Report

Desktop Study of Rehabilitation Strategies in the Pilbara – Christmas Creek Approvals

Environmental Studies

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Fortescue
The New Force in Iron Ore

	Desktop Study of Rehabilitation Strategies in the Pilbara – Christmas Creek Approvals		**CC-RP-EN-0065**
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1. INTRODUCTION

Fortescue Metals Group (Fortescue) is an integrated business comprised of mines (Cloudbreak, Christmas Creek and Solomon hub), a rail network (main line and Hamersley line) and port operations (Port Hedland) based in the Pilbara region of Western Australia, with its head office located in Perth.

The Christmas Creek mine site in the eastern Pilbara was originally approved on 16 December 2005 as part of the *Stage B Project: An East-West Railway Line and Christmas Creek and Mindy Mindy mines* (Ministerial Statement 707, EPBC ref. 2004/1562).

As part of Christmas Creek's Life of Mine Approvals and expansion plans, the Environmental Protection Authority (EPA) has provided an Environmental Scoping Document (ESD) to define the requirements of the Public Environmental Review (PER) document to be prepared in accordance with the *Western Australian Environmental Protection Act 1986* (EP Act) and the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Christmas Creek proposes the modification/expansion or development of additional:

- Mine pits
- Ore stockpiles
- Remote crushing hubs and conveyors
- Ore processing facilities
- Remote crushing hubs and conveyors
- Ore processing facilities (OPF) and train loading facilities
- Waste rock storage facilities (WRSF)
- Tailings storage facilities (TSF)
- Growth medium storage areas
- Power lines
- Roads and borrow pits
- Surface Water management infrastructure
- Water bores, injection borefields, reticulation, transfer, storage and settlement ponds and evaporation basins
- Desalination plant
- Accommodation facilities and wastewater treatment plants

- Bulk and satellite fuel storage
- Laboratory, warehouses, laydown area, workshops, maintenance facilities, wash bay facilities
- Explosives and chemical storage
- Administration buildings
- Laydown and storage facilities.

The EPA considers rehabilitation and mine closure as one of several preliminary key environmental factors relevant to the proposal. The EPA objective is: “to ensure that premises can be closed, decommissioned and rehabilitated in an ecologically sustainable matter, consistent with agreed outcomes and land uses, and without unacceptable liability to the State.”

As part of the development of the PER document, the EPA has requested a desktop study of successful and unsuccessful rehabilitation strategies and outcomes in similar geologies and vegetation types in the Pilbara, including a discussion of the different methodology and success rates for the various proposed disturbance types, including:

- Created landforms (e.g. waste rock dump, tailings storage facility)
- Short term disturbances (e.g. borrow pits and access tracks)
- Long-term disturbances (e.g. construction camp, permanent accommodation village and administration buildings)
- Linear and/or fragmentation disturbances (e.g. roads, powerlines, borefields).

This document addresses these requirements and also provides a summary of how rehabilitation and revegetation is managed at Fortescue.

1.1 Site Description

1.1.1 Location

Christmas Creek is located 110 km north of Newman, in the Pilbara region of Western Australia (Figure 1).

Figure 1: Location of Christmas Creek

1.1.2 Climate

Christmas Creek is located in the Pilbara region, and the nearest Bureau of Meteorlogy (BoM) station is Newman Airport weather station, located approximately 110 km from the site. The Pilbara has an arid-tropical climate with two distinct seasons, a hot summer from October to April and a mild winter from May to September with a mean maximum temperature of 31.4^{o}C and mean minimum temperature of 17.3^{o}C. In summer, maximum daytime temperatures may reach 46^{o}C, whilst in winter, minimum night time temperatures may fall to -2^{o}C (BoM 2014), experiencing a temperature range of 48^{o}C.

Rainfall in the Pilbara is often sporadic and may occur throughout the year (in summer and winter). Summer rainfall is typically associated with tropical storms in the north, or tropical cyclones that cross the coast and move inland.

1.1.3 Geology

The regional stratigraphy in the Pilbara region of Western Australia is relatively continuous, with similar geological processes occurring across the region. These processes have resulted in the enrichment of the iron deposits (Fortescue, 2009). The project area lies within the Hamersley Basin where granitoid rocks of the Pilbara Craton (2,800 – 3,500 Ma), are overlain by the Archaean Fortescue Group, which is overlain by the Archaean-proterozoic Hamersley Group of which the Marra Mamba Formation (MMF) is the lowermost unit (Environ Australia, 2005). Mineralisation is confined to the Nammuldi Member of the MMF, which is characterised by extensive, thick and podded iron enriched Banded Iron Formation, separated by equally extensive units of siliceous and carbonate rich chert and shale (Fortescue, 2009). The Nammuldi Member is overlain by various Tertiary detrital deposits of varying maturity which may also contain iron mineralisation.

The mineralogy of the ore units is dominated by iron oxides (>55 %) comprising goethite, hematite and to a lesser extent martite, together with ochreous goethite. Other minerals present are kaolinite (alumina <5%) with free and matrix quartz (silica <10%). High grade ore frequently occurs as lenses within low grade ore, often contains high levels of silica, and can be in contact with waste rock zones (Tetra Tech, 2012).

Overburden includes silts, clays, sands and shales (goethitic & hematitic) of the Nammuldi Member. The geochemistry of a range of mine waste samples from the Christmas Creek Deposit has previously been assessed by Graeme Campbell and Associates (GCA, 2005) with regard to the implications for mine waste management. Based on the results of this previous study, the regolith and waste-bedrocks to be excavated during open-pit mining is expected to be non-acid forming (NAF) sulfide minerals. Enrichment in minor elements from NAF lithotypes is expected to be low and soluble-salt concentrations low to moderate (GCA, 2005). The Roy Hill Shales, located below the ore zone, are classified as potentially-acid forming (PAF). However,

open-pit mining is not anticipated to extend to a depth where the Roy Hill Shales will be intersected (GCA, 2005).

1.1.4 Vegetation

Christmas Creek likes within the Fortescue Botanical District of the Eremaean Botanical Province. The vegetation of this province is typically open, and frequently dominated by spinifex, wattles and occasional eucalypt (Beard, 1975).

In the most recent Christmas Creek Life of Mine Flora and Vegetation Assessment (ENV, 2013), a total of 541 taxa including 14 Priority Flora and 20 weed species have been recorded in the survey area. Fifteen broad vegetation types and eleven vegetation associations have been mapped (Table 1).

Table 1: Vegetation Types (VT) and Vegetation Associations (VA) mapped in the Christmas Creek survey area

Habitat	Code	Description of Vegetation Type and Vegetation Association
Creek and Drainage Lines	VT1	Open Woodland of *Eucalyptus victrix, E. camaldulensis* with pockets of *Acacia coriacea* subsp. *pendens* over *Grevillea wickhamii* subsp. *aprica, Petalostylis labicheoides* and *A. tumida* over *Triodia longiceps, Chrysopogon fallax, Themeda triandra* and *Aristida* species.
	VT2	Low Woodland to Low Open Forest of *Acacia aneura, A. citrinoviridis, A. pruinocarpa* over *A. tetragonophylla* and *Psydrax latifolia* over *Chrysopogon fallax, Stemodia viscosa, Blumea tenella, Themeda triandra* and *Triodia* and *Aristida* species.
	VT8	Closed Scrub to Tall Shrubland of *Acacia pruinocarpa, A. tumida, A. ancistrocarpa, A. maitlandii, A. kempeana, A. tetragonophylla* with occasional *E. gamophylla* and *Corymbia* spp. over *Triodia epactia, Themeda triandra* and *Aristida* species.
	VT9	Closed Scrub to Shrubland of *Acacia ancistrocarpa, A. maitlandii, A. kempeana, A. monticola,* occasional *E. gamophylla* and *Corymbia deserticola* over *Senna* species, *Triodia basedowii* and *Aristida* species.
Flats and Broad Plains	VT3	Low Woodland to Low Open Forest of *Acacia aneura, A. pruinocarpa, A. tetragonophylla, A. tenuissima, Grevillea wickhamii* subsp. *aprica, Psydrax latifolia* over *Dodonaea petiolaris* and *Triodia* and *Aristida* species.
	VT4	Low Open Woodland of *Acacia aneura, Acacia pruinocarpa, Acacia xiphophylla, Acacia victoriae* over *A. tetragonophylla, Psydrax latifolia* and *Psydrax suaveolens* over *Ptilotus obovatus* and mixed *Maireana* and *Sclerolaena* species.
	VT10.1	Low Open Woodland of *Acacia xiphophylla, Acacia victoriae, Acacia aneura* var. *aneura* over *Acacia tetragonophylla, Ptilotus obovatus* and mixed *Senna, Maireana* and *Sclerolaena* species.
	VT10.2	Low Open Woodland of *Acacia xiphophylla, Acacia aneura, Eremophila platycalyx* subsp. *pardalota* over Low Open Shrubland of *E. cuneifolia*, *Maireana pyramidata*, *Senna artemisioides* subsp. *oligophylla* over sparse tussock grassland of mixed species.
	VT30.1	High open Shrubland of *Acacia synchronicia* with *Senna glaucifolia* (*Sclerolaena* spp. and other halophytes) over *Aristida* species.
	VT30.1 +10.1	Mosaic of VT30.1 and VT10.1, patches of vegetation were too small to map separately.
	VT30.1 +04	Mosaic of VT30.1 and VT4, patches of vegetation were too small to map separately.
	VT30.2	Scattered shrubs of *Acacia synchronicia* over low shrubland to low open shrubland of

