Revegetation of Nabarlek minesite

Preliminary characterisation of vegetation on the minesite and on adjacent natural landscapes in September 2003

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Nabarlek minesite and adjacent riparian forest (2003)

Australian Government
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Contents

Tables

Plates

Figures

Executive summary

1. Nabarlek is the first uranium mine in Australia to be rehabilitated under a contemporary regulatory regime and, hence, exemplifies many issues highly relevant to the future rehabilitation of Ranger uranium mine.
2. ARRTC (2003) identified the following three key research issues with respect to the revegetation component of rehabilitation in the ARR that need to be addressed: what are the criteria for assessing revegetation success?; what are the indicators of success and how do we monitor them?; and what can we learn from Nabarlek?
3. There has only been one vegetation assessment at Nabarlek since mine closure eight years ago (Adams & Hose 1999), one major soil function study (Tongway 2001) and a photo-point monitoring study reported by Welch and Gibson (2002). The assessment of revegetation success is contentious (Prendergast *et al*. 1999), was carried out only two years after revegetation commenced and, nevertheless, cannot be verified (Klessa 2001). The other two studies are an incomplete base from which to assess the success of revegetation.
4. Hence, this project has two aims: (i) to develop cost-effective ground-based and remote sensing monitoring and assessment methods for vegetation that can be applied to Ranger uranium mine; and (ii) to provide a robust, quantitative assessment of the success of revegetation at Nabarlek based on a comprehensive characterisation of soils and plants across the minesite in comparison to adjacent reference or analogue sites.
5. This report is a preliminary report only, summarising the results of a ground-based vegetation survey conducted in the late dry season of 2003. A comprehensive characterisation of mine site vegetation condition in relation to reference sites and a comprehensive assessment of revegetation success will be made with additional wet season data. Additionally, complementary analysis of high resolution remote sensing captures of Nabarlek in both seasons will commence this year and will provide a “whole of landscape assessment” to overcome undersampling problems associated with ground-based surveys. Furthermore, the results of two CDU postgraduate studies examining soil-plant relationships are yet to be submitted, and will be included in future assessments.
6. Nevertheless, our preliminary results suggest that, although eight years has elapsed since revegetation commenced in 1995, it so far remains unsuccessful for at least half the mine site with respect to the original objective of blending in with the surrounding woodland. This was also the consensus view of the Nabarlek Rehabilitation Workshop in 2000, five years after revegetation.
7. We recommend that key research into soil-plant relationships at Nabarlek be implemented through postgraduate studies at CDU, especially in relation to: soil constraints to plant growth and survival; soil seed bank of weeds and native species; and ecological interactions between weeds, fire and native plant succession. We recommend also that further assessment of Landscape Function Analysis as a complementary tool for monitoring rehabilitation success is not warranted because more direct measures of soil and plant performance will become available.
8. We recommend that management options for a new revegetation plan, particularly for the Evaporation Ponds area, should be developed. Practical, pragmatic and defensible options could be explored and considered by the Nabarlek Minesite Technical Committee (MTC)

in partnership with the Nabarlek Traditional Land Owners. Management options could incorporate also continued quantitative monitoring and assessments of revegetation success, and critical new research knowledge. A necessary first step, however, is that new closure criteria need to be developed by the Nabarlek MTC in consultation with the Traditional Land Owners.

9. On site management could be implemented in the form of increased government and industry support for the current Demed revegetation, fire and weed management programs, currently undertaken as part of the Nabarlek Mining Management Plan.

Results summary

1. The rehabilitated mine and adjacent analogue or reference areas were stratified into six sampling sites to systematically encompass the large variation in ground surface features (Mine sites: Evaporation Ponds 1 & 2; Waste Rock Dump; & Mine Pit; Reference sites: Eucalyptus woodland & Riparian forest). Three 50 m-transects were located randomly in each strata and orientated along an up slope-down slope gradient. Transects were subdivided into 0.1 ha subsamples (10 m x 10 m plots) to estimate canopy and ground cover attributes. Canopy cover (trees & shrubs) was characterised by: species diversity; density and height of trees and shrubs; projected percentage foliage cover; and dbh of trees. Ground cover was characterised by: species diversity; composition of major plant classes (grasses, herbs & sedges); cover and biomass of major plant classes; cover and biomass of weeds; and the cover of non-living attributes (litter, logs, bareground & rocks). Fifty 1.0 m^2 quadrats were sampled along the length of transects (0.005 ha) to estimate seedling density by species where possible and, hence, canopy recruitment. Three soil subsamples were taken also from each transect for analysis of soil properties.

2. Forty-nine canopy species were recorded in September 2003 including 10 *Eucalyptus* and *Corymbia* spp, 2 *Melaleuca* spp, 1 *Pandanus* sp and 11 *Acacia* spp. Canopy vegetation on Reference sites and Mine sites were characterised and compared. Reference sites had: twice as many canopy species; 13 times more trees which were twice as tall and thick; 3.5 times more shrubs; and 5 times more canopy cover. Regression relationships were developed to predict the density of trees and shrubs from their canopy cover (%), on a site and species basis.

3. A total of 85 ground cover species were recorded on the September 2003 survey. Of these 41 (44.2%) were grasses, 43 herbs (50.6%) and 4 (5.2%) sedges. Fifteen grasses (46.3%) and 19 herbs (44.2%) were classified as weeds. No weed grasses were found on Reference sites and no weed sedges were found. Overall, ground cover comprised 40% weed species.

4. Ground cover vegetation on Reference sites and Mine sites were also characterised and compared. There were 2.5 times more native species found on Reference sites than on Mine sites, and 4.8 times more weed species on Mine sites than Reference sites. No grass weeds were found on Reference sites, which had twice as many native grass species than did Mine sites. Mine sites had twice as many weed grass species than native grass species. Similar results were found for herbs.

5. In contrast to Reference sites, Mine sites had twice as much ground cover of grasses and similar covers of herbs and sedges. However, Reference sites had 4.4 times more ground cover of native species than Mine sites but, in contrast, Mine sites had 310 times more

weed cover than Reference sites. Whilst no grass weeds were found on Reference sites, Mine sites had on average 46.7% cover of grass weeds. Mine sites had 61 times more herb ground cover than Reference sites, but Reference sites had 12 times more native herb cover than Mine sites.

6. Mine sites had twice as much biomass of grasses than Reference sites, 21 times more biomass of herbs, and similar amounts of sedges. Grasses contributed most to ground cover biomass and comprised four dominant species: native Black Spear grass (comprising two species; *Heteropogon triticeus* for Eucalyptus woodland & *Heteropogon contortus* for all other sites); Mission grass weed (comprising both the perennial & annual species, *Pennisetum polystachion* & *P. pedicellatum*, respectively); Para grass weed (*Urochloa mutica*); and Rhodes Feather Top weed (*Chloris virgata*). Although there were similar amounts of grass biomass on Reference sites and Mine sites overall, there were extreme differences in the contributions from native and weed species.

7. Reference sites had similar biomasses of native Back Spear grass, although from two different species (2.5 t.ha-1). In contrast, Reference sites had 90 times more Black Spear grass biomass than Mine sites and no grass weeds. On Mine sites Mission grass had the most biomass (3.9 t.ha-1), followed by Para grass and Rhodes Feather Top grass with similar biomasses (0.5 t.ha-1). These high biomasses of grass cover dominate fuel loads in the dry season and, hence, pose an extremely high fire risk.

8. There was a negative correlation between the number of native ground cover species and the number of weed species across the minesite; the more weed species there were the less native species were found. Additionally, there was generally a negative correlation between the ground cover of weeds and the total density of trees and shrubs, suggesting that weeds could be suppressed on the minesite by successful succession of vegetation from shrubland-grassland to woodland. The one exception was a site in EP1 where the highest abundance of Para grass (90% cover) co-occurred with the highest density of Melaleucas, a situation that also occurs on the Magela floodplain. This suggests that Para grass needs to be continually controlled in the long-term despite increases in canopy cover of paperbark trees.

9. There were no differences in the cover of litter, bareground, logs and sticks between Reference and Mine sites, suggesting that soil organic carbon should not be a limiting factor to plant growth. In contrast, there was 22 times more rock cover on Mine sites than on Reference sites, mostly on the Pit and Waste Rock Dump sites.

10. Very high densities of woody seedlings (non-resprouting plants <10 cm high) were found on Reference sites (Riparian: 49 + 23 seedlings/transect; Woodland: 13 + 6 seedlings per transect). In contrast, no woody seedlings were found on any of the Mine sites sampled, suggesting very little recruitment of canopy species. At least six species of canopy plants were positively identified at both Reference sites based on leaf morphology. Results suggest that woody plant density on the minesite is unlikely to increase in the short term and, may well decrease as a result of losses due to fire.

11. There were large differences in soil properties between Reference sites and Mine sites (e.g. Mine sites had 15 times more Sulphate, 56 times more Phosphorus, 55 times more Magnesium & 85 times more Uranium). With respect to most soil properties the two Reference sites were similar, as were the two Evaporation Pond sites and the Waste Rock Dump and Pit sites. Soil pH was similar in Reference and Mine sites, and is in a favourable range for plant growth and where aluminium toxicity would not be an issue.

The Evaporation Pond sites appear to be retaining nutrients, and nutrient and salt levels are generally higher than at the other sites, reflected in their EC levels. However, soil salinity levels may exhibit seasonal trends and, hence, these results will be re-examined as part of the CDU Honours project.

12. Multivariate analyses were used to explore soil-plant relationships across all sites as a tool to help simplify and assess revegetation success using all complex intercorrelated soil and plant attribute variables. Factor Analysis (Principal Components Analysis, PCA using correlation matrices) and Multi-Dimensional Scaling (MDS using Euclidean distance similarity matrices) were chosen because they are fundamentally different methods of multivariate analysis. Nevertheless, they produced very similar results and, hence, only PCA results are presented here. The factor scores of each site for the first Principal Components of soil and plant characteristics were ordinated for simultaneous comparison. The graphical model characterises soil-plant relationships for all sites along a successional gradient from “poor vegetation-poor soil” to “poor vegetation-good soil” on Mine sites, towards “good vegetation-good soils” on Reference sites. Hence, in terms of soil and vegetation development, all Mine sites can be conceptualised as moving along a successional trajectory towards analogue conditions. Whilst soil-plant characterisations presented here appear “subjective” they are, nevertheless, supported by a range of quantitative analyses and a priori knowledge that indicate performance of plant growth, vegetation community structure and composition, and resilience to disturbance from fire and weeds. It should be emphasised, however, that whilst this model is encouraging in terms of reducing the complexity of assessing revegetation success, it can only highlight key hypotheses to test by well-designed experiments.

13. Although eight years has elapsed since Nabarlek was revegetated, half the Mine sites sampled are classified as “poor vegetation-poor soil” sites and, hence, unsuccessful with respect to revegetation success as defined by the original closure criteria. Although the other half of Mine sites are classified as “good soil-poor vegetation sites”, they may not progress towards analogue conditions remain because of poor vegetation development (i.e. low tree density, intermediate shrub density, high weed biomass/cover and, hence, high fire risk). Significant management intervention at these sites would be needed to cross the threshold to self-sustaining vegetation communities analogous to Reference sites.

14. Most of the variance in the vegetation axis used in the above model is explained by either tree density or total canopy cover (R2 ~ 80% for both). This suggests that a rapid and cost-effective means of measuring total canopy cover, such as from remote sensing captures, may provide a powerful complementary tool to help monitor revegetation success. Despite the huge sampling effort invested in the ground-based vegetation surveys, only 0.51% of the variable minesite was sampled.

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1 Background

1.1 Nabarlek revegetation issues

Nabarlek is a former uranium mine located in western Arnhem Land, Northern Territory. The ore body was discovered in 1970 by Queensland Mines Limited (QML), mined and processed between 1980 and 1994 (Plate 1a), and decommissioned between 1994-95. Rehabilitation earthworks commenced in mid-1995 and revegetation via seeding in late 1995 (Plate 1b). It is the first contemporary uranium mine to be rehabilitated in Australia and, hence, exemplifies many issues highly relevant to the future rehabilitation of Ranger uranium mine.

As summarised by Johnston and Milne (2004), revegetation at Nabarlek has received considerable discussion because of a lack of agreement among stakeholders as to the desired outcome (Klessa 2001, McGill and Fox 2001). In December 1993, QML and the Northern Land Council agreed in a Settlement Deed that the primary objective of the revegetation program was to return mined areas "to a self sustaining woodland community that blends in with the surrounding environment" (Prendergast et al 1999). QML subsequently employed Adams Ecological Services to act as an independent expert to determine whether or not satisfactory revegetation of the minesite had occurred, and they reported that revegetation was satisfactory (Adams & Hose 1999). However, in a review of their report, Prendergast et al (1999) disagreed with most of their findings, concluding that: further revegetation work was required if succession to a woodland community was to be achieved; grasses and weeds dominated ground cover on up to 50% of the mine site; appropriate indicators of revegetation success needed to be identified; remedial action at a number of sites was required because of excessive erosion; the conclusions in the report by Adams and Hose (1999) were not supported by the data presented and, as a result, the report should be revised; and that an active management plan was needed to address issues such as fire management, weed and feral animal eradication, erosion control and contaminant transport.

A workshop was therefore held in April 2000 to discuss rehabilitation issues at Nabarlek, particularly the contentious views surrounding revegetation success, and to identify further research and management actions that may be required (Klessa 2001). About 40 relevant stakeholders considered the following questions (summarised by Johnston & Milnes 2004):

1. Has rehabilitation reached a stage where the mining company can be discharged of its responsibility?
2. If not, has adequate monitoring data been collected that will allow the success of rehabilitation to be measured?
3. What are the lessons learnt that can be applied now, or further research that should be done?

