.8656	-1.639
United	>0.05	45.4471	50.1158	0.907
Rehabilitation Age	>0.05	0.3585	0.3476	1.031
Exotic				
Mine Site				
Mangoola	**<0.001**	80.4913	16.7979	4.792
Mt Owen	>0.05	-0.339	4.3054	-0.079
Mount Thorley Warkworth	>0.05	0.7007	1.9724	0.355
United	>0.05	-15.9286	12.3465	-1.29
Rehabilitation Age	>0.05	0.8518	0.4975	1.712

Table A6.3 shows the results of the Logistic GLM analyses of the rehabilitation stem counts by size class. The results are variable, however they indicate that both mine site and age of rehabilitation have a significant effect on the development tree structure on the rehabilitation sites.

Table A6.3 Tree Stem Counts by Stem Class Logistic GLM Analysis Results
For tree stem count variable the p-value, estimate, standard error, and t-value is reported.

Tree stem count by size class	P-Value	Estimate	Standard Error	t value
Eucalypts 30-49 cm DBH				
Mine Site				
Mangoola	>0.05	0.07069	3314.929	0
Mt Owen	>0.05	17.58957	2701.939	0.007
Mount Thorley Warkworth	>0.05	-0.18723	3984.001	0
United	>0.05	-6.38267	8854.919	-0.001
Rehabilitation Age	**<0.001**	0.3187	0.04897	6.508
Eucalypts 20-29 cm DBH				
Mine Site				
Mangoola	**<0.001**	-18.8697	2085.518	-0.009
Mt Owen	**<0.001**	0.08767	0.51979	0.169
Mount Thorley Warkworth	**<0.001**	-19.0676	3172.088	-0.006
United	**<0.001**	-4.61	1.04503	-4.411
Rehabilitation Age	**<0.001**	0.2714	0.03043	8.919
Non-Eucalypts 20-29 cm DBH				
Mine Site				
Mangoola	**0.003**	-0.04	4883.00	0
Mt Owen	>0.05	19.02	4013.00	0.005
Mount Thorley Warkworth	>0.05	-0.15	5861.00	0
United	>0.05	-3.38	12810.00	0
Rehabilitation Age	**<0.001**	0.16	0.05	3.1
Eucalypts 10-19 cm DBH				
Mine Site				
Mangoola	>0.05	5.2462	5.4656	0.96
Mt Owen	>0.05	2.6918	8.8023	0.306
Mount Thorley Warkworth	>0.05	-4.3822	6.5923	-0.665
United	>0.05	-9.998	21.9665	-0.455
Rehabilitation Age	>0.05	1.2433	0.7983	1.557
Non-Eucalypts 10-19 cm DBH				
Mine Site				
Mangoola	**<0.001**	18.235	2511.723	0.007
Mt Owen	>0.05	15.4595	2511.724	0.006
Mount Thorley Warkworth	>0.05	-0.1738	3718.345	0
United	>0.05	-7.123	8316.927	-0.001

Tree stem count by size class	P-Value	Estimate	Standard Error	t value
Rehabilitation Age	>0.05	0.3586	0.1161	3.09
Eucalypts 5-9 cm DBH				
Mine Site				
Mangoola	>0.05	-8.473	9.625	-0.88
Mt Owen	>0.05	-19.281	15.501	-1.244
Mount Thorley Warkworth	>0.05	-10.4	11.609	-0.896
United	>0.05	-22.281	38.683	-0.576
Rehabilitation Age	0.05	2.844	1.406	2.023
Non-Eucalypts 5-9 cm DBH				
Mine Site				
Mangoola	**<0.001**	14.7597	3.5435	4.165
Mt Owen	>0.05	-3.1552	5.7068	-0.553
Mount Thorley Warkworth	>0.05	2.5934	4.274	0.607
United	>0.05	-24.2892	14.2416	-1.706
Rehabilitation Age	**0.02**	1.1566	0.5175	2.235
Eucalypts <5 cm DBH				
Mine Site				
Mangoola	>0.05	-58.798	55.767	-1.054
Mt Owen	>0.05	-141.16	89.812	-1.572
Mount Thorley Warkworth	>0.05	62.859	67.263	0.935
United	>0.05	-125.782	224.13	-0.561
Rehabilitation Age	>0.05	14.238	8.145	1.748
Non-Eucalypts <5 cm DBH				
Mine Site				
Mangoola	**<0.001**	22.7658	6.1469	3.704
Mt Owen	>0.05	8.4102	9.8995	0.85
Mount Thorley Warkworth	**<0.001**	29.3551	7.414	3.959
United	>0.05	15.5673	24.7046	0.63
Rehabilitation Age	>0.05	-0.9106	0.8978	-1.014

Table A6.4 shows the results of the Logistic GLM analyses of the rehabilitation stem counts. The results are variable, however they indicate that both mine site and age of rehabilitation have a significant effect on the development of tree structure on the rehabilitation sites.

Table A6.4 Stem Count Logistic GLM Analysis Results
For each tree abundance category the p-value, estimate, standard error, and t-value is reported.

	P-Value	Estimate	Standard Error	t value
All Stems				
Mine Site				
Mangoola	>0.05	-25.189	56.402	-0.447
Mt Owen	>0.05	-155.115	90.835	-1.708
Mount Thorley Warkworth	>0.05	78.116	68.029	1.148
United	>0.05	-196.986	226.682	-0.869
Rehabilitation Age	**0.01**	20.036	8.238	2.432
Total Eucalypts				
Mine Site				
Mangoola	>0.05	-63.048	58.099	-1.085
Mt Owen	>0.05	-159.791	93.567	-1.708
Mount Thorley Warkworth	>0.05	46.535	70.075	0.664
United	>0.05	-180.564	233.501	-0.773
Rehabilitation Age	**0.02**	19.424	8.485	2.289
Total Non-Eucalypts				
Mine Site				
Mangoola	**<0.001**	37.8588	6.2612	6.047
Mt Owen	>0.05	4.6758	10.0836	0.464
Mount Thorley Warkworth	**<0.001**	31.5817	7.5519	4.182
United	>0.05	-16.4222	25.164	-0.653
Rehabilitation Age	>0.05	-0.653	0.9145	0.67

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