Habitat	Code	Description of Vegetation Type and Vegetation Association
		Eremophila spongiocarpa, *Atriplex bunburyana* and *Sclerolaena cuneata*, over scattered tussock grasses of *Dactyloctenium radulans*, *Eragrostis pergracilis* and *Panicum decompositum.*
	VT30.3	Scattered tall shrubs of *Acacia synchronicia* over low open shrubland of *Senna artemisioides* subsp. *oligophylla* (thinly sericeous), *Atriplex bunburyana* and *Sclerolaena cuneata* over scattered tussock grasses of *Dactyloctenium radulans.*
Ranges, Hills and Hillslopes	VT16	Hummock Grassland of *Triodia basedowii* with pockets of *Triodia epactia* and *Triodia lanigera* with emergent patches of *Eucalyptus leucophloia, Corymbia deserticola* over *Acacia ancistrocarpa, Acacia hilliana, Acacia acradenia, Acacia pyrifolia, Hakea lorea* subsp*. lorea* over *Goodenia stobbsiana* and mixed *Senna* species.
	VT17	Hummock Grassland of *Triodia basedowii* with pockets of *Triodia epactia* and *Triodia lanigera* with emergent patches of *Eucalyptus leucophloia, Corymbia deserticola* over *Acacia ancistrocarpa, A. pyrifolia, Hakea lorea* subsp*. lorea* over *Goodenia stobbsiana* and mixed *Senna* and *Ptilotus* species.
Marsh Vegetation	VA1	*Tecticornia* sp. Christmas Creek, *T. auriculata*, *Muehlenbeckia florulenta* low closed heath over *Eragrostis pergracilis*, *E. tenellula* scattered tussock grasses and *Cullen cinereum*, *Nicotiana heterantha*, *Pterocaulon sphaeranthoides* open herbland.
	VA2	*Muehlenbeckia florulenta* shrubland to open heath over *Tecticornia indica* subsp. *bidens* low scattered shrubs to low open shrubland over *Eleocharis papillosa*, *Schoenoplectus dissachanthus* (very) open sedgeland with *Nicotiana heterantha, Marsilea hirsute* open herbland.
	VA3	**Vachellia farnesiana*, *Acacia ampliceps* open scrub over *Tecticornia* sp. Christmas Creek (K.A. Shepherd & T. Colmer et al. KS 1063), **Aerva javanica* and *Cullen cinereum* low open shrubland over **Cenchrus setiger*, *Dactyloctenium radulans* and **C. ciliaris* tussock grassland.
	VA4	*Melaleuca glomerata* open scrub over **Aerva javanica*, *Tecticornia* spp. low open shrubland over *Cleome viscosa*, *Nicotiana heterantha*, *Swainsona kingii* herbland.
	VA5	*Acacia synchronicia*, *Melaleuca glomerata*, *Eremophila youngii* subsp. *lepidota* scattered tall shrubs over *Tecticornia indica* subsp. *bidens*, *Eremophila spongiocarpa* low open shrubland over *Sporobolus virginicus*, **Cenchrus ciliaris*, *Dactyloctenium radulans* tussock grassland.
	VA6	*Tecticornia* sp. Dennys Crossing (K.A. Shepherd & J. English KS 552), *T. indica* subsp. *bidens*, *Muehlenbeckia florulenta* low open heath over *Eragrostis pergracilis* (very) open tussock grassland and *Cyperus bulbosus* scattered sedges with *Nicotiana heterantha* , *Swainsona kingii* scattered to very open herbland.
	VA7	*Tecticornia indica* subsp. *bidens*, *T.* sp. Dennys Crossing (K.A. Shepherd & J. English KS 552), *Eremophila spongiocarpa* low open heath to low closed heath over *Eragrostis* spp., *Enneapogon* spp., **Cenchrus* spp. scattered tussock with *Nicotiana heterantha*, *Pterocaulon sphaeranthoides, Gomphrena kanisii* scattered herbs.
	VA8	*Tecticornia auriculata* (and *T.* sp. Dennys Crossing (K.A. Shepherd & J. English KS 552) open heath over *Eragrostis pergracilis*, *Chloris pectinata* tussock grassland and *Cyperus bulbosus* scattered sedges with *Swainsona kingii*, *Nicotiana heterantha* scattered herbs.
	VA9	*Acacia synchronicia* scattered tall shrubs over *Tecticornia indica* subsp. *bidens*, *Eremophila spongiocarpa* low open shrubland over *Eragrostis pergracilis*, **Cenchrus ciliaris* tussock grassland with *Lawrencia densiflora*, *Euphorbia australis*, *Goodenia forrestii* scattered herbs.
	VA10	*Acacia synchronicia*, *A. xiphophylla* high shrubland over *Eremophila* spp., *Enchylaena tomentosa* var. *tomentosa*, *Maireana pyramidata* scattered low shrubs over **Cenchrus ciliaris*, *Eragrostis pergracilis*, *Triraphis mollis* very open tussock grassland and *Goodenia forrestii, Sclerolaena cornisheiana, Stemodia grossa*.scattered herbs.
	VA11	Lake bed likely to support annual herbs and grasses episodically.
Infrastructure	VT0	Areas cleared for mining, infrastructure and associated activities.

2. DESKTOP ASSESSMENT OF REHABILITATION STRATEGIES IN THE PILBARA

2.1 Rehabilitation and Revegetation at Fortescue

Definitions applicable to this section include:

- **Closure domains**: landforms or infrastructure that has similar rehabilitation, decommissioning and closure requirements/objectives as defined in the *Guideline for Preparing Mine Closure Plans* (Department of Mines and Petroleum (DMP), 2011)
- **Controlled sites**: include sits that are under Fortescue's legal control including exploration sites, project sites, operational sites (sites that are managed and operated by Fortescue and sites that are managed by Fortescue but operated by contractors) and the Perth offices
- **Rehabilitation**: a return of disturbed land to a stable, productive and or self-sustaining condition, consistent with the post operational land used (DMP/Environmental Protection Authority (EPA), 2011).
- **Revegetation**: establishment of self-sustaining vegetation cover after earthworks have been completed, consistent with the post-operational land use (DMP/EPA, 2011).

Rehabilitation at Fortescue's controlled sites is undertaken under a *Rehabilitation and Revegetation Management Plan* (45-PL-EN-0023), which has been developed to satisfy the requirements of Ministerial Statements 690, 707, 771 and 899. The plan does not include exploration rehabilitation and revegetation activities, which are addressed separately in an *Exploration Environmental Management Plan* (E-PL-EN-0002), and *Exploration Drill Hole Stabilisation and Site Rehabilitation Procedure* (E-PR-EN-0010).

The following supporting documents guide Fortescue's rehabilitation and revegetation activities:

- *Borrow Pit Management Plan* (45-PL-EN-0018)
- *Design Specification for Mine Pit Backfill and Associated Surface Water Management Structures* (100-SW-EN-0046)
- *Groundwater Management Plan* (45-PL-EN-0029)
- *Overburden Management Re-Growth and Waste Procedure* (45-PR-EN-0012)
- *Planning for Closure – Design of Mineral Waste Rock Landforms* (100-PR-EN-1017)
- *Surface Water Management Plan* (45-PL-EN-0024)
- *Tailings Storage Facility Closure Management Guidelines* (CH-GU-OP-0001)
- *Vegetation Clearing and Topsoil Management Procedure* (45-PR-EN-0013)

- *Rehabilitation and Revegetation Monitoring Procedure* (45-PR-EN-0027)
- *Weed Management Plan* (45-PL-EN-0013)
- *Revegetation Management Plan: Cloudbreak* (CB-PL-EN-0026)
- *Solomon Mine Closure Plan* (SO-PL-EN-0002)
- *Christmas Creek Conceptual Mine Closure Plan* (100-RP-EN-9058)
- *Cloudbreak Mine Closure Implementation and Monitoring Plan* (CB-PL-EN-0030).

At Christmas Creek, it is anticipated that rehabilitation activities will take place over the life of mine at the following closure domains:

- Waste Rock Landforms
- Pits
- Tailings Storage Facilities
- Industrial Infrastructure
- Heavy Industrial Infrastructure
- Water Infrastructure
- Roads
- Haul Roads
- Rail
- Borrow Pits
- Exploration.