Workshop delegates concluded that the state of revegetation at Nabarlek did not meet the expectations of stakeholders and that more information was required to assess revegetation.

In summary, the most important rehabilitation issue examined at this workshop was how to assess the success of revegetation, particularly with respect to details. For example, how do we determine whether or not the revegetated minesite is a self-sustaining ecosystem with landscape characteristics acceptable to all stakeholders? (Klessa 2001).

Plates 1 a & b 1:25,000 colour aerial photos of Nabarlek uranium mine in (a) during mining (1982), and (b) seven years after rehabilitation (2002). Sample vegetation transects used in the 2003 survey are indicated (see text).

1.2 ARRTC Key Knowledge Needs

The 11th meeting of ARRTC (2002) identified several key knowledge gaps or needs (KNN) for continued environmental protection in the ARR from uranium mining activities and, recommended that ***eriss*** shift research focus at Ranger uranium mine from current mining operations to rehabilitation issues after mine closure. In response ***eriss*** developed a comprehensive research agenda to address the Key Knowledge Needs that spanned current mining operations and the rehabilitation phase. Rehabilitation basically encompasses the following process: develop rehabilitation goals and closure criteria; design and implement the final landform; and revegetate the landform to establish a self-sustaining ecosystem analogous to the surrounding landscape. The redeveloped landform, soils and vegetation need to be monitored during and after rehabilitation in order to assess how successful rehabilitation has been, or is likely to be (Corbett 1999). Accordingly, the key research issues or questions identified by ***eriss*** with respect to the revegetation component of rehabilitation, and excluding revegetation establishment techniques, are:

1 What are the success criteria for assessing revegetation success?

2 What are the indicators of success and how do we monitor them?

3 What can we learn from Nabarlek?

In a review of revegetation of mined land in the wet-dry tropics of northern Australia, Corbett (1999) identified the following five categories of methods used to monitor the development and success of rehabilitated areas:

1 Quantitative ecological assessment (traditional soil-plant assessments)

2 Ecosystem Function Analysis (EFA)

3 Remote sensing

4 Faunal recolonisation

5 Other indices of ecosystem recovery

1.3 Previous vegetation and soil assessments at Nabarlek

The natural vegetation surrounding the mine site comprise two dominant communities at either end of a topography-drainage spectrum: closed woodland (dry sclerophyll forest) dominated by *Eucalyptus* spp, found on well drained upland and hill slopes; and riparian forest, dominated by *Melaleuca* and *Pandanus* spp, found in low-lying or poorly drained lowland creek systems. Ground cover comprises a mixture of annual and perennial grasses and herbs, with sedges occurring in areas subject to seasonal inundation (Brennan & Bach 1994).

There has only been one vegetation assessment study at Nabarlek since mine closure (Adams & Hose 1999), one major soil function study (Tongway 2001) and one photo-point monitoring study (Welch & Gibson 2002), all outlined below.

1.3.1 Adams Ecological Consultants (1996-1997)

QML employed Adams Ecological Consultants to assess revegetated areas on the Nabarlek minesite. They used traditional quantitative and qualitative methods to characterise soil properties and vegetation in undisturbed reference areas and across the minesite. From their studies of growth, abundance of trees and shrubs native to the Nabarlek area, and an analysis of soil properties, they concluded that the revegetated areas of the mine site blended in with the vegetation of the surrounding landscape and that major ecological processes have been re-established.

However, Prendergast *et al*. (1999) disputed these findings in a review of their report, which subsequently acted as a catalyst for an SSD-sponsored workshop on Nabarlek rehabilitation issues in 2000 (Klessa 2001). The consensus view of the workshop was that there was a lack of data from which the report’s conclusions were drawn and which could be verified, and that the overall summary of the Adams report was highly subjective and could not be justified on the basis of the scientific evidence presented, and that the short time span since the revegetation of the minesite and their field study was limiting also. Hence, one of the major recommendations of the workshop was to obtain the raw data used in the Adams consultancy report in order to review their assessment that revegetation at Nabarlek was satisfactory. To date this raw data has been unobtainable, which effectively means that revegetation success at Nabarlek has never been adequately assessed.

1.3.2 Ecological Function Analysis (2001)

Rehabilitation success has been monitored largely in the past by following vegetation development using traditional quantitative measures of soil and plant characteristics. This approach relies heavily on plant composition data and an array of soil property measures as indicators of successful revegetation. However, Tongway (2001) considered these methods to be too slow and uninformative with respect to assessment of critical ecosystem processes and functions, and suggested using Ecosystem Function Analysis (EFA) to monitor and assess rehabilitation success. EFA is well described in the literature and is detailed in Section 5.2. Tongway *et al*. (2001) attempted to verify EFA indicators in the field at eight rehabilitated mine sites across Australia, one of which includes Nabarlek. The results of this validation exercise were mixed, however, with Nabarlek being a specific example of failure with respect to the soil infiltration index.

1.3.3 Photo-monitoring points (2002)

Under the Nabarlek General Authorisation No A82/482, annual photo-point monitoring of vegetation is required. EWLS undertook the first photo-point monitoring exercise in 2002, and the results reported by Welch and Gibson (2002). They did not, however, assess the success of revegetation in relation to the original rehabilitation objective. They reported that: large pockets of vegetation were burnt prior to the 2002 visit, giving the appearance of "poor condition"; all of the revegetated areas were dominated by *Acacia* spp with an average height of 5-8m; many trees were damaged or killed by past fires; substantial infestations of Para grass (*Urochloa mutica)* were present on the mine site and could be the most significant weed problem in future.

2 Project aims

The two project aims outlined below were shaped by ARRTC Key Knowledge Needs with respect to future ***eriss*** research on the rehabilitation of Ranger uranium mine, using Nabarlek as a test case, and the absence of a comprehensive quantitative assessment of revegetation success at Nabarlek despite the fact that eight years has elapsed since rehabilitation.

1 Develop cost-effective ground-based and remote sensing vegetation monitoring and assessment methods that can be applied to Ranger uranium mine; and

2 Provide a current, quantitative assessment of the success of revegetation at Nabarlek based on comprehensive data of soil-vegetation characteristics.

This report is a preliminary progress report only, and assesses data collected in the late dry season of 2003. Comprehensive characterisation of mine site vegetation condition in relation to reference sites, and an accompanying assessment of revegetation success, will be made with data that encompasses both the wet and dry seasons. The initial base-line ground survey and remote sensing Quickbird (QB) capture (see Section 3.5) were undertaken in the late dry season of 2003 (September-October), and a further survey is planned for the late wet season this year (April-May 2004) to capture seasonal differences in vegetation attributes. Work on the analysis and interpretation of the high resolution multispectral QB captures, in combination with the ground-based surveys as truthing points, is planned to commence in 2004 and so will be reported separately. Additionally, the results of two postgraduate studies examining soil-plant relationships are yet to be submitted and will be included in the final assessment (see Appendix 9.6.1 & 9.6.2).

3 Methods

3.1 Study design and site selection

Examination of 1:25,000 colour aerial photographs of Nabarlek minesite and adjacent landscapes taken in 2002 shows a post-mining environment that is typically highly variable in land surface features such as vegetation canopy cover and ground cover. Similar land surface patterns are reflected in a recent 2003 high resolution Quickbird satellite image (Fig. 1). Hence, much of the present land cover variation reflects landform, soil development and revegetation processes since rehabilitation on the minesite, and natural landscape variation in adjacent, undisturbed areas. In order to systematically encompass variation in ground-based vegetation samples, the rehabilitated mine site was stratified into four sampling sites according to function during the operational phase of the mine. These sites are (Fig. 1):

1 Evaporation Pond 1 (EP1; Plates 2d, 5b-d)

2 Evaporation Pond 2 (EP2; Plates 2d, 3d, 6a)

3 Waste Rock Dump (WRD; Plates 2b, 3a&b, 4d, 5a)

4 Mine Pit (PIT; Plate 3c)

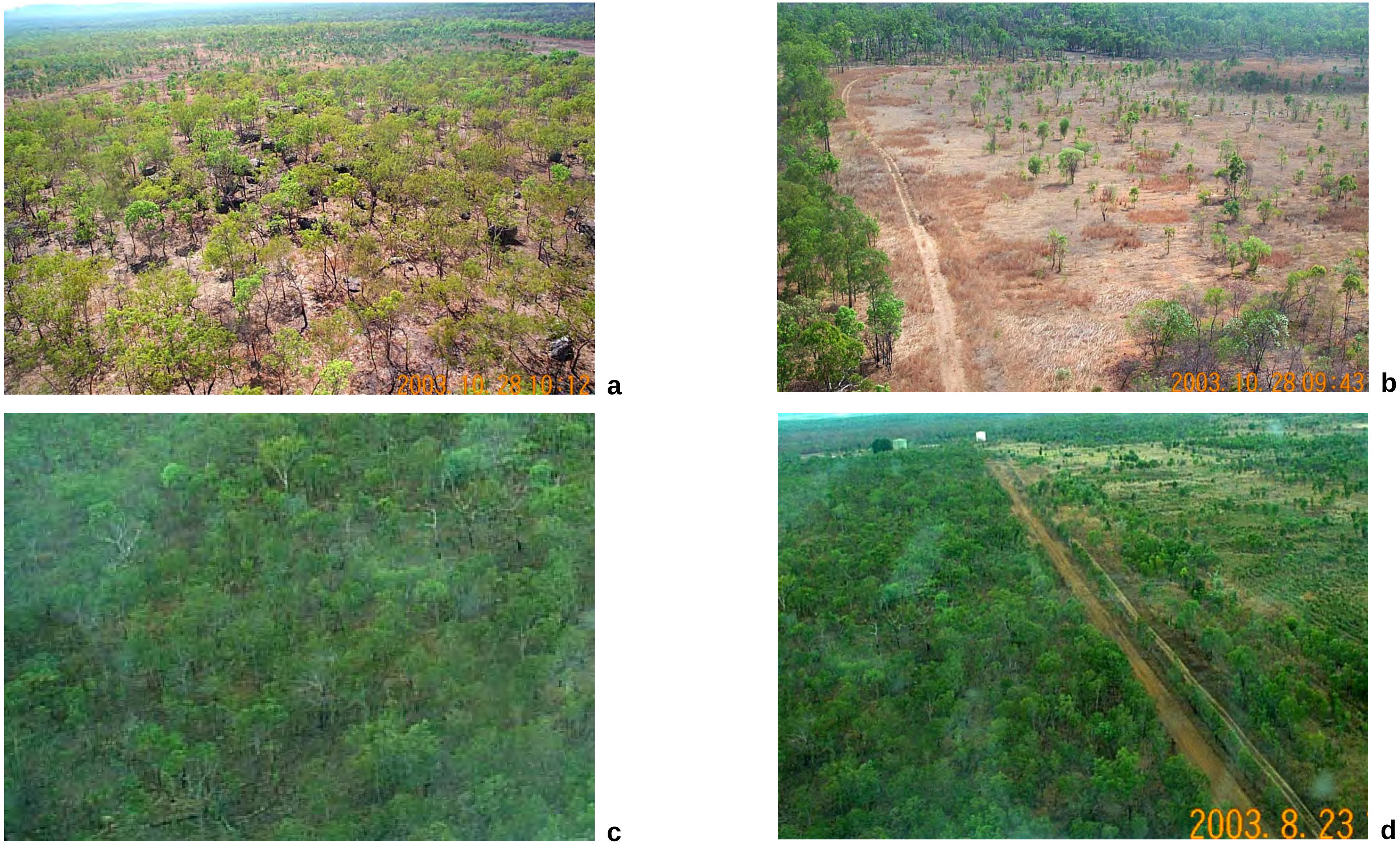
The total area of minesite sample strata is 71.2 ha, representing the total area rehabilitated since closure. Two adjacent Reference or analogue sites were chosen for comparison to the above Mine sites following examination of pre-mining aerial photographs. Reference sites were selected that had similar soil and vegetation characteristics to the rehabilitated areas before mining. The two analogue sites appear to represent the two extremes in topography and soil type found within the surrounding landscapes and, hence, most likely encompasses major differences in vegetation composition and structure in undisturbed areas. These are (Fig. 1):