2.2 Industry Guidelines

The previous Commonwealth Department of Industry, Tourism and Resources produced two guidance documents as part of its Leading Practice Sustainable Development Program for the Mining Industry (DITR, 2006): *Mine rehabilitation* and *Mine Closure and Completion*. The documents outline the principles and practices of mine site rehabilitation and closure activities. The *Mine rehabilitation* document covers sustainable development, stakeholder consultation, materials characterisation and handling, landform construction, waste storage, vegetation establishment and closure activities including the development of criteria and rehabilitation monitoring.

The Environmental Protection Authority (WA) has developed a guidance document *Guidance for the Assessment of Environmental Factors – Rehabilitation of Terrestrial Ecosystems*

(EPA, 2006) to encourage best practice in setting appropriate and effective objectives for rehabilitation and assessing subsequent outcomes.

The Department of Mine and Petroleum has also developed the *Guidelines for Preparing Mine Closure Plans* (DMP, 2011).

2.3 Strategies and Case Studies

2.3.1 Characterisation of Soil Profiles and Waste Material

Waste characterisation is critical in order to assess the adequacy of the material's property as a rehabilitation material and to promote self sustaining native vegetation growth. Characterisation of soil materials and waste materials should occur as early as possible so as to enable adequate planning and selective placement of materials, and so as to avoid adverse effects on the closure process and rehabilitation performance (DITR, 2006).

Properties for testing typically include mineralogy, acidity, salinity, sodicity, erodibility, strength, water holding capacity, particle size distribution, potential for acid formation, nutrient and metal availability, hydraulic conductivity and biological components (Jasper and Braimbridge, 2006).

Erodibility describes the susceptibility of a given material to erosion and is essential to consider for the construction of waste landforms and tailings storage facilities (DITR, 2006). Erodibility can be predicted to some extent on the basis of material properties, or with greater accuracy using laboratory or field trials (Loch, 2000).

Fortescue has undertaken geochemical waste characterisation of mine waste samples (GCA, 2005), waste rock and tailings characterisations (Coffey, 2012 and Tetra Tech, 2012) and investigations into acid and metalliferous drainage potential (AMD) in mined materials as part of their closure and rehabilitation planning works.

2.3.2 Vegetation, topsoil and growth medium management

The management of growth media for rehabilitation purposes, which includes topsoil, subsoil, or combinations of soil material/rock/fertiliser; as well as vegetation grub, is a critical issue in the Pilbara. The extensive nature of iron ore deposits and the associated infrastructure footprint means that large areas need to be rehabilitated. In many cases, soil material is stored in stockpiles, and over time, this can reduce its viability as a growth medium. Several studies have been undertaken to determine practices that can enhance soil's structural and biological integrity over time.

In arid zones such as the Pilbara, soils contain limited organic matter. Topsoil, which can be defined as the top 200 mm of the soil profile which is biologically active (A horizon), contains a

seedbank which makes it a valuable resource for successful revegetation. Topsoil is an important resource as it has:

- High nutrient content relative to other sections of the soil profile;
- High water holding capacity;
- Structural and physical properties that aid plant growth; and
- Viable seed and organic material content

Subsoil, located beneath the topsoil zone, can also serve as a suitable growth medium although it is not as biologically active as topsoil.

Management of vegetation, topsoil and growth medium (e.g. topsoil + subsoil) can include, as a minimum:

- Adequate planning for all stages of land clearance, topsoil movement and data collection.
- Collection and recovery of topsoil, subsoil and vegetation material to an adequate depth, and soil storage in stockpiles nominally designated as two metres in current best management practice, (e.g. Ecologia, 2010 and Pilbara Iron, 2007).
- Hauling material directly to areas where direct return is feasible, as is usually preferred for optimum revegetation success (e.g. Chevron, 2012) or stockpiling in designated areas
- Spreading material from stockpiles onto the rehabilitated surface.

2.3.3 Reconstruction of soil profile

One of the critical components of successful rehabilitation and subsequent revegetation is the construction of a soil profile, which normally includes topsoil, subsoil and benign waste. In some cases, a clay barrier seal or capillary break layer may be required. Surface material may vary, depending on site by site availability and adequacy of material in terms of stability and potential to support plant establishment. Materials can include topsoil, oxidised waste rock, compacted silty sandy clay, clayey oxidised waste rock, tailings, waste rock with minimal fines and quarried rock with minimal fines (DITR, 2006).

Where topsoil is available, a freshly rehabilitated surface should ideally have a cover of 50 – 100 mm of topsoil over a subsoil material (DITR, 2006). On sloped surfaces, adequate protection is required by using rocky topsoil or incorporating rocky materials. Topsoil with high erodibity should only be used in shallow depths (e.g. 50 mm). The depth of topsoil used and underlying material also depends on the nature of the target vegetation community, in some cases; a thicker layer of topsoil in combination with a capillary break may be required. Trials

should be conducted to determine the optimum combination of materials, ripping depth and any soil amelioration or covers required.

For example, a waste landform at a Southern WA Goldfields site underwent a trial to compare a number of different cover treatments in terms of their effect on pH and EC of the cover profile. The cover materials used were topsoil, waste rock, road ballast and uncovered tailings. Over ten years, the data showed that a cover material was required to enable plant establishment, and that treatments involving both a layer of waste rock and topsoil is likely to result in the highest vegetative cover (Outback Ecology, 2012). Soil profile reconstruction at Bottle Creek Gold Mine in WA involved 500 mm of waste rock, topsoil spread to a depth of 100 mm and deep ripping along the surface of the contour (Anderson *et al*., 2002).

Some approaches for tailings storage facility rehabilitation have been summarised in Lacy *et al*. (2004), including:

- Chemical amendments: altering the physical structure or chemical composition of the tailings to promote vegetation establishment and survival. This can include the use of gypsum, lime and fertilisers.
- Chemical stabilisation – can be used to stabilise surfaces by using sealants to produce a crust, preventing wind and water erosion. This includes adhesives, polymers, bitumen based compounds and cement.
- Physical stabilisation – the application of a cover to counter the effects of wind and water. Materials can include oxide waste rock, laterite waste rock, topsoil, competent fresh rock (non acid forming), mill scats and alluvial mining gravels.
- Vegetation stabilisation – vegetation growth on a tailings storage facility depends on the ability of the material to support plant growth. It has the same impact as a physical barrier.

An example of a soil profile that was designed to manage potentially acid-forming wastes (PAF) was the use of a store/release cover at the Mt McClure Gold Mine. A store/release cover is one suited to seasonal, moisture deficit climates such as the Pilbara, which stores rainfall infiltration during the wet season and subsequently releases it through evapotranspiration during the dry season (DITR, 2006). This is relevant in an arid/semi-arid setting as water availability if the rate determining factor for sulphide oxidation. In this study, water retention studies were conducted on benign waste material at the side and oxide regolith and caprock were selected and placed at 1000 and 1500 mm depth to minimise rainfall percolation to underlying wastes (Campbell, 2004).

2.3.4 Selecting appropriate species and seed management

Species selection should consider landform topography, the nature of the soil or growth medium used on the rehabilitated surface, the ability of species to colonise and establish and the target

vegetation community in the surrounding area. The species list should have both species diversity and structural diversity (e.g. species from various strata such as grasses and low lying shrubs for groundcover which provides landform stability, and taller shrubs and trees which can provide fauna habitat) and should consider keystone species of the area as well as any species that may be specifically required by site specific or legal commitments. Species lists should initially be developed from baseline flora and vegetation surveys. An example list of species found at Christmas Creek is listed in Appendix A (ENV Australia, 2013a, 2013b and Biota, 2004).

It is the intent that revegetation at Christmas Creek and Fortescue controlled sites will involve seeding with native, local provenance seed from a broad vegetation formation or community representative of the area that has been rehabilitated. Seed collection and management should be undertaken as per established guidelines, e.g. Florabank guidelines (Florabank, 1998-2010) and with research and development activities assisting in refining and improving the overall process.

Rio Tinto Iron Ore have a seed management and collection process involving provenance and priority flora seed collection, subsequent storage in a company-owned storage facility and involvement in collaborations with research institutions to further understanding about seed ecology and restoration (Pilbara Iron, 2007).

BHP Billiton Iron Ore has developed all aspects of their seed management process over several years, including (Stokes, 2014):

- Utilising baseline flora surveys to guide seed orders and final seed mixes,
- Seed collectors supplying information with all seed batches (covering collection location and specimen identification),
- Storage conditions that meet international standards,
- Targeted broadcast seeding of specific mixes to certain landform types within a rehabilitation project,
- Rehabilitation and Development programs, including the completed Pilbara Seed Atlas research and initiation of the Restoration Seedbank Initiative.

BHP Billiton Iron Ore's research and development programs focus on each aspect of the seed management cycle, and together with the analysis of the rehabilitation monitoring results, both contribute to the adaptive management approach and continuous improvement of seed management (Stokes, 2014).

2.3.5 Vegetation Establishment

Establishment of a vegetation community can involve one or more of the following (DITR, 2006):

- Direct topsoil return
- Seeding
- Hydroseeding
- Planting of seedling, including those from tissue culturing
- Translocation
- Habitat transfer and natural re-colonisation.

Direct seeding involves sowing seed directly into prepared ground, either by hand for small areas or otherwise inaccessible areas, or through mechanical seeding, in which a specialised seeder is usually mounted onto earthworks machinery and seed can be distributed during ripping. Direct seeding is usually more efficient in terms of time, cost and labour compared to tubestock planting, and allows for a more diverse seed mix, but relies on the availability of seed, and the properties of the growth medium. Several sites in arid Australia have used a combination of direct topsoil return, seeding and natural recolonisation, such as iron ore sites at Rio Tinto Iron Ore (Pilbara Iron, 2007).

The planting of seedlings (or tubestock) is not commonly conducted in arid land mine rehabilitation due to the high costs associated in acquiring and planting tube stock and ongoing irrigation requirements (BHP Billiton, 2009). Hydroseeding, although not commonly used in the Pilbara, can be used in highly erosive conditions and is done by applying seed mixed with a tackifier and fertiliser if required directly on to the surface (Florabank, 1999).

2.3.6 Completion Criteria

The development of acceptable and achievable completion criteria is a necessary part of mine closure planning. Completion criteria are defined as agreed standards or levels of performance, which demonstrate successful closure of a site (DITR, 2006). Once achieved, they demonstrate to the mining company, regulators and other stakeholders that financial assurances and liabilities can be removed and/or lease relinquishment can ultimately occur.

The first stage of the development of competition criteria is the setting of rehabilitation objectives. In Australia, post mining objectives are generally related to creating safe, stable and non-polluting landforms, capable of sustaining an agreed post-mining land use (DMP and EPA, 2011). A common desired post mining outcome is the achievement of a self sustaining ecosystem that exhibits comparable characteristics to the local natural environment (e.g. Osborne and Brearley, 2000, Jasper *et al*., 2003). From these broad objectives, more specific criteria can be identified, which are complimented by appropriate monitoring tools and quantitative standards. Criteria can cover aspects ranging from physical elements, such as drainage and erosion, to biological aspects, such as vegetation and fauna habitat (Outback Ecology, 2011).

Mining operations typically operate on a shorter time frame than that of ecosystem development and this creates a need for an agreed framework in which all stakeholders can assess the acceptability of rehabilitation, at an early stage. Completion criteria which focus on the essential foundations of the ecosystem can provide this framework. In general, the first priority should be to establish an appropriate physical foundation, followed by appropriate biological components, then finally post-closure management. The proposed criteria can be defined by the SMART acronym, in that they are intended to be specific, measurable, achievable, relevant, and timely.

Generally a framework is proposed in which broad rehabilitation objectives are supported by more-specific criteria. Each criteria in turn is supported by an appropriate monitoring tool and where possible a quantitative standard. Overall objectives for rehabilitation, as well as specific targets and standards, should only represent what can be achieved (Nichols *et al*., 2005) and should be related to ecosystem functionality and processes, not simply composition. Criteria to assess rehabilitation success need to be simple, objective, and easy to measure if they are to be regularly used for management of the rehabilitation areas, even if the ecosystem processes involved are complex (Bellairs, 1998).

Once developed, the criteria will provide a focus for rehabilitation monitoring, and may lead to refinements to the current monitoring approach. A monitoring program should be designed and implemented that feeds the “adaptive learning loop” (Tongway and Ludwig, 2011) and feedback is implemented until rehabilitation can be seen on track toward the rehabilitation objectives. A monitoring program must be designed to provide the required data, should be suited to the host environment and must take into account the scale and variability of an area, and should monitor parameters that are directly linked to the criteria. In general, the cessation of the monitoring can occur when the rehabilitation area demonstrates that it has become self-sustaining and is resilient in the face of stochastic events. The area should also have met and/or exceeded the defined criteria for a number of successive monitoring events and have achieved a set threshold level.

An example of completion criteria for a site in the Kimberley of Western Australia included criteria based on:

- Percent of native perennial grasses
- Traditional Owner species of interest, and
- Re-sprouter (fire tolerant) plants.

In this site, as with many Pilbara sites, stability of waste rock landforms was a critical aspect of rehabilitation success, indicated by a criterion for establishing a set percentage of native perennial grass cover, and site specific requirements required the inclusion of traditional owner selected species and species capable of tolerating a regular fire regime (Yanez *et al*., 2012).

2.3.7 Rehabilitation and Revegetation Monitoring

The selection of parameters to monitor, and how frequently, depends on what information the parameter provides, how sensitive its response, its correlation with known ecosystem processes and predictability, its ease and cost of measurement and repeatability or degree of subjectivity, and suitability for monitoring data relevant to the established completion criteria. The choice of monitoring parameters is quite extensive but should include those that are known or expected to be most limiting to rehabilitation success (DITR, 2006).

Typically, monitoring of rehabilitation can include:

- an assessment of surface and slope stability
- the performance of constructed covers (where installed over mine or mineral processing wastes)
- properties of the soil or root zone media (chemistry, fertility and water relations)
- plant community structural attributes (such as cover, woody species density and height)
- plant community composition (such as presence of desired species, weeds)
- selected indicators of ecosystem functioning (such as soil microbial biomass)
- photographic monitoring of the area.

Monitoring may also extend, where required, to surveys of selected fauna groups to assess their colonisation (including mammals and avifauna) or as bioindicators of broader ecosystem trends (e.g. ants).

Various monitoring tools have been used in the Pilbara, and include:

- Ecosystem Function Analysis (EFA): developed by CSIRO, it provides a monitoring approach that has been adapted from its original use in rangeland ecosystems for use in mine sites. Described in Tongway (2001), it consists of the main component of landscape function analysis (LFA) which uses soil surface feature to estimate indices of soil stability, infiltration and nutrient cycling. EFA includes LFA plus measures of vegetation dynamics and habitat complexity. Using the LFA, it is possible to define and rapidly record the influence of vegetation along with non-vegetation based indices toward completion criteria (for stability, infiltration and nutrient cycling), and therefore, assess rehabilitation success or help to identify areas performing below expectation. Transects are also used to monitor erosion through mean bank erosion. EFA monitoring tool has been used in Pilbara sites including Rio Tinto Iron Ore (Pilbara Iron, 2007).

- The Point Centre Quarter method is most commonly used in low rainfall areas where the vegetation is naturally sparse such as in a mulga or chenopod shrubland in arid and semi-arid areas. PCQ has been determined to be the most effective monitoring program in some areas as the PCQ method allows for efficient monitoring in these sparse conditions and provides accurate data for plant cover, density and species richness (Mitchell, 2007). The method is also flexible and can be tailored to suit different vegetation requirements, for example criteria for multiple layers of vegetation in the dry tropics of Northern Queensland and specific species information for invasive perennials in the Northern tropics. PCQ also uses actual measurements rather than estimations by eye and plants can be any distance from the transect within the monitoring area (Outback Ecology, 2011). Disadvantages to this method include the exclusion of the quantitative analysis of annual plant species. The PCQ method, however, is commonly used in climatic regions where perennial plant species provide permanent functions in the landscape, while annual plants are only temporary and are not seen as providing a strong, lasting effect on the landscape, with the exception of providing nutrients, particularly in desiccation.
- Alternatively, the quadrat method assesses both perennial and annual plant cover and density and is commonly used in a variety of environments such as the dry tropics of the Pilbara and tropical and sub-tropical climates of the Kimberley. The quadrat method can be applied to areas with various plant cover and density; however the main disadvantages of this method include its reliance on visual assessments for cover and propensity to human error (Floyd and Anderson, 1987). Quadrats can be used as small quadrats along a transect or a large (e.g. 50 x 50 m) quadrat used to capture data.
- Numerous other methods exist and are being used to monitor vegetation cover, such as the ground cover determination using the point-intercept methodology (Viert *et al*., 2010) used for reclamation monitoring at a Goldfields site. Regardless of the method, it is critical to recognise the benefits and flaws of each particular method and to select a method that best balances the type and quality of information collected against cost, efficiency and timeliness, and that the monitoring method provides the relevant information required to measure rehabilitation progress against the defined criteria.
- LiDAR (Light Detecting and Ranging) techniques are being developed, which allow for a wide variety of applications, through airborne scanners and ground based scanners, to monitor data such as topography, plant height, cover and landform stability (Mangan and Pratt, 2014).

2.3.8 Potential Rehabilitation Strategies for Christmas Creek closure domains

Table 2 shows a summary of rehabilitation strategies for Christmas Creek's closure domains, as proposed in the Christmas Creek Conceptual mine closure plan (100-RP-EN-9058).