1 Eucalyptus dominated woodland (WL; Plates 2a&b, 3a, 4b&c)

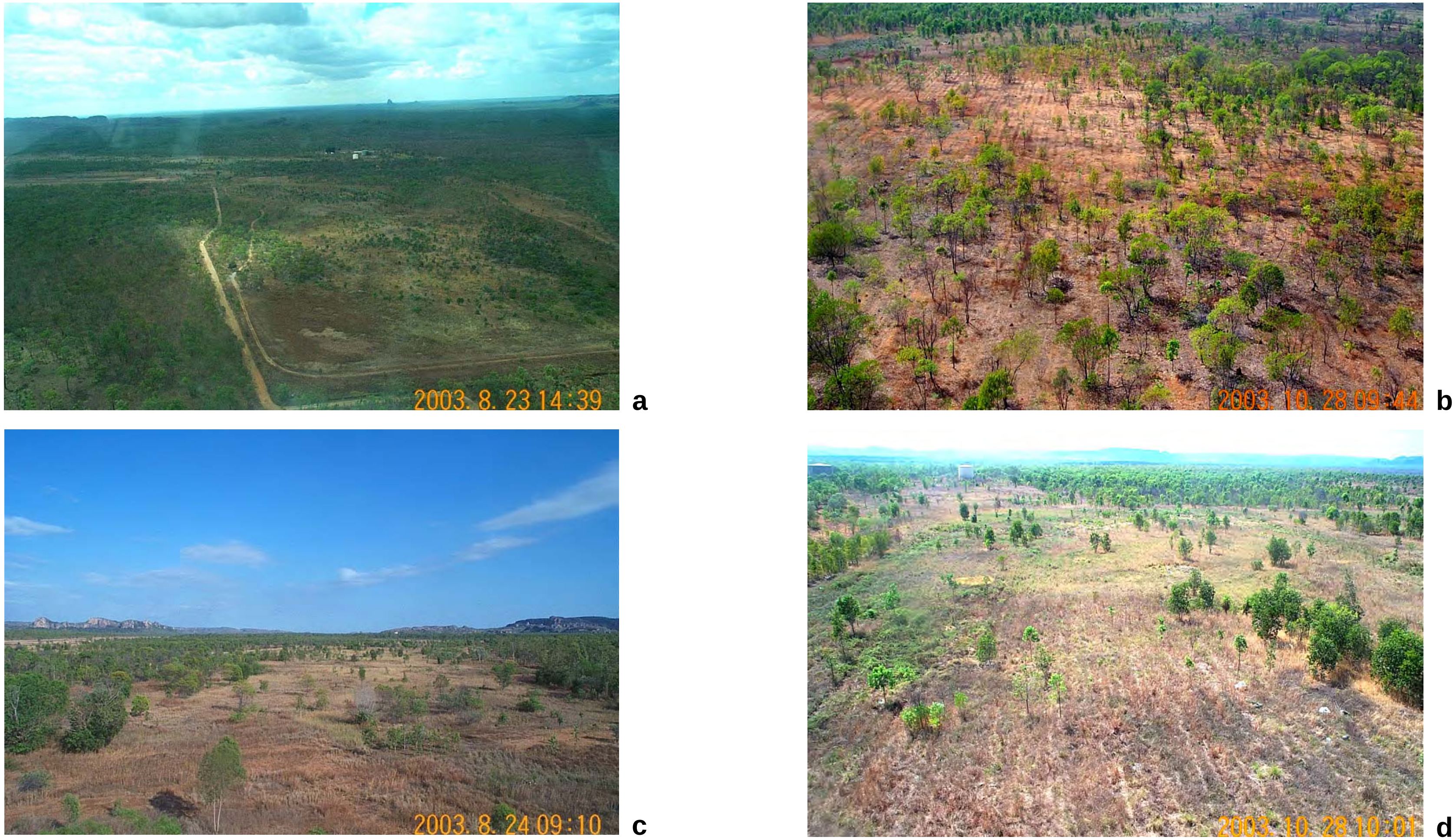
2 Riparian forest (RIP; Plates 2c&d, 4a)

Three transects 50m in length were located in each site on aerial photographs (i.e. 3 replicates /strata). Each study site was divided into thirds and one transect was located randomly within each third of the study site. Transects were located in the field using a GPS and positioned along an up slope-down slope gradient to maximise within-transect variability in vegetation composition and structure. Star pickets 1m in height and capped with yellow plastic marked the start and end of transects (Plates 4a-d), and at 10m intervals. Each star picket was tagged with a fire resistant metal ID tag.

Transects are further stratified into subsamples to rapidly estimate canopy cover and ground cover attributes (Fig 2). Each transect has three 10m x 10m (0.01ha, Plates 4a&c), positioned at the start, middle and end of each transect, and totalling 0.01ha (or 0.36 ha across the minesite). Hence, only 0.51% of the total rehabilitated area was sampled across the variable minesite. The borders of the plots were demarcated using a compass, tape and string, and are now marked by metal tent pegs with blue plastic cattle tags (done during the following wet season survey). For ease of sampling, each 0.01ha plot was divided into two 5m x 10m or 0.005ha subplots, and data recorded in each and subsequently pooled. Appendix 9.1.1 summarises the dGPS coordinates of all transects and their 10m subdivisions. Appendix 9.1.2 summarises the area of each sample strata on the minesite. Fifty continuous $1m^2$ sample quadrats (Plate 4c) were located along the length of each transect (Fig. 2) to estimate woody seedling density, and treated as either 50 sub-samples or one $50m^2$ sample depending on analysis.



Plates 2 a–d Reference or analogue sites: (a) Eucalyptus dominated woodland (WL) and (b) Eucalyptus dominated woodland adjacent to mine site (Waste Rock Dump, WRD); (c) Riparian forest; and (d) Riparian forest adjacent to mine site (Evaporation Ponds EP2 & EP1)



Plates 3 a-d Mine sites: (a) Waste Rock Dump (WRD) site adjacent to Eucalyptus dominated woodland (WL) on left; (b) WRD site; (c) Mine Pit site (PIT) with higher tree and shrub density; and (d) Evaporation Pond 2 (EP2)

Plates 4 a-d Ground transects (50m length) for: (a) Riparian forest (RIP) site showing 10m x 10m plots; (b) Eucalyptus woodland (WL) site showing transect picket and 10m x 10m plot; (c) WL site showing transect line and 1m^2 quadrat sample unit for woody seedlings; and (d) Waste Rock Dump (WRD) site showing transect line (note dense Mission grass weed cover)

Plate 5 a-d Dense grass cover on the minesite: (a) native Black Spear grass (*Heteropogon contortus*), southern end of WRD; (b) Para grass (*Urochloa mutica*) and Melaleuca shrubs in poor drainage areas of EP1; (c) transect line running through mixed Para grass and annual Mission grass (*Pennisetum pedicellatum*) sward on EP1; and (d) 1.5 – 2.0m tall annual Mission grass on EP1.

Plates 6 a-d (a) Passionfruit vine (*Passiflora foetida*) covering rocky soil outcrop on EP2; (b) Demed revegetation plot of mixed Melaleuca and other shrubs, and visiting ARRTC members (September 2003); (c) remaining infrastructure; and (d) Acacia-Black Spear grass mix a fire hazard

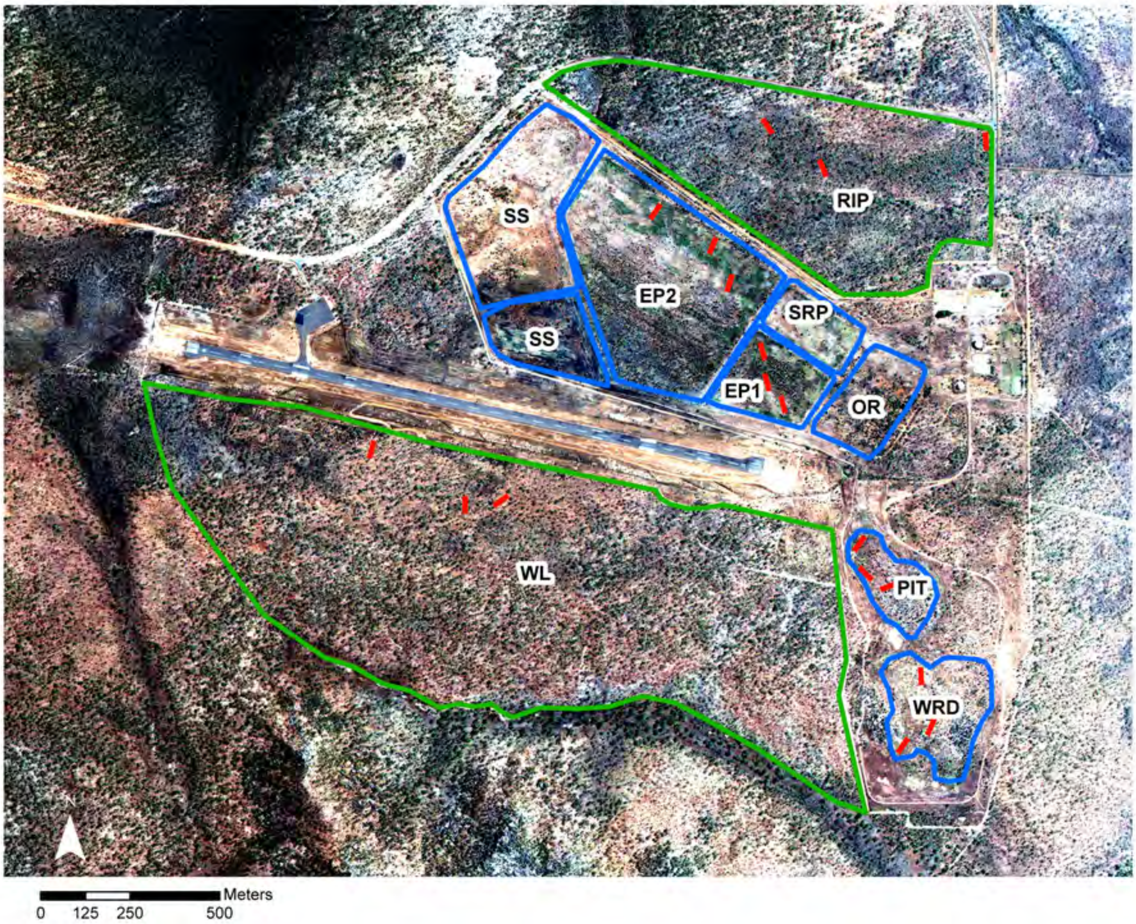
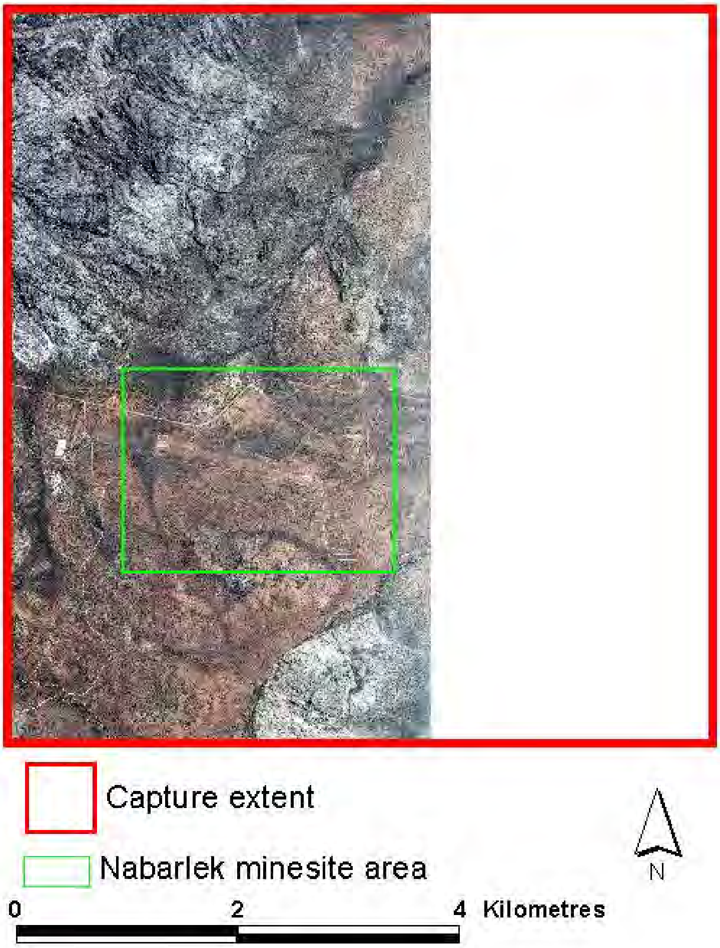


Figure 1 a-c (a) Quickbird satellite image (October 2003) showing variable post-mining environment on Nabarlek and adjacent unmined landscapes. Pre-mining infrastructures (1990) are highlighted and used as sample strata for ground-based vegetation sampling (boundaries are highlighted in blue). Location of vegetation sample transects in each strata are shown with the boundaries highlighted in red. R Riparian forest; W Eucalyptus dominated woodland; WRD Waste Rock Dump; PIT Mine Pit; EP1 (Tailings) and EP2 Evaporation Ponds 1 and 2 respectively. The Surplus Material Stockpile (SS), Stockpile (SPR) and Ore (OR) strata were not sampled separately. SS was amalgamated with EP2, and SPR and OR with EP1.

1b



1c

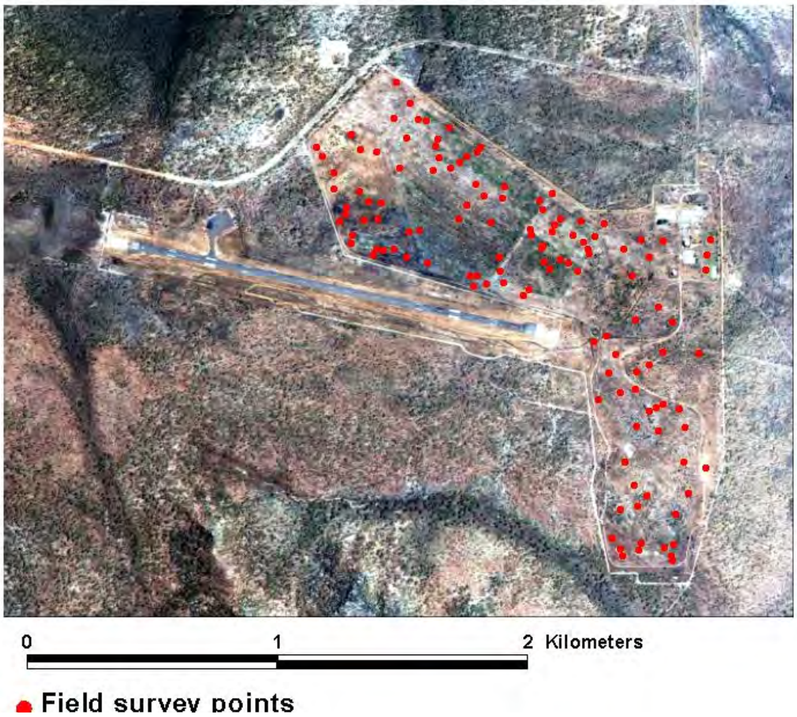


Figure 1a-c continue (b) Quickbird capture area (November 2003). The eastern third of the Quickbird data was cropped due to smoke effects. The green box highlights the area of the data that is referred to elsewhere in the report. (c) Location of ancillary field (helicopter & ground) survey points used to interpret Quickbird remote sensing data (December 2003).