Table 2: Potential Closure and Rehabilitation Strategies for selected Christmas Creek closure domains

Closure Domain	Closure and Rehabilitation Strategies

Closure Domain	Closure and Rehabilitation Strategies
Landforms (waste rock dump, tailings storage facility)	• Waste landform and tailings storage facility rehabilitation design to be conducted in alignment with company waste landform design guidelines and industry best practice. • Clear vegetation and soil from disturbed areas. • Progressively batter waste rock dump slopes to <20 degrees and contour to blend with topography. Include back sloping berms in design. • Establish water diversion works where required. • Use adequate capping material and growth media where required, particularly for tailings storage facilities. Investigate and use optimum waste rock and topsoil cover to establish a stable water shedding surface with a suitable native seed mix. • Direct replace cleared soil where practical or respread stockpiled soil and vegetation material where available. • Deep rip on contour. • Seed with local provenance seed. • Monitor landform stability, ecosystem function and vegetation establishment.
Short term disturbances (borrow pits, access tracks)	Borrow Pits • Rehabilitation for borrow pits to be conducted in alignment with internal borrow pit management plan. • Clear vegetation and soil from all disturbed areas for use in rehabilitation. • Backfill borrow pits where sufficient material is available. • Batter and contour pit walls to <20 degrees to resemble surrounding topography were practicable. • Ensure ponding is minimised in borrow pits and other artificially created depressions through self drainage or by ensuring surface water flows or drainage lines are directed around the pit or depressions. • Spread soil and vegetation material on the surface where available. • Deep rip the borrow pit floor to relieve compaction and assist with infiltration of water. • Seed with local provenance seed if practical. • When directly downstream from a road, the road must have surface water drainage channels to divert water away from borrow pits. • Monitor landform stability, ecosystem function and vegetation establishment.
	Access Tracks • Where topsoil has been removed, rehabilitate access track by pushing in windrows and repreading soil and vegetative material. • Re establish natural landform and drainage patterns. • Deep rip the surface. • Allow to revegetate naturally. • Monitor ecosystem function and vegetation establishment.
Long term disturbances (construction camps, villages, administration buildings)	• Liaise with required stakeholders where relevant in case any infrastructure needs to be retained. • Power, water and drainage systems to be shut off and buildings and infrastructure decommissioned and removed from site. • Remove scrap metal from site. • Bury remaining inert scrap materials. • Excavate and remove and/or bury concrete material. • Remove any hydrocarbon contaminated soils for remediation. • Contour area to restore natural drainage patterns. • Rip surface to alleviate compaction and encourage regrowth of native vegetation. Selected areas may be designated for hand seeding. • Monitor landform stability, ecosystem function and vegetation establishment.
Linear/Fragmentation disturbances (roads, powerlines, borefields)	Haul Roads and Access Tracks • Stakeholder consultation to determine future post- operational use for haul roads, roads and access tracks. • Those roads and tracks not required by the company will be rehabilitated. • Remove culverts and other associated infrastructure.

Closure Domain	Closure and Rehabilitation Strategies
	• Remove any hydrocarbon contaminated soils for remediation. • Contour to restore natural drainage. • Re-spread stockpiled topsoil and vegetation material where available. • Deep rip surface to alleviate compaction and encourage re-growth of native vegetation. • Seed with local native vegetation if necessary. • Restrict access. • Monitor ecosystem function and vegetation establishment.
	Powerlines • Dismantle and remove all power generation equipment, associate infrastructure and transmission lines from site. • Remove scrap metal and bury remaining inert scrap materials which are not suitable for sale or recycling. • Excavate and remove or bury concrete. • Remove any hydrocarbon contaminated soils for remediation. • Contour to restore natural drainage. • Rip surface to alleviate compaction and encourage re-growth of native vegetation. • Monitor ecosystem function and vegetation establishment.
	Borefields • Selected water supply bores will be retained for post decommissioning monitoring. • Those bores not required for ongoing monitoring willb e shut down, bore casings cut off below ground surface and holes plugged. • Above ground pipelines and pumps to be flushed and removed from site. • Below ground pipes will be cut off below ground surface and remain buried. • If excessively disturbed, areas around the bores and pipeline route will be contoured, ripped and seeded with suitable species.

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Appendix 1: Example list of species found at Christmas Creek

Habitat	Species	Dominant
Creeklines and Drainage Lines	*Abutilon amplum*	
	Abutilon cryptopetalum	
	Abutilon fraseri	
	Abutilon lepidum	
	Abutilon macrum	√
	Acacia acradenia	
	Acacia aff. aneura (long, flat, recurved; FMR 35.3)	√
	Acacia aff. aneura (narrow fine veined; site 1259)	√
	Acacia ancistrocarpa	√
	Acacia aneura	√
	Acacia ayersiana	√
	Acacia coriacea subsp. *pendens*	√
	Acacia cowleana	
	Acacia maitlandii	√
	Acacia monticola	
	Acacia paraneura	√
	Acacia pruinocarpa	√
	Acacia pyrifolia	√
	Acacia pyrifolia var. *pyrifolia*	√
	Acacia rhodophloia	
	Acacia synchronicia	
	Acacia tetragonophylla	√
	Acacia trachycarpa	√
	Acacia tumida var. *pilbarensis*	√
	Achyranthes aspera	
	Aeschynomene indica	
	Alternanthera angustifolia	
	Alternanthera denticulata	
	Alysicarpus muelleri	
	Amaranthus centralis	
	Amaranthus interruptus	
	Amaranthus undulatus	
	Ammannia baccifera	
	Ammannia multiflora	
	Amphipogon sericeus	
	Androcalva luteiflora	
	Anthobolus leptomerioides	
	Aristida contorta	√
	Aristida inaequiglumis	√
	Aristida obscura	
	Aristida pruinosa	
	Atalaya hemiglauca	√

Habitat	Species	Dominant
	Atriplex bunburyana	
	Blumea tenella	
	Boerhavia burbidgeana	
	Boerhavia coccinea	√
	Boerhavia paludosa	
	Bonamia sp. Dampier (A.A. Mitchell PRP 217)	
	Bothriochloa bladhii subsp. *bladhii*	
	Brachyachne convergens	
	Brachyachne prostrata	
	Bulbostylis barbata	
	Bulbostylis turbinata	
	Calandrinia ptychosperma	
	Calotis porphyroglossa	
	Centipeda minima subsp. *macrocephala*	
	Cheilanthes austrotenuifolia	
	Chloris pectinata	√
	Chrysopogon fallax	√
	Cleome oxalidea	
	Cleome viscosa	
	Clerodendrum floribundum var. *anfustifolium*	
	Commelina ensifolia	
	Convolvulus angustissimus subsp. *angustissimus*	
	Corchorus lasiocarpus subsp. parvus	√
	Corchorus parviflorus	√
	Corchorus tridens	√
	Corymbia candida subsp. *candida*	√
	Corymbia deserticola subsp. *deserticola*	√
	Corymbia ferriticola subsp. *ferriticola*	
	Corymbia hamersleyana	√
	Crotalaria dissitiflora subsp. *benthamiana*	
	Crotalaria medicaginea var. *neglecta*	√
	Cucumis maderaspatanus	
	Cullen cinereum	
	Cullen leucanthum	
	Cymbopogon ambiguus	
	Cymbopogon procerus	√
	Cyperus iria	
	Cyperus squarrosus	
	Cyperus vaginatus	
	Dactyloctenium radulans	
	Dampiera candicans	√
	Dichanthium sericeum subsp. *humilius*	

Habitat	Species	Dominant
	Dicladanthera forrestii	
	Digitaria ctenantha	
	Dodonaea coriacea	
	Dodonaea petiolaris	
	Duperreya commixta	
	Dysphania rhadinostachya	
	Dysphania rhadinostachya subsp. *rhadinostachya*	
	Ehretia saligna var. *saligna*	
	Enchylaena tomentosa var. *tomentosa*	
	Enneapogon lindleyanus	
	Enneapogon polyphyllus	
	Enneapogon robustissimus	
	Eragrostis cumingii	√
	Eragrostis desertorum	
	Eragrostis leptocarpa	√
	Eragrostis tenellula	√
	Eragrostis xerophila	√
	Eremophila cuneifolia	
	Eremophila forrestii subsp. *forrestii*	√
	Eremophila lanceolata	√
	Eremophila latrobei subsp. *filiformis*	√
	Eremophila longifolia	
	Eremophila spongiocarpa	
	Eremophila youngii subsp. *lepidota*	√
	Eriachne lanata	√
	Eriachne mucronata	
	Eriachne pulchella subsp. dominii	
	Eriachne pulchella subsp. *pulchella*	√
	Eriachne tenuiculmis	
	Eucalyptus leucophloia subsp. *leucophloia*	√
	Eucalyptus victrix	√
	Euphorbia alsiniflora	
	Euphorbia biconvexa	
	Euphorbia boophthona	
	Euphorbia tannensis subsp. *eremophila*	
	Evolvulus alsinoides var. *decumbens*	
	Evolvulus alsinoides var. villosicalyx	
	Fimbristylis microcarya	
	Gomphrena cunninghamii	
	Gomphrena kanisii	
	Goodenia forrestii	
	Goodenia lamprosperma	

Habitat	Species	Dominant
	Goodenia microptera	
	Goodenia nuda	
	Goodenia prostrata	
	Goodenia stobbsiana	
	Gossypium robinsonii	√
	Grevillea wickhamii subsp. hispidula	
	Hakea chordophylla	
	Hakea lorea subsp. *lorea*	
	Haloragis gossei	
	Hibiscus coatesii	
	Hibiscus sturtii var. aff. *grandiflorus*	
	Hibiscus sturtii var. *campylochlamys*	
	Hybanthus aurantiacus	√
	Indigofera monophylla	√
	Indigofera monophylla (PAN57-9)	
	Ipomoea coptica	
	Ipomoea muelleri	√
	Ipomoea polymorpha	
	Iseilema membranaceum	
	Iseilema vaginiflorum	
	Jasminum didymum subsp. lineare	
	Keraudrenia nephrosperma	
	Lepidium muelleri-ferdinandii	
	Lipocarpha microcephala	
	Maireana planifolia	
	Maireana planifolia x *villosa*	
	Maireana pyramidata	√
	Maireana tomentosa	
	Maireana triptera	
	Maireana villosa	
	Marsilea hirsuta	
	Melaleuca glomerata	√
	Melaleuca linophylla	√
	Mollugo molluginea	
	Nicotiana occidentalis subsp. *obliqua*	
	Nicotiana occidentalis subsp. *occidentalis*	
	Nicotiana rosulata subsp. *rosulata*	
	Notoleptopus decaisnei var. Orbicularis	
	Operculina aequisepala	
	Panicum decompositum	
	Paraneurachne muelleri	√
	Paspalidium clementii	

Habitat	Species	Dominant
	Paspalidium tabulatum	
	Perotis rara	√
	Petalostylis labicheoides	√
	Phyllanthus maderaspatensis	
	Pluchea dunlopii	
	Pluchea rubelliflora	
	Plumbago zeylanica	
	Polycarpaea corymbosa var. *corymbosa*	
	Polycarpaea holtzei	
	Polycarpaea longiflora	
	Polymeria calycina	
	Portulaca pilosa	
	Psydrax latifolia	
	Psydrax suaveolens	
	Pterocaulon sphacelatum	
	Ptilotus astrolasius	
	Ptilotus auriculifolius	
	Ptilotus calostachyus	√
	Ptilotus clementii	
	Ptilotus fusiformis	
	Ptilotus gomphrenoides var. *gomphrenoides*	
	Ptilotus helipteroides	
	Ptilotus macrocephalus	
	Ptilotus nobilis	
	Ptilotus obovatus	√
	Ptilotus polystachyus	
	Ptilotus schwartzii	√
	Rhagodia eremaea	
	Rhagodia sp. Hamersley (M. Trudgen 17794)	
	Rhynchosia minima	
	Rostellularia adscendens var. *clementii*	
	Rostellularia adscendens var. *latifolia*	
	Scaevola spinescens	
	Schoenoplectus laevis	
	Sclerolaena cornishiana	
	Sclerolaena costata	
	Sclerolaena cuneata	
	Sclerolaena tetragona	
	Senna artemisioides subsp. *helmsii*	√
	Senna artemisioides subsp. *oligophylla*	
	Senna artemisioides subsp. *oligophylla* x *helmsii*	
	Senna glaucifloia x *ferraria*	

Habitat	Species	Dominant
	Senna glaucifolia	√
	Senna glaucifolia x aff. *oligophylla*	√
	Senna glutinosa subsp. *glutinosa*	√
	Senna glutinosa subsp. *glutinosa* x *stricta*	
	Senna glutinosa subsp. *luersenii* x *stricta*	
	Senna glutinosa subsp. *luerssenii*	√
	Senna glutinosa subsp. x *luerssenii*	
	Senna notabilis	√
	Senna sp. Karijini (M.E. Trudgen 10392)	
	Senna venusta	√
	Sesbania cannabina	
	Setaria dielsii	
	Sida ectogama	√
	Sida fibulifera	√
	Sida platycalyx	
	Sida sp. dark green fruit (S. van Leeuwen 2260)	
	Sida sp. verrucose glands (F.H. Mollemans 2423)	
	Solanum horridum	
	Solanum lasiophyllum	
	Solanum phlomoides	√
	Solanum sturtianum	
	Sporobolus australasicus	√
	Stemodia grossa	
	Streptoglossa bubakii	
	Striga squamigera	
	Tephrosia densa	
	Tephrosia rosea var. Fortescue creeks	
	Tephrosia supina	
	Themeda triandra	√
	Trachymene oleracea	
	Trachymene oleracea subsp. *oleracea*	
	Tragus australianus	
	Trianthema glossostigma	
	Trianthema triquetra	
	Tribulus astrocarpus	
	Tribulus hirsutus	
	Tribulus suberosus	
	Trichodesma zeylanicum	
	Triodia basedowii	
	Triodia epactia	√
	Triodia longiceps	√
	Triodia pungens	

Habitat	Species	Dominant
	Triodia sp. Shovellana Hill	√
	Triraphis mollis	
	Triumfetta clementii	
	Urochloa occidentalis	
	Zaleya galericulata	
Flats and Broad Plains	*Abutilon fraseri*	
	Abutilon lepidum	
	Abutilon macrum	
	Abutilon otocarpum	
	Abutilon oxycarpum subsp. *prostratum*	
	Acacia aff. aneura	√
	Acacia aff. aneura (long, flat, recurved; FMR 35.3)	√
	Acacia aff. aneura (narrow fine veined; site 1259)	√
	Acacia ancistrocarpa	√
	Acacia aneura	√
	Acacia aneura (grey bushy form; MET 15 732)	√
	Acacia ayersiana	√
	Acacia bivenosa	
	Acacia coriacea subsp. *pendens*	√
	Acacia maitlandii	√
	Acacia marramamba	√
	Acacia paraneura	√
	Acacia pruinocarpa	√
	Acacia pteraneura	√
	Acacia pyrifolia var. *pyrifolia*	
	Acacia sericophylla	√
	Acacia sibirica	
	Acacia synchronicia	√
	Acacia tenuissima	
	Acacia tetragonophylla	√
	Acacia trachycarpa	
	Acacia tumida var. *pilbarensis*	
	Acacia xiphophylla	√
	Aeschynomene indica	
	Alternanthera angustifolia	
	Alternanthera denticulata	
	Alternanthera nana	
	Alysicarpus muelleri	
	Amaranthus interruptus	
	Androvalca luteiflora	
	Anthobolus leptomerioides	
	Aristida contorta	√

Habitat	Species	Dominant
	Aristida holathera var. *holathera*	
	Aristida inaequiglumis	√
	Aristida latifolia	
	Aristida obscura	
	Aristida pruinosa	√
	Atalaya hemiglauca	√
	Atriplex bunburyana	
	Atriplex codonocarpa	
	Austrobryonia pilbarensis	
	Blumea tenella	
	Boerhavia burbidgeana	
	Boerhavia coccinea	
	Boerhavia paludosa	
	Bonamia rosea	
	Bothriochloa bladhii subsp. *bladhii*	
	Brachyachne prostrata	√
	Bulbostylis barbata	√
	Bulbostylis turbinata	
	Calandrinia ptychosperma	√
	Calotis porphyroglossa	
	Calotis squamigera	
	Centipeda minima subsp. *macrocephala*	
	Cheilanthes austrotenuifolia	
	Cheilanthes sieberi subsp. *sieberi*	√
	Chloris pectinata	√
	Chrysocephalum gilesii	
	Chrysopogon fallax	√
	Cleome oxalidea	
	Cleome viscosa	
	Commelina ensifolia	√
	Convolvulus angustissimus subsp. *angustissimus*	
	Corchorus lasiocarpus subsp. *lasiocarpus*	
	Corchorus lasiocarpus subsp. *parvus*	
	Corchorus parviflorus	√
	Corchorus tridens	√
	Corymbia candida subsp. *dipsodes*	
	Corymbia hamersleyana	√
	Crotalaria dissitiflora subsp. *benthamiana*	
	Crotalaria medicaginea var. *neglecta*	
	Cucumis maderaspatanus	
	Cullen cinereum	
	Cymbopogon ambiguus	√