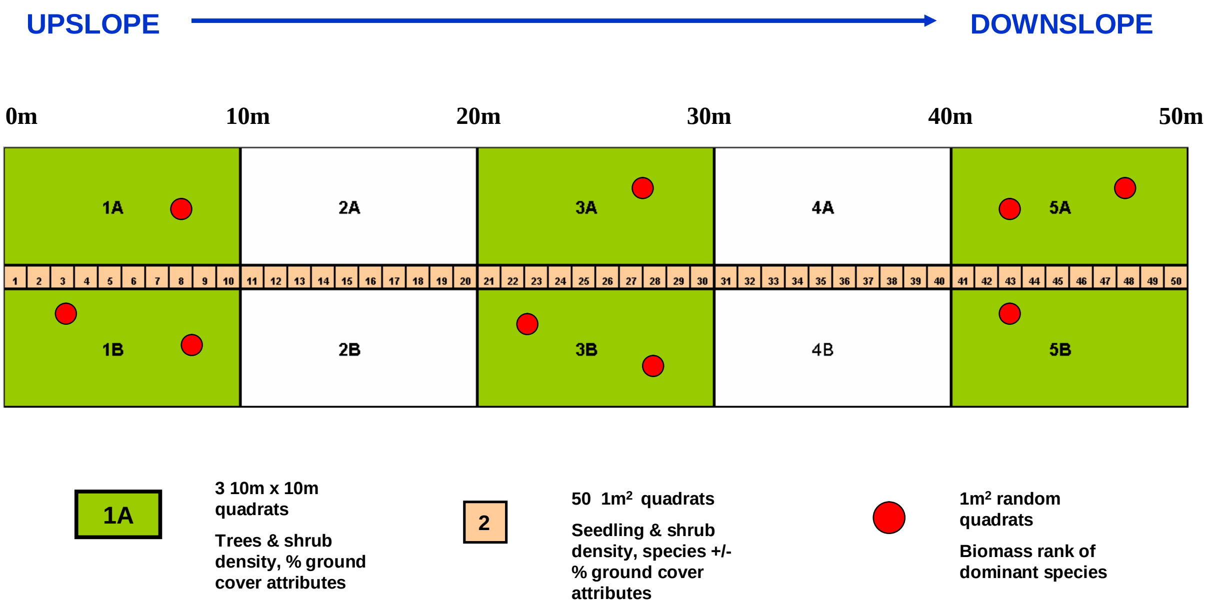


Figure 2 Sample transect design showing position of 10m x10m plots (green: 0.01ha) which are further subdivided into two 5m x 10m subplots (0.005ha); and 50 contiguous 1m^2 quadrats (pink) aligned along the centre of the transect. Three random 1m^2 quadrats (red) were sampled in each green plot to test an alternative method of estimating ground cover biomass. Nabarlek, September 2003.

3.2 Ground-based transects

3.2.1 Canopy cover

Canopy cover comprise trees and shrubs. Trees were classed as those individuals >= 2m and, that for shrubs < 2m and >= 0.10m (Walker & Hopkins 1984). Individuals < 0.10m were classed as woody seedlings and were only recorded in the 1m^2 quadrats. The canopy cover of trees and shrubs were characterised using the following attributes:

1 species composition;

2 density;

3 projected foliage cover;

4 total stand size structure and by dominant species; and

5 productivity or growth rate (as an index of vigour & rate of vegetation succession).

Accordingly, the following variables were recorded for each 0.01ha plot along transects:

1 number of each species;

2 height of individuals (m) & diameter at breast height (dbh) of trees; and

3 canopy cover (%) of trees and shrubs.

Individual trees and shrubs were identified to species where possible. Unidentified individuals were given a code and, where possible, specimens of bark, leaves, fruit, buds and flowers were collected for later identification by the NT Herbarium. Height (m) was estimated to the nearest 1m. The lengths (m) of the long axis (LA) and short axis (SA) of individual canopies were estimated to the nearest 0.5m. Assuming a horizontally projected oval (elliptical)-shaped canopy, individual canopy cover was calculated as $Area = \pi (LA/2).(SA/2)$ (Horadam 1968, page 385). For subsequent analysis, total canopy cover/plot was expressed in terms of absolute cover (m^2) and as a percentage of each 0.01ha plot.

Diameter is a good predictor of tree and shrub biomass (Adams & Hose 1999). Hence, diameter at breast height (dbh mm, over bark at 1.5m above ground) was measured for each individual tree in order to provide a new baseline to monitor plant growth rate and, hence, and index of productivity during vegetation succession. Similarly, changes in height of small or young trees may also index productivity. Adams and Hose (1999) measured tree and shrub diameters across the minesite in 1996 and 1997 and, hence, means values derived from this study can be compared in future studies to mean values from their study as another index of revegetation success since 1995. Mean values will be used because raw data from the Adams and Hose (1999) revegetation assessment are unavailable.

Additional variables measured (but not analysed here) include foliage density (% cover against skyline); height (m) of fire scars; and density of standing dead trees and shrubs.

3.2.2 Ground cover (0.01ha plots & 1m^2 quadrats)

0.01 ha plots

Ground cover comprise the sedge, grass and herb layers, in addition to non-living ground cover attributes (litter, logs & twigs, bare ground, rocks, extent of surface water). Litter was defined as dead, unrooted herbaceous vegetation. Logs were defined as fallen trees or shrubs >= 5cm diameter on average. Twigs were defined as dead, woody parts of trees or shrubs < 5cm diameter. Ground cover was characterised using the following attributes:

1 composition of major vegetation classes (sedges, grasses & herbs);

2 cover and biomass of major vegetation classes;

3 cover of dead plant material (indexing potential carbon recycling);

4 native biodiversity;

5 degree of weed invasion; and

6 risk from fire.

Accordingly, the following variables were measured in each 0.01ha plot along transects:

1 number of species in each major vegetation class;

2 projected foliage cover of major vegetation classes and mean height (m); and

3 projected cover of non-living ground cover attributes such as litter, logs and twigs, bare ground, rocks and extent of surface water.

Plants in each major vegetation class were identified to species where possible. Unidentified individuals were given a code and, where possible, specimens of seed, fruit, buds and flowers were collected for later identification by the NT Herbarium. Mean height (m) of each major cover class was estimated to the nearest 0.2m. Projected cover of all plant species >1% cover was estimated using the Braun-Blanquet cover abundance scale (% cover of plots). Plants with < 1% cover scores were recorded as trace species. Projected cover of non-living attributes were also recorded using the Braun-Blanquet cover abundance scale (% cover of plots). Projected cover estimates can produce total cover estimates > 100% because of vertical overlap of ground cover features (e.g. 100% litter cover under 80% cover of grass).

As a separate exercise calibration curves (Appendix 9.3) were derived to predict biomass (Y, kg.ha^{-1}) of dominant ground cover plant mixes such as native riparian sedge-grasses, Para grass, Black Spear grass, Mission grass & Passionfruit vine, from mean height (X, m), in order to assess fuel loads or fire risk at all sites, particularly with respect to the contribution of extensive weeds during the dry season (e.g. Mission grasses *Pennisetum polystachion & P. pedicellatum*; & Passionfruit vine *Passiflora foetida*, Plate 6a).

1m^2 quadrats

The major purpose of these small plots was to estimate the density of woody seedlings (tree or shrub species < 10cm) to provide baseline data for assessing species recruitment and, to provide quantitative information on herbaceous species. The density of woody seedling species provides an important indicator of revegetation success because it indexes recruitment into the tree and shrub classes, summarising seed production, growth and survival processes. Scrutiny of each plot ensured that all species of woody seedlings were detected and, hence, observation of new individuals in the next monitoring period will provide recruitment information to assess vegetation community change. The composition of herbaceous species was also recorded for each plot to provide complementary data to the 0.01ha plots.

In plots 5 (i.e. 0-5m), 15, 25, 35 and 45 of each transect ground surface cover data were recorded that complements similar data recorded in 0.01ha plots. For example, % cover < 1m of grasses, other vegetation, litter, logs (>10 cm diameter), twigs (< 10 ; > 0.5 cm diameter), rocks (> 10 cm^2 area) and bare ground. As with the 0.01ha plots, this allows assessment of ground surface characteristics, resource retention, native biodiversity, degree of weed invasion and risk of fire. More importantly, such data will allow comparison of information obtained for different plots sizes (1m^2, 25m^2 & 100m^2) to help determine optimal sampling strategies in future studies for a range of vegetation attributes.

3.2.3 Species richness

The number of plant species recorded in any survey will depend on search effort, basically plot size (e.g. species-area relationships, see Krebs 1994) and time. Additionally, because of the diversity of life histories and the variability of environmental conditions at the time of sampling, comprehensive inventories of plant species for any given study area will usually take a number of years. Nevertheless, analysis of species-area relationships and, hence, determination of optimal plot sizes for canopy and ground cover species will not be reported here. Based on previous experience, an *a priori* decision was made to use a 0.01ha plot size along transects for canopy species, and it is assumed also to be adequate for ground cover species. Hence, the approach adopted to compare species richness (number of species) between sites was to standardise search effort by using a consistent relatively large plot size at all sites. A more robust comparison of plant species richness between sample sites will be made by combining data from the 2003 dry season survey and the planned 2004 wet season survey.

3.2.4 Soil properties

Soil subsamples were taken in September 2003 from the start, middle and end of each transect in a 4m^2 area at about 8m, 25m and 32m about 3m away from the centre line. A trowel was used to collect 6 scrapes of top soil to 5cm depth at each location. The soil samples were then bulked for analysis of soil properties on a transect basis. Samples were then air dried and stones, litter and gravel were removed by coarse and fine dry sieving. Material less than 2mm diameter was used for soil chemical analyses. Additional soil analysis was undertaken from bulk soil samples collected at the Riparian and Evaporation Pond 1 sites, used for seedling trials (see Appendix 9.7.1). Table 1 lists the soil attributes that were measured from bulked transect subsamples. Analyses for soil attributes 1-19 were undertaken by INCITEC PIVOT Pty Ltd, and those for 20-24 (basically metals) by Charles Darwin University (Environmental Analytical Chemistry Unit).

Table 1 List of soil attributes for analysis. Nabarlek (September 2003)

Attribute	Attribute
Colour (Munsell)	Chloride (mg/kg)
Texture	Electrical conductivity (dS/m)
pH (1:5 Water)	Copper (DTPA, mg/kg)
pH (1:5 $CaCl_2$)	Zinc (DPTA, mg/ka)
Organic carbon (%)	Manganese (DPTA, mg/kg)
Nitrate nitrogen (mg/kg)	Iron (DPTA, mg/kg)
Sulfate sulfur (MCP, mg/kg)	Boron (Hot $CaCl_2$, mg/kg)
Phosphorus (Colwell, mg/kg)	Magnesium (mg/kg)
Potassium (Amm-acetate, Meq/100g)	Manganese (repeat, mg/kg)
Calcium (Amm-acetate, Meq/100g)	Lead (mg/kg)
Aluminium (KCL, Meq/100g)	Thorium (mg/kg)
Sodium (Amm-acetate, Meq/100g)	Uranium (mg/kg)

3.3 Statistics

The ground-based vegetation survey was designed *a priori* to compare response variables between sites, or combinations of sites, using fixed factor ANOVA. A matrix of weighted means of canopy cover and ground cover attribute values for each site characterises the vegetation at each site. Response variables include: canopy cover (%), mean height (m) and dbh (mm) of trees and shrubs; density of trees and shrubs ($0.01ha^{-1}$ transect plot); ground cover of plants (%); biomass of ground cover ($kg.ha^{-1}$); weed abundance and species richness (see below). There were three transect replicates per site (2 x Reference sites: Riparian forest & Eucalyptus woodland; 4 x Mine sites: Waste Rock Dump, Pit, Evaporation Ponds 1 & 2), representing the maximum number of replicates possible under given time and cost constraints, but perhaps not necessarily the optimal number. Input data were mean subsample values per transect (for 0.01ha plots the mean of 3 plots/transect; for $1m^2$ subsamples the mean of 50 quadrats/transect). Data were examined for homogeneity of variances, normality and examined graphically for outliers (Zar 1974). If appropriate, non-normal ordinal data were transformed using natural logarithms (*Ln X+0.1*), and that for percentages, arcsine *X*, where $X=\sqrt{1/p}$ (Zar 1974). For the response variables listed above, the following *a priori* hypothesis testing contrasts were made between all sites, Reference and Mine sites, canopy cover type (trees vs shrubs) and ground cover type (grasses, herbs, sedges; weeds vs natives). Where simple comparisons between mean values were required, such as with soil attributes, simple t-tests were used.

Linear regression analysis was used to predict *a priori* relationships between variables (see Appendix 9.3). For example, between biomass (Y, ODW, $kg.ha^{-1}$) of dominant ground cover mixes and their mean height (X, m). As for the ANOVAs above, analysis was for a combination of sites (e.g. Reference sites vs Mine sites) and for selected key tree species. One aim of this project (see section 2.0) is to estimate canopy cover across the whole landscape at Nabarlek from remote sensing captures using automated methods, possibly providing an indirect estimate of tree and shrub density (depending on the ability to differentiate species without accompanying information). Hence, the regression relationship between the density of trees and shrubs and their projected canopy cover is of primary interest. Multiple linear regression analysis was used to examine variable relationships when there was more than one independent variable of interest. The Statistica™ software package (Statsoft 2003) was used to run all statistical tests.