Habitat	Species	Dominant
	Cymbopogon obtectus	
	Cyperus iria	
	Cyperus rigidellus	
	Dactyloctenium radulans	√
	Dichanthium sericeum	
	Dichanthium sericeum subsp. *humilius*	
	Digitaria brownii	
	Digitaria ctenantha	√
	Dodonaea petiolaris	√
	Duperreya commixta	
	Dysphania rhadinostachya	√
	Dysphania rhadinostachya subsp. *rhadinostachya*	
	Ehretia saligna var. *saligna*	√
	Enchylaena tomentosa var. *tomentosa*	
	Enneapogon caerulescens var. *caerulescens*	
	Enneapogon polyphyllus	√
	Enneapogon robustissimus	√
	Enteropogon ramosus	√
	Eragrostis cumingii	√
	Eragrostis desertorum	√
	Eragrostis dielsii	√
	Eragrostis eriopoda	
	Eragrostis leptocarpa	√
	Eragrostis pergracilis	
	Eragrostis tenellula	√
	Eragrostis xerophila	√
	Eremophila cuneifolia	√
	Eremophila forrestii subsp. *forrestii*	√
	Eremophila lanceolata	√
	Eremophila latrobei	√
	Eremophila latrobei subsp. *filiformis*	√
	Eremophila latrobei x *forrestii*	√
	Eremophila longifolia	
	Eremophila platycalyx subsp. *pardalota*	√
	Eremophila spongiocarpa	
	Eremophila youngii subsp. *lepidota*	√
	Eriachne benthamii	√
	Eriachne helmsii	
	Eriachne mucronata	√
	Eriachne pulchella subsp. *dominii*	√
	Eriachne pulchella subsp. *pulchella*	√
	Eucalyptus gamophylla	√

Habitat	Species	Dominant
	Euphorbia aff. australis var. 1 (MET 12 337)	
	Euphorbia alsiniflora	
	Euphorbia boophthona	
	Euphorbia tannensis subsp. *eremophila*	
	Evolvulus alsinoides var. villosicalyx	
	Frankenia setosa	
	Glycine canescens	
	Gomphrena affinis subsp. pilbarensis	
	Gomphrena cunninghamii	√
	Gomphrena kanisii	
	Goodenia forrestii	
	Goodenia lamprosperma	
	Goodenia microptera	
	Goodenia muelleriana	
	Goodenia nuda	
	Goodenia prostrata	√
	Goodenia stobbsiana	
	Gossypium australe	
	Grevillea berryana	√
	Grevillea wickhamii subsp. *hispidula*	√
	Hakea chordophylla	√
	Hakea lorea subsp. *lorea*	
	Heliotropium heteranthum	
	Hibiscus burtonii	
	Hibiscus coatesii	
	Hibiscus sturtii var. aff. *grandiflorus*	
	Hibiscus sturtii var. *campylochlamys*	
	Hibiscus sturtii var. *grandiflorus*	
	Hybanthus aurantiacus	√
	Indigofera colutea	√
	Indigofera monophylla	
	Ipomoea coptica	
	Ipomoea lonchophylla	
	Ipomoea muelleri	√
	Ipomoea polymorpha	
	Iseilema dolichotrichum	
	Iseilema macratherum	
	Iseilema membranaceum	
	Jasminum didymum subsp. *lineare*	
	Keraudrenia nephrosperma	√
	Lepidium oxytrichum	
	Lepidium phlebopetalum	

Habitat	Species	Dominant
	Lepidium platypetalum	
	Maireana amoena	
	Maireana carnosa	
	Maireana georgei	
	Maireana planifolia	√
	Maireana planifolia x *villosa*	
	Maireana pyramidata	√
	Maireana tomentosa	
	Maireana triptera	
	Maireana villosa	
	Marsdenia australis	
	Marsilea hirsuta	
	Melaleuca glomerata	√
	Mimulus gracilis	
	Mollugo molluginea	√
	Muehlenbeckia florulenta	√
	Neptunia dimorphantha	
	Nicotiana heterantha	
	Nicotiana occidentalis subsp. *obliqua*	
	Notoleptopus decaisnei var. Orbicularis	
	Oldenlandia crouchiana	
	Operculina aequisepala	
	Panicum effusum	
	Panicum laevinode	
	Paraneurachne muelleri	√
	Paspalidium clementii	
	Paspalidium clemetii	√
	Perotis rara	√
	Petalostylis labicheoides	
	Phyllanthus erwinii	
	Phyllanthus maderaspatensis	
	Pluchea dunlopii	
	Pluchea rubelliflora	
	Pluchea tetranthera	
	Polycarpaea corymbosa var. *corymbosa*	√
	Polycarpaea holtzei	√
	Polycarpaea longiflora	
	Polygala isingii	
	Portulaca cyclophylla	
	Portulaca pilosa	
	Psydrax latifolia	√
	Psydrax suaveolens	√

Habitat	Species	Dominant
	Pterocaulon serrulatum	
	Pterocaulon sphacelatum	
	Ptilotus aervoides	
	Ptilotus astrolasius	
	Ptilotus auriculifolius	
	Ptilotus calostachyus	
	Ptilotus clementii	
	Ptilotus exaltatus	
	Ptilotus gaudichaudii	
	Ptilotus gomphrenoides var. *gomphrenoides*	
	Ptilotus helipteroides	
	Ptilotus macrocephalus	
	Ptilotus nobilis	
	Ptilotus obovatus	√
	Ptilotus polystachyus	
	Ptilotus schwartzii	
	Rhagodia eremaea	√
	Rhagodia sp. Hamersley (M. Trudgen 17794)	
	Rhynchosia minima	
	Rostellularia adscendens var. *clementii*	
	Scaevola spinescens	
	Schizachyrium fragile	
	Sclerolaena cornishiana	
	Sclerolaena costata	
	Sclerolaena cuneata	√
	Sclerolaena densiflora	
	Sclerolaena diacantha	
	Sclerolaena eriacantha	
	Sclerolaena glabra	
	Senna artemisioides subsp. *helmsii*	√
	Senna artemisioides subsp. *oligophylla*	√
	Senna artemisioides subsp. *oligophylla* x *helmsii*	
	Senna ferraria x *glaucifolia*	
	Senna glaucifolia	√
	Senna glutinosa subsp. *glutinosa*	√
	Senna glutinosa subsp. *glutinosa* x *stricta*	√
	Senna glutinosa subsp. *luerssenii*	√
	Senna glutinosa subsp. x *luerssenii*	
	Senna hamersleyensis	
	Senna hamersleyensis X sp. Karijini(M.E. Trudgen 10392) .	
	Senna notabilis	√

Habitat	Species	Dominant
	Senna sp. Karijini (M.E. Trudgen 10392)	
	Senna sp. Meekatharra (E. Bailey 1-26)	
	Senna stricta	
	Senna stricta x *glutinosa*	
	Setaria dielsii	
	Sida ectogama	√
	Sida fibulifera	√
	Sida platycalyx	√
	Sida sp. dark green fruits (S. Van Leeuwen 2260)	
	Sida sp. verrucose glands (F.H. Mollemans 2423)	
	Solanum horridum	
	Solanum lasiophyllum	√
	Solanum phlomoides	√
	Spermacoce brachystema	
	Sporobolus australasicus	√
	Stenopetalum nutans	
	Streptoglossa bubakii	√
	Streptoglossa cylindriceps	
	Synaptantha tillaeacea var. *tillaeacea*	
	Tecticornia indica subsp. *bidens*	
	Tephrosia rosea var. Fortescue creeks	
	Tephrosia supina	
	Themeda triandra	
	Trachymene oleracea	
	Trachymene oleracea subsp. *oleracea*	
	Tragus australianus	√
	Trianthema glossostigma	√
	Trianthema triquetra	
	Trianthema turgidifolia	
	Tribulus astrocarpus	√
	Tribulus suberosus	
	Trichodesma zeylanicum	
	Triodia epactia	√
	Triodia longiceps	√
	Triodia pungens	√
	Triodia sp. Shovelanna Hill	√
	Triodia wiseana	
	Urochloa occidentalis	
	Urochloa pubigera	
	Vigna sp. central (M.E. Trudgen 1626) PN	
	Wahlenbergia tumidifructa	
	Xerochloa laniflora	

Habitat	Species	Dominant
Ranges, Hills and Hillslopes	*Abutilon cunninghamii*	
	Acacia acradenia	√
	Acacia adsurgens	
	Acacia aff. aneura (long, flat, recurved; FMR 35.3)	√
	Acacia aff. aneura (narrow fine veined; site 1259)	√
	Acacia ancistrocarpa	
	Acacia ayersiana	
	Acacia colei var. *colei*	
	Acacia inaequilatera	
	Acacia pruinocarpa	√
	Acacia pyrifolia var. *pyrifolia*	
	Acacia synchronicia	
	Acacia tetragonophylla	
	Acacia tumida var. *pilbarensis*	√
	Amphipogon sericeus	
	Aristida contorta	
	Aristida holathera var. *holathera*	
	Atalaya hemiglauca	√
	Boerhavia coccinea	
	Bonamia sp. Dampier (A.A. Mitchell PRP 217)	
	Brachyachne prostrata	
	Bulbostylis barbata	
	Calytrix carinata	
	Cheilanthes austrotenuifolia	
	Cleome viscosa	
	Clerodendrum floribundum var. *angustifolium*	√
	Corchorus lasiocarpus subsp. *lasiocarpus*	√
	Corchorus lasiocarpus subsp. *parvus*	
	Corchorus parviflorus	
	Corymbia candida subsp. *dipsodes*	√
	Corymbia hamersleyana	√
	Cucumis maderaspatanus	
	Cymbopogon ambiguus	
	Dampiera candicans	
	Dodonaea coriacea	
	Dodonaea pachyneura	
	Dodonaea petiolaris	
	Duperreya commixta	
	Dysphania rhadinostachya	
	Dysphania rhadinostachya subsp. *rhadinostachya*	
	Dysphania sphaerosperma	
	Enneapogon polyphyllus	