3.4 Soil-plant relationships

Multivariate analysis is used to explore soil-plant relationships across all sites (mean values/transect, n=18) as a tool to help simplify and assess revegetation success using all complex intercorrelated soil and plant attribute variables. Factor Analysis (Principal Components Analysis, PCA using correlation matrices) and Multi-Dimensional Scaling (MDS using Euclidean distance similarity matrices) were chosen because they are fundamentally different methods of multivariate analysis. Nevertheless, they produced very similar results and, hence, only PCA results are examined here. Hence, Factor Analysis is used to examine multivariate relationships between all vegetation and soil attributes. It basically allows reduction of a large number of variables of interest, and detection of structure in the relationships between variables (i.e. classification).

Vegetation attribute variables were reduced to two Principle Components (PC1 & PC2) and their loadings (contributions) examined after varimax rotation. A similar data reduction process was undertaken for all soil attribute variables. Because varimax rotation was used, only the first vegetation and soil PCs were examined for structure in data. Structure was examined by plotting the Factor scores (values/transect) of the vegetation PC1 against the corresponding Factor scores for the soil PC1. This ordination method allows characterisation of vegetation and soil attributes of all sites using all data. It should be emphasised, however, that statistical classification methods are *hypothesis generating* rather than *hypothesis testing*. If there was a strong pattern linking poor vegetation development with poor soil development, then the underlying causal mechanisms need to be tested for experimentally (e.g. poor plant growth due to waterlogging).

3.5 Remote sensing

Ground based sampling provided information on canopy cover, ground cover and soil attributes for six sites, each covering three 50m transects. However, it is impossible to sample the whole landscape effectively using ground-based sampling alone. Despite the huge effort expended on ground-based vegetation surveys (7 people x 9 days), only 0.51% of the minesite was sampled. Hence, because it is possible that ground-based vegetation surveys may under sampled the variable post-mining environment, they were timed with the acquisition of remotely-sensed data.

Given an appropriate resolution and temporal availability, remotely-sensed data provides the opportunity for monitoring the entire minesite and surrounds, enabling “whole of landscape comparisons” (Corbett 1999). As it is only broad canopy and ground cover attributes that are obtained from remotely sensed data, such data are complementary to detailed ground-based studies.

3.5.1 Objectives

The aim of the remote sensing component of the vegetation assessment at Nabarlek is to evaluate the use of Quickbird data for minesite rehabilitation assessment and monitoring. Specifically, the objectives are to:

1 Estimate canopy cover and key ground cover attributes for the minesite and surrounding landscape;

2 Investigate the optimal season for Quickbird data capture at Nabarlek; and

3 Monitor the canopy and ground covers over time.

3.5.2 Data characteristics

Quickbird satellite imagery provides panchromatic data at 61cm spatial resolution and 2.44m multispectral imagery. The multispectral data includes four bands covering the visible to near infrared.

Quickbird data covering the minesite and surrounding landscape was captured on the 3rd September 2003. The eastern portion of data was affected by smoke from bushfires. As the acquisition date timed well with ground-based sampling, the data affected by smoke was cropped and the remainder retained for processing (Fig. 1b). The image data was received (November 2003) from Sinclair Knight Merz after the application of geocorrection procedures on the data. Note that the full extent of coverage will be requested with the next post wet season capture to be spatially compatible with airborne gamma data already obtained.

Ancillary fieldwork

A visual analysis of the data showed distinct cover patterns that were not identified as part of the ground-based work. The cover attributes of these sites were classified using a combination of helicopter and ground-based observations (Fig. 1c).

3.5.3 Advantages and limitations

AIM 1. Estimate canopy and key ground covers for the minesite and surrounding landscape

Trees can be visualised from the Quickbird data. In offsite riparian zones, although cover can be estimated, the tree canopies are closed or overlapping in some areas. For smaller trees and shrubs on the minesite, many of those visualised in the Quickbird data are small and indicated by shade, rather than an actual tree canopy. This is a result of the 2. 44m spatial resolution of the spectral data. Although the near infrared region of the spectrum is useful for determining green tree cover, to estimate canopy cover in this case, processing needs to account for shade areas that are a result of tree canopies, as well as green tree cover (or mixes of these categories), whilst excluding shade not representing a canopy.

A Normalised Difference Vegetation Index (NDVI) of the Quickbird data show Para grass present on the Evaporation Ponds at the time of image capture, having the same spectral response as green canopies. Methods for differentiating these covers and other ground covers of a spatial or spectral mix will be implemented. This assessment includes separation analysis of weed ground covers.

AIM 2. Investigate the optimal season for Quickbird data capture at Nabarlek

Another Quickbird capture will be obtained with the post wet season field-based work. Apart from scaling up across the minesite from the field-based data, the remotely sensed data will be used to investigate the separability of different covers to determine the optimal timing for data capture. It may be that some species not separable in one season may be differentiated in another. This aim has implications for other minesite assessments.

AIM 3. Monitor the canopy and land covers over time

The combination of ground-based surveys (transect, point sampling and observations taken from a hovering helicopter) with temporal remotely sensed data will be used to assess any cover changes over time as a result of weed management, fire, regeneration and seasonal growth.

4 Results

4.1 Ground-based transects

4.1.1 Canopy cover of trees & shrubs

4.1.1.1 Species composition

Forty nine tree and shrub species were recorded on all transects during the September 2003 survey (Appendix Table 9.2.2). Fifty seven canopy species have been recorded for Nabarlek to date, including 10 *Eucalyptus* and *Corymbia* spp, two *Melaleuca spp*, *Pandanus spirolis* and 11 *Acacia* spp. Six *Acacia* spp were used to revegetate the minesite by direct seeding commencing in December 1995 (Appendix Table 9.2.3). Reference sites had 2.6 times more canopy species than Mine sites ($F_{5/2}$ = 26.72, P<0.001), and species richness was similar within Mine sites and within Reference sites (Fig. 3).

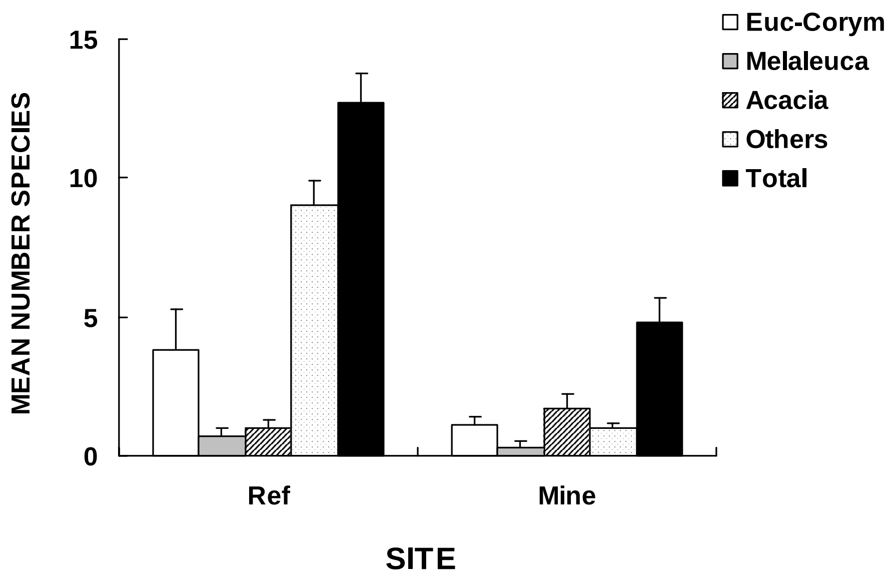


Figure 3 Mean number of *Eucalyptus-Corymbia*, *Melaleuca*, *Acacia* and all Other species found on Reference sites and Mine sites (mean number species/0.01ha plot/transect). RIP Riparian forest; WL Eucalyptus dominated woodland; WRD Waste Rock Dump; PIT Mine Pit; EP1 and EP2 Evaporation Ponds 1 and 2 respectively. Nabarlek, September 2003.

Canopy species were classed into the following four Plant Types: *Eucalyptus* and *Corymbia* spp; *Melaleuca* spp; *Acacia* spp; and Others. There was a significant interaction between location (Reference sites vs Mine sites) and Plant Type ($F_{3/64}$ = 26.88, P<0.001), reflecting the fact that: more Eucalyptus and Corymbia species were found on Woodland sites; more Acacia species were found on Mine sites and, in contrast, more *Eucalyptus-Corymbia* and *Other* species were found on Reference sites. However, there was a significant interaction between location (across all sites) and Plant Type ($F_{15/48}$ = 5.7, P<0.001); no *Melaleucas* were found on eucalyptus dominated Woodland sites and, in contrast, EP2 had 1/6th the number of Acacia species than all other Mine sites.

4.1.1.2 Density trees and shrubs

The density of canopy species differed significantly by Site and Canopy Type (tree or shrub), but there was a significant scalar interaction between the two (Table 2a, Fig. 4): the density of trees and shrubs on Reference sites was 3.4 and 12.6 higher than on Mine sites, respectively (shrubs: $F_{1/16} = 41.8$, $P<0.001$; trees: $F_{1/16} = 16.7$, $P<0.001$; Fig. 8b). Shrub density was 3 times tree density on Reference sites and Mine sites had similar tree and shrub densities. There were no significant differences in tree density between both Reference sites and all Mine sites, and similar results were found for shrub density (Fig. 4).

Table 2a-c 2-ANOVA of stand density and canopy cover (mean number & % canopy cover of 3 x 0.01ha plots/transect, respectively) by canopy type (n=2; tree or shrub) and site (RIP=Riparian forest; WL=Eucalyptus woodland, EP1 & EP2=Evaporation Ponds 1 & 2 respectively; WRD=Waste Rock Dump; PIT= Mine Pit), for (a) all sites (n=6), (b) Reference sites (n=2) and (c) Mine sites (n=4). Nabarlek, September 2003.

		Density		Cover	
Factor	df	F	P	F	P
(a) All sites					
Site	5	11.0	<0.001	6.07	0.009
Canopy Type	1	8.2	0.009	22.32	<0.001
Site x Canopy Type	5	3.5	0.017	3.37	0.019
Error	24				
(b) Reference sites					
Site	1	1.20	NS	0.61	NS
Canopy Type	1	8.81	0.02	12.82	0.0007
Site x Canopy Type	1	0.07	NS	0.39	NS
Error	8				
(c) Mine sites					
Site	3	3.71	0.03	3.53	0.04
Canopy Type	1	0.02	NS	15.63	0.001
Site x Canopy Type	3	0.32	NS	2.78	NS
Error	16				

4.1.1.3 Canopy cover

Percentage cover of canopy plants differed significantly by Site and Canopy Type (tree or shrub), but there was a significant scalar interaction between the two (Table 2a-c, Fig. 5): shrub and tree cover on Reference sites were both 4.8 times greater than on Mine sites (shrubs: $F_{1/16} = 13.69$, $P=0.009$; trees: $F_{1/16} = 22.2$, $P<0.0002$; Fig. 8c), although tree cover was far greater than shrub cover. There were no significant differences in tree canopy cover between both Reference sites and between all Mine sites combined and, similarly for shrub canopy cover between Reference sites (Fig. 5). However, there was a significant difference in shrub canopy cover between Mine sites ($F_{3/8}$ = 5.6, P=0.023): EP2 had four times less canopy cover than other Mine sites because of a lower shrub density. Hence, although there were less trees than shrubs, they provided far greater canopy cover. Additionally, Mine sites had less total canopy cover than Reference sites.

4.1.1.4 Stand size structure (height & tree dbh)

The number of individuals in all 2m size classes was greater on Reference sites than Mine sites, with the greatest difference occurring in the 0.10m – 2m size interval encompassing shrubs (Fig. 6a). This result may reflect greater natural recruitment from the seedling size class (<0.10m) into the shrub class on Reference sites. Even in a relative sense, there was 25% more shrubs on Reference sites than on Mine sites (75% cf 50%; Fig. 6b).

The mean height of canopy plants differed significantly by Site and Canopy Type (tree or shrub), however, there was a significant cross-over interaction between the two ($F_{1/28}$ = 14.8, P<0.001; Fig. 7a): trees on Reference sites were 1.6 times taller than trees on Mine sites ($F_{1/15}$ = 11.29, P=0.004), and shrubs on Mine sites were 1.7 times taller than shrubs on Reference sites ($F_{1/13}$ = 46.9, P<0.001; Fig. 8d). Woodland trees were 1.7 times taller than Riparian trees ($F_{1/4}$ = 8.9, P=0.04), and there was no significant difference in tree height across all Mine sites. There was no difference in the height of shrubs between Reference sites and, similarly, between Mine sites. Hence, trees on the minesite were smaller than trees on adjacent analogue sites and, in contrast, shrubs on the minesite were taller than shrubs on adjacent analogue sites.

There was no significant difference between tree girth (dbh) on Reference sites and, similarly for Mine sites. However, tree girth on Reference sites was twice that of Mine sites ($F_{1/16}$ = 22.0, P< 0.001; Fig. 7b & 8e).

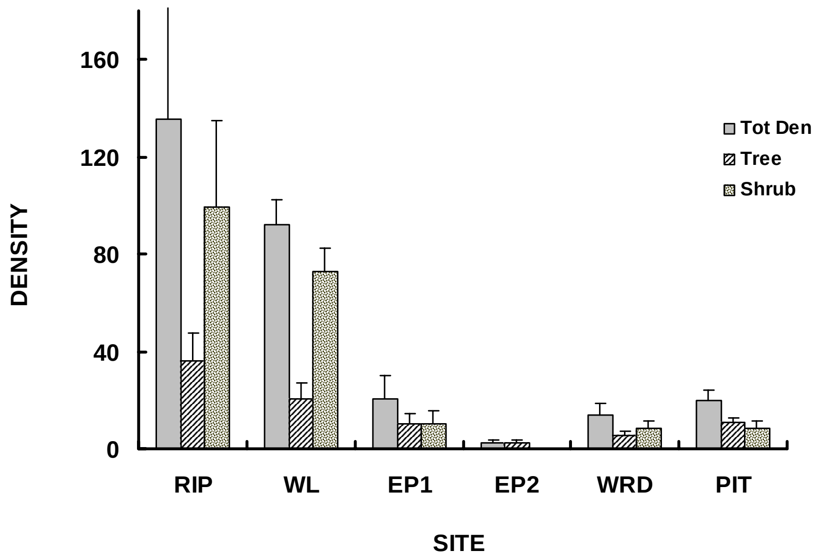


Figure 4 Mean density (numbers/0.01ha plot/transect) of trees, shrubs and combined total by Site. RIP Riparian forest; WL Eucalyptus dominated woodland; WRD Waste Rock Dump; PIT Mine Pit; EP1 and EP2 Evaporation Ponds 1 and 2 respectively. The mean numbers in 3 x 0.01ha plots/transect were first derived, and then averaged across the 3 transects/site. Vertical lines on bars are standard errors. Nabarlek, September 2003.

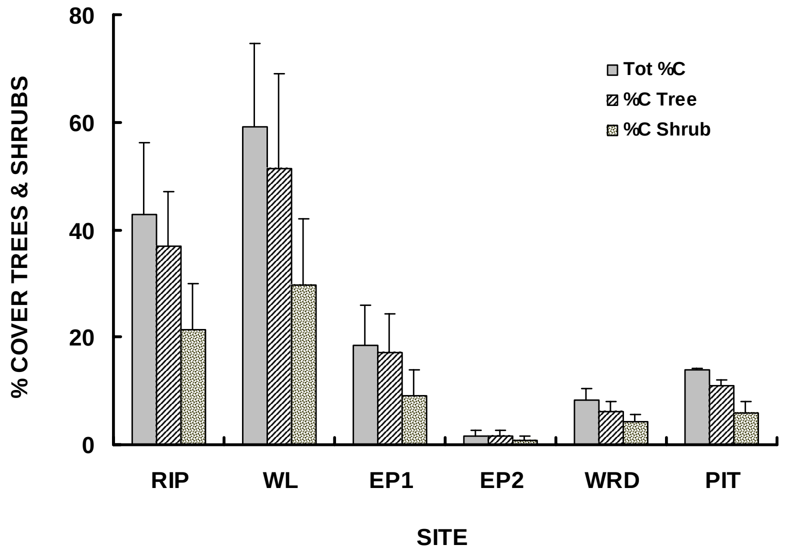


Figure 5 Mean percentage canopy cover (%Cover 0.01ha plot/transect) of trees, shrubs and combined total by site. RIP Riparian forest; WL Eucalyptus dominated woodland; WRD Waste Rock Dump; PIT Mine Pit; EP1 & EP2 Evaporation Ponds 1 & 2 respectively. The mean cover of 3 x100m^2 plots/transect were first derived, and then averaged across the 3 transects/site. Vertical lines are standard errors. Nabarlek, September 2003.

4.1.1.5 Reference sites vs Mine sites

Canopy cover on Reference and Mine sites are characterised and compared using all the attributes analysed above (species richness, density of trees & shrubs, projected foliage cover of trees & shrubs, tree & shrub height & tree dbh; see Fig. 8a-e, respectively). In contrast to Mine sites, Reference sites had more: canopy species; more trees which were taller and older (i.e. with greater girth); shrubs; and, hence, overall greater canopy cover.

4.1.1.6 Relationships between canopy cover attributes

Even across species, attributes such as stand density, canopy cover, height and dbh are all generally correlated. A predictive relationship between the density of trees (&/or shrubs) and canopy cover may then be a powerful tool for extrapolating canopy cover estimates derived from remote sensing captures to estimates of stand density. Remotely sensed data offer total coverage of the landscape, avoiding inherent undersampling problems associated with ground-based surveys of land surface features on variable mine environments (Section 3.3).

Figure 9a shows the variable scatter-plot between mean tree density (mean numbers/0.01ha /transect) and mean canopy cover (% cover/0.01ha/transect) across all sites. The relationship expands towards upper values due to different trajectories for Reference sites. Hence, when partitioned between sample sites (Fig. 9 b-d), significant relationships can be teased out explaining a high proportion of variability. The relationship for Mine sites is significantly nonlinear (Fig. 9d), explaining 20% more variance in the data. Additional predictive stand density-cover models were obtained for dominant tree species across all sites, such as *Melaleuca* spp, *Pandanus spp* and *Eucalyptus* spp (Fig. 10a-c, respectively), and for data combined across sites such as that for shrubs (Fig. 11). Hence, stand density-cover relationships can be obtained for different vegetation communities. The predictive power of such models can be increased significantly with the addition of other allometric variables such as mean stand height (Table 3a-c) and, importantly, such data can be obtained from remotely sensed images using high resolution DEMs, or inferred from overlays of vegetation community types using independently derived data.

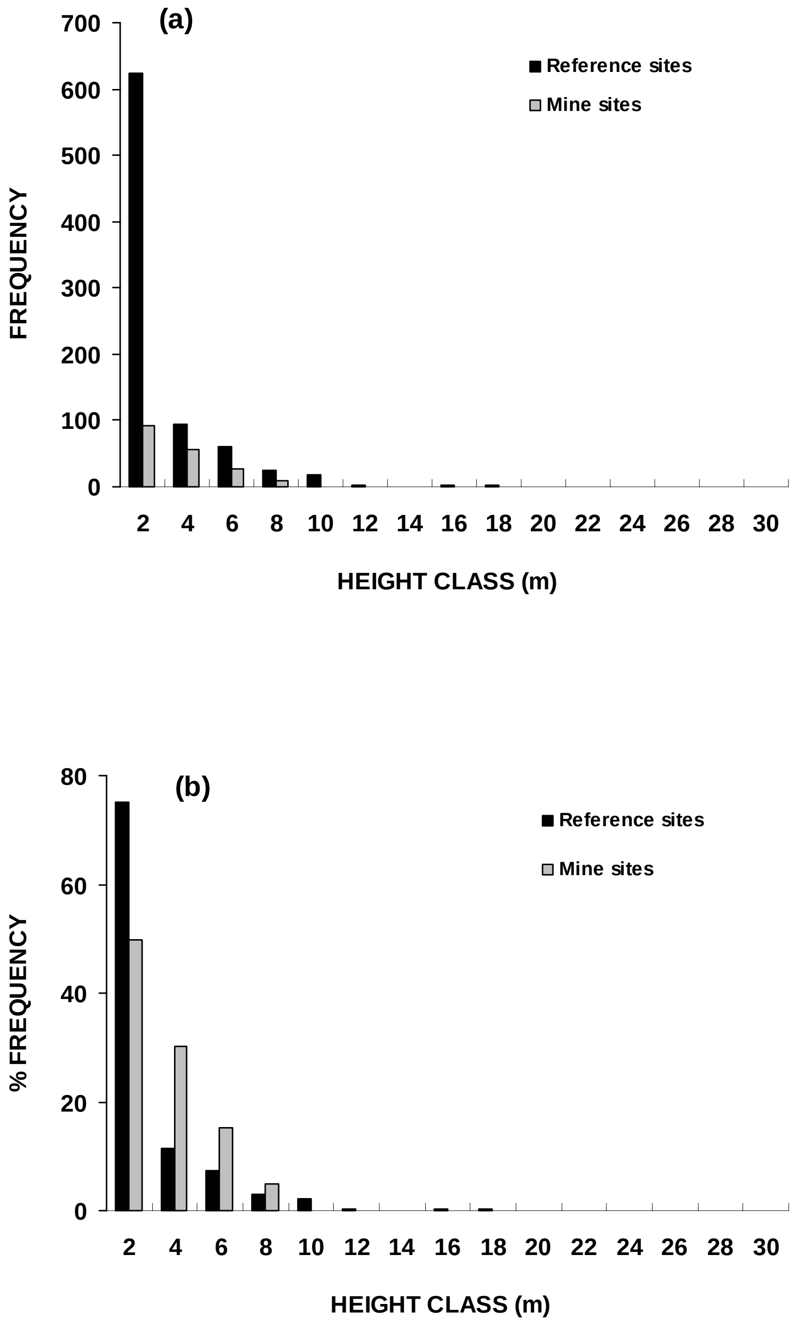
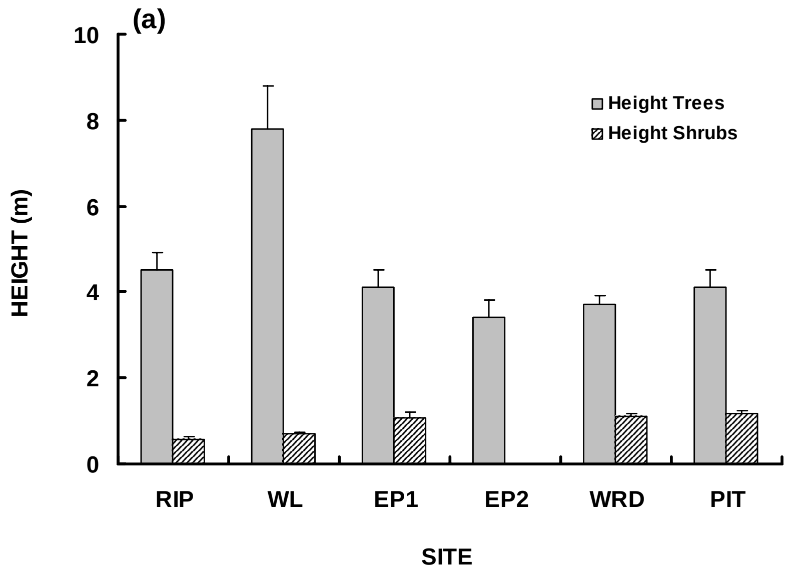


Figure 6 a & b Stand height structure (2 m height classes) of combined Reference sites and combined Mine sites for (a) raw frequencies and (b) percentage frequencies. Note that size class 2 represents the interval 0.1m – 2.0m (non-seedlings), and that for 4 the 2.0m – 4.0m height interval. Nabarlek, September 2003.



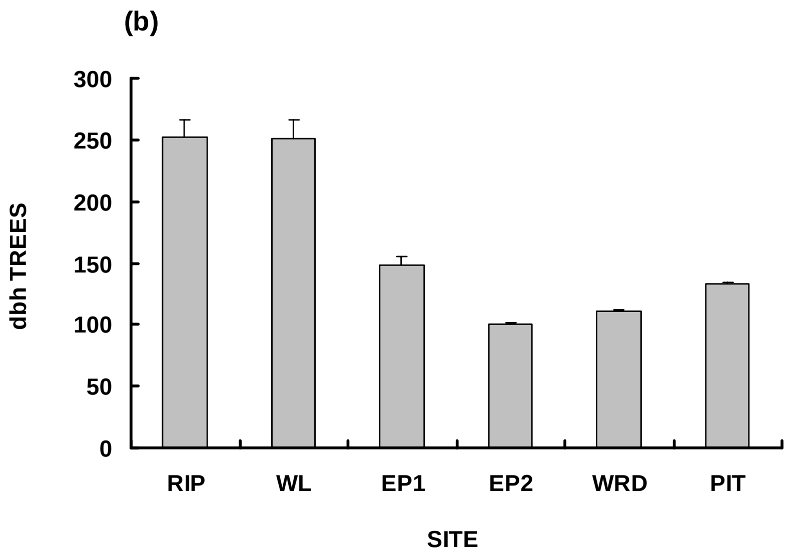


Figure 7 a & b (a) Mean height (m) of shrubs and trees, and (b) mean diameter at breast height (dbh, cm) of trees, by site. RIP Riparian forest; WL Eucalyptus dominated woodland; WRD Waste Rock Dump; PIT Mine Pit; EP1 and EP2 Evaporation Ponds 1 and 2 respectively. The mean values of individual trees in 3 x 0.01ha plots/transect were first derived, and then averaged across the 3 transects/site. Vertical lines are standard errors. Nabarlek, September 2003.