Habitat	Species	Dominant
	Enneapogon robustissimus	
	Eremophila forrestii subsp. *forrestii*	
	Eremophila lanceolata	
	Eremophila latrobei subsp. *filiformis*	
	Eriachne lanata	√
	Eriachne mucronata	√
	Eriachne pulchella subsp. *dominii*	
	Eriachne pulchella subsp. *pulchella*	
	Eucalyptus leucophloia subsp. *leucophloia*	√
	Euphorbia alsiniflora	
	Fimbristylis dichotoma	
	Fimbristylis simulans	
	Gomphrena cunninghamii	
	Gomphrena kanisii	
	Goodenia microptera	
	Goodenia stobbsiana	√
	Goodenia triodiophila	
	Gossypium robinsonii	√
	Grevillea wickhamii subsp. *hispidula*	√
	Hakea chordophylla	√
	Hakea lorea subsp. *lorea*	
	Hibiscus coatesii	
	Hibiscus goldsworthii	√
	Hibiscus sp. Gardneri	
	Hibiscus sturtii var. *campylochlamys*	
	Hibiscus sturtii var. *truncatus*	
	Hybanthus aurantiacus	
	Indigofera monophylla	√
	Iseilema membranaceum	
	Jasminum didymum subsp. *lineare*	
	Maireana georgei	
	Maireana planifolia x *villosa*	
	Maireana villosa	
	Mollugo molluginea	
	Notoleptopus decaisnei var. Orbicularis	
	Oldenlandia crouchiana	
	Paraneurachne muelleri	
	Paspalidium clementii	
	Perotis rara	
	Pluchea tetranthera	
	Polycarpaea corymbosa var. *corymbosa*	
	Polycarpaea holtzei	

Habitat	Species	Dominant
	Polycarpaea longiflora	
	Polygala isingii	
	Psydrax latifolia	
	Pterocaulon sphacelatum	
	Ptilotus aervoides	
	Ptilotus astrolasius	
	Ptilotus auriculifolius	
	Ptilotus calostachyus	√
	Ptilotus clementii	
	Ptilotus fusiformis	
	Ptilotus helipteroides	
	Ptilotus incanus	
	Ptilotus nobilis	√
	Ptilotus obovatus	
	Ptilotus rotundifolius	√
	Ptilotus schwartzii	
	Rhagodia sp. Hamersley (M. Trudgen 17794)	
	Santalum lanceolatum	
	Schizachyrium fragile	
	Senna artemisioides subsp. *oligophylla* x *helmsii*	
	Senna ferraria x *glaucifolia*	
	Senna glutinosa subsp. *glutinosa*	√
	Senna glutinosa subsp. *glutinosa x luerssenii*	
	Senna glutinosa subsp. *luerssenii*	
	Senna glutinosa subsp. *pruinosa*	
	Senna glutinosa subsp. x *luerssenii*	
	Senna notabilis	√
	Senna sericea	
	Sida arenicola	
	Sida ectogama	
	Sida sp. Excedentifolia	
	Sida sp. Pilbara	
	Solanum horridum	
	Solanum lasiophyllum	
	Solanum phlomoides	√
	Solanum sturtianum	
	Sporobolus australasicus	
	Streptoglossa bubakii	
	Tephrosia oxalidea	
	Tephrosia spechtii	
	Themeda triandra	
	Trachymene oleracea	

Habitat	Species	Dominant
	Trachymene oleracea subsp. *oleracea*	
	Trianthema glossostigma	
	Trianthema triquetra	
	Tribulus suberosus	
	Trichodesma zeylanicum	
	Triodia basedowii	√
	Triodia epactia	√
	Triodia longiceps	
	Triodia pungens	√
	Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	√
Fortescue Marsh Vegetation Associations	*Abutilon cryptopetalum*	
	Abutilon macrum	
	Abutilon otocarpum	
	Acacia ampliceps	
	Acacia aptaneura	√
	Acacia coriacea subsp. *pendens*	√
	Acacia synchronicia	√
	Acacia tetragonophylla	√
	Acacia xiphophylla	√
	Aeschynomene indica	
	Alternanthera nodiflora	
	Amaranthus undulatus	
	Ammannia multiflora	
	Angianthus tomentosus	
	Aristida contorta	
	Atriplex bunburyana	
	Atriplex flabelliformis	
	Bergia perennis subsp. *obtusifolia*	
	Boerhavia coccinea	
	Boerhavia paludosa	
	Bothriochloa bladhii subsp. *bladhii*	
	Centipeda minima subsp. *macrocephala*	
	Chenopodium auricomum	√
	Chloris pectinata	√
	Cleome viscosa	
	Cressa australis	
	Cullen cinereum	
	Cyperus bulbosus	√
	Cyperus iria	
	Dactyloctenium radulans	√
	Digitaria brownii	
	Dysphania plantaginella	

Habitat	Species	Dominant
	Dysphania rhadinostachya subsp. *rhadinostachya*	
	Eleocharis papillosa	√
	Enchylaena tomentosa var. *tomentosa*	
	Enneapogon caerulescens	√
	Enneapogon polyphyllus	√
	Enteropogon ramosus	
	Eragrostis desertorum	
	Eragrostis elongata	
	Eragrostis pergracilis	√
	Eragrostis tenellula	
	Eremophila forrestii subsp. *forrestii*	
	Eremophila spongiocarpa	√
	Eremophila youngii subsp. *lepidota*	√
	Eriachne benthamii	
	Eriachne pulchella subsp. *dominii*	
	Eucalypus victrix	
	Euphorbia australis	
	Evolvulus alsinoides var. *decumbens*	
	Frankenia ambita	
	Glycine canescens	
	Gnephosis arachnoidea	√
	Gomphrena kanisii	
	Goodenia forrestii	
	Heliotropium pachyphyllum	
	Hibiscus sturtii var. *platychlamys*	
	Ipomoea coptica	
	Ipomoea muelleri	
	Iseilema vaginiflorum	
	Lawrencia densiflora	√
	Leptochloa fusca subsp. *fusca*	
	Lotus cruentus	
	Maireana amoena	
	Maireana carnosa	
	Maireana integra	
	Maireana luehmanii	
	Maireana pyramidata	
	Maireana triptera	
	Marsilea hirsuta	
	Melaleuca glomerata	√
	Mimulus repens	√
	Muehlenbeckia florulenta	√
	Muellerolimon salicorniaceum	

Habitat	Species	Dominant
	Neptunia dimorphantha	
	Nicotiana heterantha	√
	Panicum decompositum	
	Paspalidium clementii	
	Peplidium sp. E Evol. Fl. Fauna Arid Aust (A.S. Weston 12768)	
	Peripleura obovata	
	Pluchea dunlopii	√
	Pluchea rubelliflora	√
	Polycarpaea corymbosa var. *corymbosa*	
	Portulaca pilosa	
	Pterocaulon sphaeranthoides	√
	Ptilotus auriculifolius	
	Ptilotus helipteroides	
	Ptilotus nobilis subsp. *nobilis*	
	Rhagodia eremaea	
	Samolus repens var. *floribundus*	
	Scaevola spinescens	
	Schoenoplectus dissachanthus	√
	Sclerolaena cornishiana	
	Sclerolaena cuneata	√
	Sclerolaena densiflora	√
	Sclerolaena diacantha	
	Senna artemisioides subsp. *oligophylla*	
	Senna sp. Karijini (M.E. Trudgen 10392)	
	Setaria dielsii	
	Sida fibulifera	
	Sida rohlenae subsp. *rohlenae*	
	Solanum horridum	√
	Solanum lasiophyllum	√
	Solanum sturtianum	
	Sporobolus australasicus	√
	Sporobolus virginicus	
	Stemodia grossa	
	Streptoglossa bubakii	√
	Streptoglossa decurrens	
	Streptoglossa odora	
	Swainsona kingsii	
	Tecticornia auriculata	
	Tecticornia globulifera	√
	Tecticornia indica subsp. *bidens*	√
	Tecticornia medusa	

Habitat	Species	Dominant
	Tecticornia sp. Christmas Creek (K.A. Shepherd & T. Colmer et al. KS 1063)	√
	Tecticornia sp. Dennys Crossing (K.A. Shepherd & J. English KS 552)	√
	Tragus australianus	
	Trianthema glossostigma	
	Trianthema triquetra	
	Tribulus occidentalis	
	Triraphis mollis	
	Typha domingensis	
	Xerochloa laniflora	