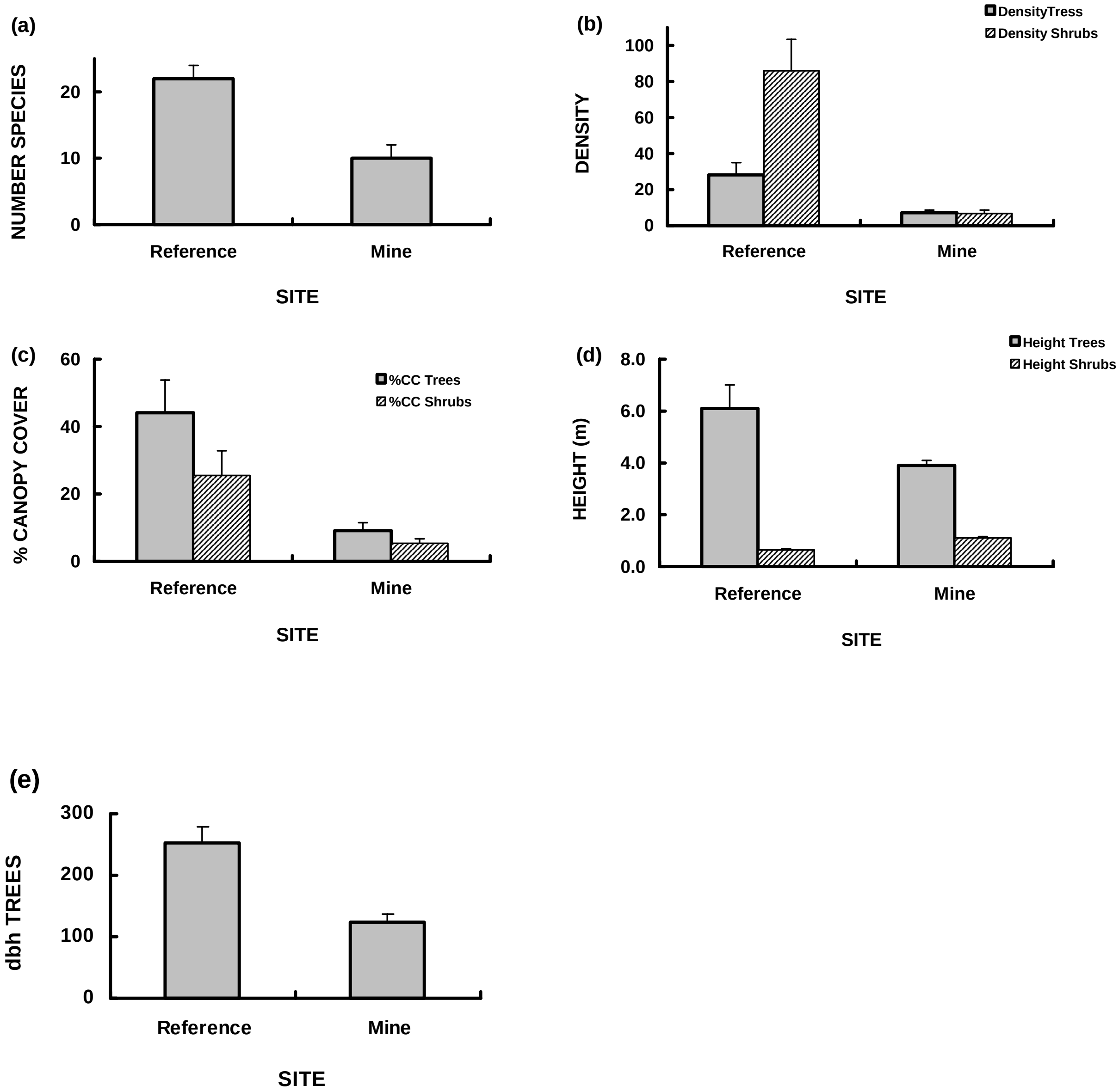


Figure 8 a-e Comparison between Reference sites and Mine sites for the following canopy cover characteristics: (a) mean number of species; (b) mean density of trees and shrubs; (c) mean canopy cover (%) of trees and shrubs; (d) mean height (m) of trees and shrubs; and (e) mean dbh (cm) of trees. The mean attribute values in 3 x 0.01ha plots/transect were first derived, then averaged across the 3 transects/site, and finally averaged across both Reference sites and all Mine sites. Vertical lines are standard errors. Nabarlek, September 2003.

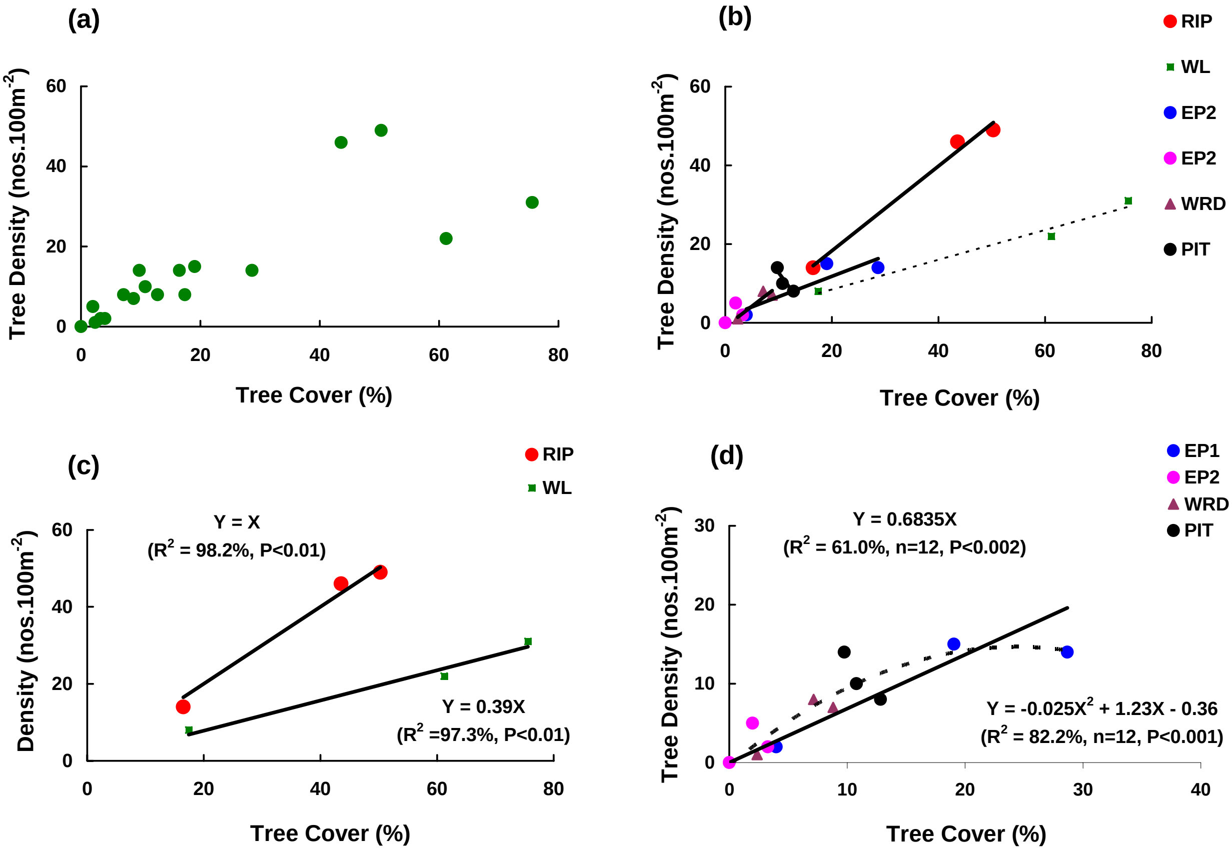


Figure 9 a-d Regression relationships between mean tree density/transect and mean canopy cover (%)/transect for: (a) all sites; (b) all sites but marked by location; (c) Reference sites only; and (d) Mine sites only. Regression equations are shown. The mean density of trees and canopy cover for 3 x 0.01ha/plots/transect were first derived, and then averaged across the 3 transects/site. Nabarlek, September 2003.

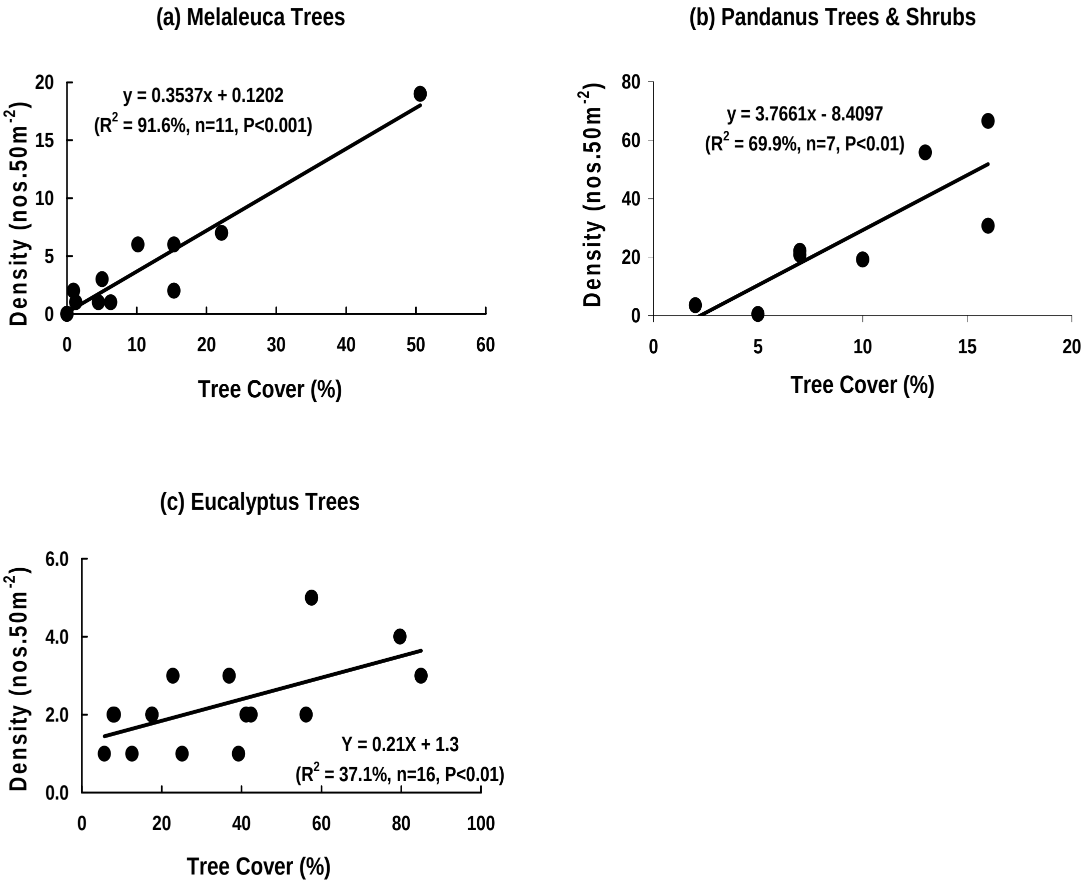


Figure 10 a-c Regression relationships between mean tree density/50m^2 transect subplots and mean percentage canopy cover (%)/50m^2 transect subplot for (a) *Melaleuca spp*, (b) *Pandanus spp* (includes shrubs) and (c) *Eucalyptus spp*. Nabarlek, September 2003.

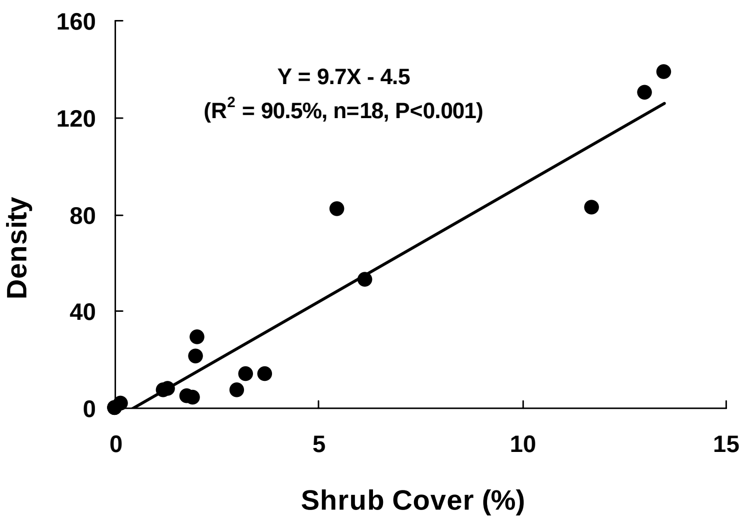


Figure 11 Regression relationship between mean shrub density/transect and mean canopy cover (%)/transect for all shrubs combined across sites. The mean attribute values for 3 x 0.01ha plots /transect are first derived, and then averaged across the 3 transects/site. Nabarlek, September 2003.

Table 3a-c Summary of multiple regression relationships between components of stand density (D) and canopy cover (trees: %Ct; shrubs: %Cs) and height (trees: Ht; shrubs: Hs). P is regression probability. Nabarlek, September 2003.

Stand component	Equation	n	R	$\%R^2$	P
(a) Total trees/shrubs	D = 135.5 + 1.4%Ct + 7.9%Cs – 14.5Ht – 81.9Hs	17	0.9357	82.6	0.0002
(b) Trees	D = 3.4 + 0.5%Ct	17	0.8081	63.1	<0.001
	D = 15.4 + 0.66%Ct – 3.2Ht	17	0.8484	68.0	<0.001
(c) Shrubs	D = 2.54 + 9.2%Cs	18	0.7756	57.7	0.0002
	D = 98.7 + 6.0%Cs – 89.6Hs	18	0.8710	71.8	0.0002

4.1.2 Ground cover of sedges, grasses & herbs (100m^2 plots & 1m^2 quadrats)

4.1.2.1 Species composition of grasses, herbs & sedges

A total of 85 ground cover species were recorded during the September 2003 vegetation survey (Appendix 9.2.1). Of these 41 (44.2%) were grasses, 43 herbs (50.6%) and 4 (5.2%) sedges. Of the grasses, 15 (36.6%) are classified as weeds, and that for herb weeds 19 (44.2%). No weed sedges were recorded. Across all sites the ground cover comprised 40% weed species with most recorded on the minesite.

In 1994 ***eriss*** completed a vegetation survey of the Waste Rock Dump before rehabilitation and revegetation (Brennan & Bach 1994). They found that weed species comprised 30 % of all herbaceous species (Appendix 9.2.1). In 1996 and 1997 the mine site and a number of reference sites were surveyed for plants by Adams Ecological Consultants on behalf of QML (Adams & Hose 1999). They recorded 59 species of grasses and herbs, of which 22 (37.3%) were classified as weeds, similar to the results reported in this study.

Overall, there was no significant difference in the mean number of species between Reference sites and Mine sites (Table 4a; Fig. 12a). However, there was a significant interaction between Plant Type (grass, herb or sedge) and location (Table 4a): twice as many grass species were found on Mine sites than on Reference sites and, in contrast, there were no differences in the mean number of herb and sedge species.

Similarly, there was no difference in the mean number of species across all sites (Table 4b; Fig. 12b). However, there was a significant interaction between Plant Type (grass, herb or sedge) and Site (Table 4b), reflecting significant differences in the composition of ground cover species between sites. The Woodland site had about half as many grass species than Riparian sites, a similar number of herb species, and no sedges (Fig. 12b). The Mine sites had similar number of grass species, EP2 had 2-3 times more herb species, and sedges were only found on the WRD and PIT sites (Fig. 12b).

There was no significant difference in the mean number of native and weed species between Reference sites and Mine sites (Table 4a; Fig. 12c). However, there was a significant and strong cross-over interaction between Plant Type (weed or native) and location (Table 4a); there were 2.5 times more native species on Reference sites than on Mine sites, and 4.8 times more weed species were found on Mine sites than on Reference sites (Fig. 12c).

Table 4 a&b Summary of 2-ANOVAs of the following ground cover attributes (mean value/3 x 0.01ha plots/transect): number species, percentage cover and biomass by Plant Type (n=3; grasses, herbs & sedges: n=2, native or weeds: n=2, native or weed grasses or weed herbs), for (a) Reference sites vs Mine sites (n=2) and (b) all Sites (n=6; RIP=Riparian forest; WL=Eucalyptus woodland, EP1 and EP2=Evaporation Ponds 1 and 2 respectively; WRD=Waste Rock Dump; PIT= Mine Pit). Dominant grass classes were: Black Spear grass, comprising two species (*Heteropogon triticeus* for WL & *H. contortus* for all other sites); Mission Grass, comprising both the perennial and annual species (*Pennisetum polystachion & P. pedicellatum*, respectively); Para grass (*Urochloa mutica*); and Rhodes Feather Top (*Chloris virgata*). Nabarlek, September 2003.

Factor	Number species by Grass, Herb & Sedge classes			Number species by Native & Weed classes			Number grass species by Native & Weed classes		Number herb species by Native & Weed classes		% Cover of Grass, Herb & Sedge classes			% Cover of Native & Weed classes			% Cover Grasses of Native & Weed classes		% Cover Herbs of Native & Weed classes		Biomass of Grass, Herb & Sedge classes			Biomass of dominant Grass class		
	df	F	P	df	F	P	F	P	F	P	df	F	P	df	F	P	F	P	F	P	df	F	P	df	F	P
(a) Reference vs Mine sites																										
Site	1	0.32	NS	1	0.34	NS	12.1	0.001	0.86	NS	1	9.28	0.004	1	11.5	0.002	6.7	0.01	1.89	NS	1	5.81	0.02	1	3.06	NS
Cover Type	2	31.53	<0.001	1	2.66	NS	1	NS	0.13	NS	2	36.5	<0.001	1	4.61	0.041	2.24	NS	1.78	NS	2	33.31	<0.001	3	5.12	0.003
Site x Cover Type	2	4.54	0.016	1	52.53	<0.001	46.6	<0.001	17.67	<0.001	2	4.1	0.022	1	58.5	<0.001	40.15	<0.001	6.08	0.019	2	4.07	0.02	3	12.81	<0.001
Error	48			32							48			32							48			64		
(b) All sites																										
Site	5	1.1	NS	5	1.05	NS	6.3	0.0007	3.83	0.01	5	2.64	0.04	5	3.76	0.011	2.19	NS	2.17	NS	5	2.71	0.035	5	2.62	0.036
Cover Type	2	58.3	<0.001	1	0.99	NS	3.3	NS	2.37	NS	2	55	<0.001	1	30.85	<0.001	15.1	<0.001	6.52	0.017	2	53.84	<0.001	3	13.97	<0.001
Site x Cover Type	10	5.3	<0.001	5	18.43	<0.001	20.1	<0.001	10.89	<0.001	10	2.19	0.04	5	16.94	<0.001	9.2	<0.001	2.98	0.031	10	2.19	0.041	15	6.03	<0.001
Error	36			24							36			24							36			38		

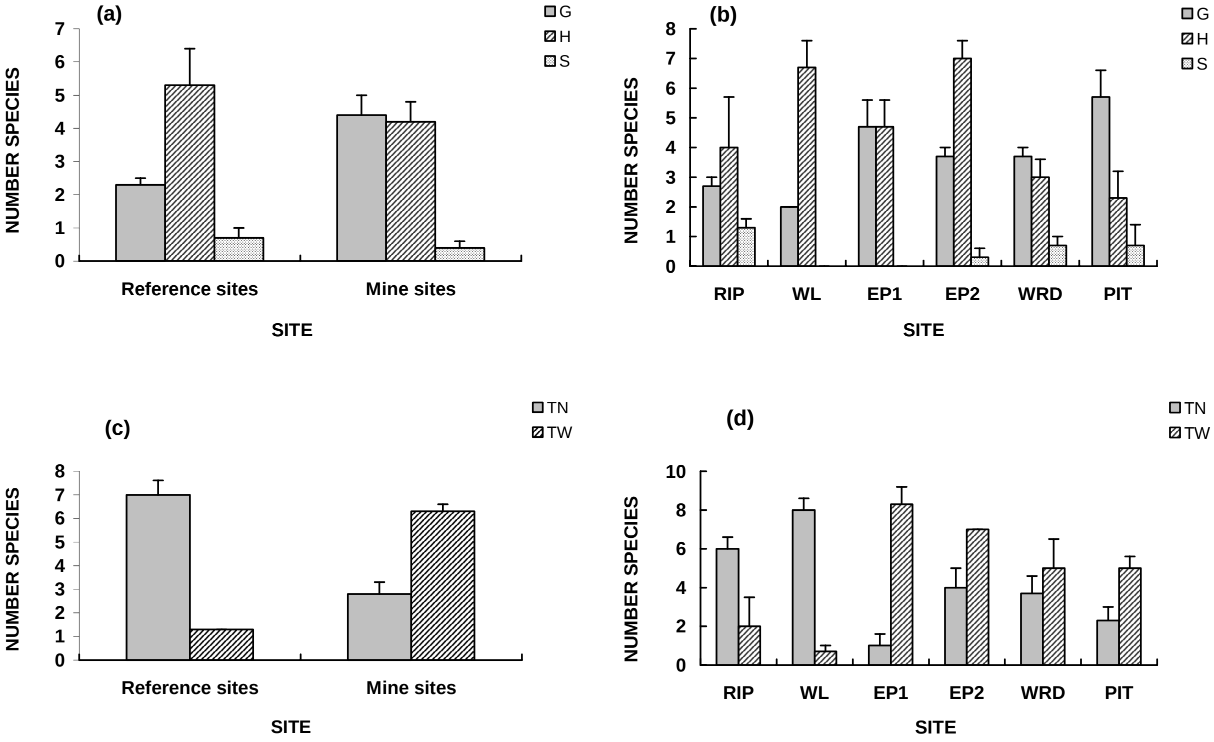


Figure 12 a-d Comparison between mean number of grass (G), herb (H) and sedge (S) species between (a) Reference sites and Mine sites and (b) all Sites. Comparison of mean number of Native (TN) and Weed (TW) ground cover species for (c) Reference sites and Mine sites and (d) for all Sites. RIP Riparian woodland; WL Eucalyptus dominated woodland; WRD Waste Rock Dump; PIT Mine Pit; EP1 & EP2 Evaporation Pond 1 & 2 respectively. The mean number of species in 3 x 0.01ha plots/transect were first derived, and then averaged across the 3 transects/site. Vertical lines are standard errors. Nabarlek, September 2003.

Similarly, there was no difference in the mean number of native and weed species across all sites (Table 4b; Fig. 12d). However, there was a significant interaction between Plant Type (native or weed) and Site (Table 4b), reflecting significant differences in species composition of native and weed ground covers between sites. Both Reference sites had similar mean numbers of native species and, in contrast, about twice as many weed species were found on the Riparian site than the Woodland site (2.0 c.f. 0.7/transect). Across all Mine sites there was 2.3 times more weed species recorded than native species, and all Mine sites had similar mixes of native and weed species (Fig. 12d).

Most of the differences between locations in the mix of native and weed species was due to differences between grasses and herbs. There was a significant difference in the number of grass species between Reference sites and Mine sites, no difference in the number of weed and native grass species between locations, but a strong significant interaction between the two (Table 4a, Fig. 13a): no grass weeds were found on Reference sites which also had twice as many native grass species than Mine sites (Fig. 13a). The Riparian sites had 1.4 times more native grass species than Woodland sites and, across the Mine sites, there were twice as many weed grass species than native grass species (Table 4b, Fig. 13b).

There was no difference in the number of herb species between Reference sites and Mine sites and no difference in the number of weed and native herb species. However, there was a strong significant cross-over interaction between the two (Table 4a, Fig. 13c): there were 2.5 times more herb weed species on Mine sites compared to Reference sites, and 4 times more native herb species on Reference sites than Mine sites. There was about 3 times more herb weed species found on the Riparian sites than Woodland sites and, in contrast, 3 times more native herbs were found in Woodland sites compared to Mine sites (Table 4b, Fig. 13d). On the Mine sites there was 3.3 times more weed herb species than native herbs, and the mix of native and weed herbs were similar across sites.

Only four species of sedges were recorded across all sites, and there was no significant difference in the mean number of species by Site ($F_{5/12} = 1.97$, NS).

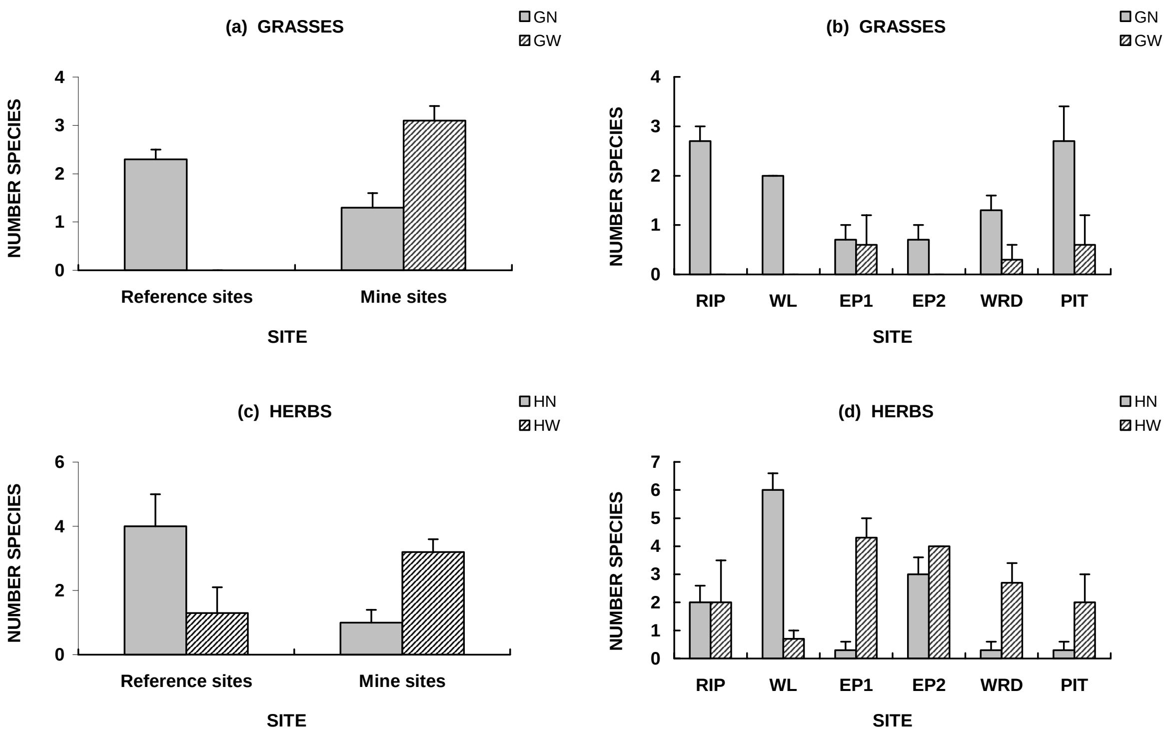


Figure 13 a-d Comparison between mean number of Native (GN) and Weed (GW) grass species between (a) Reference sites and Mine sites, and (b) all Sites. RIP Riparian woodland; WL Eucalyptus dominated woodland; WRD Waste Rock Dump; PIT Mine Pit; EP1 & EP2 Evaporation Pond 1 & 2 respectively. Similarly for mean number of Native (HN) and Weed (HW) herb species for (c) Reference sites and Mine sites, and (d) for all Sites. The mean number of species in 3 x 0.01ha plots/transect were first derived, and then averaged across the 3 transects/site. Vertical lines are standard errors. Nabarlek, September 2003.

4.1.2.2 Ground cover

There were significant differences in ground cover (% cover/0.01ha plots/transect) between Reference sites and Mine sites, and Plant Type (grasses, herbs & sedges). However, there was a significant interaction between the two (Table 4a; Fig. 14a): in contrast to Reference sites, Mine sites had twice as much ground cover of grasses ($F_{1/4} = 8.70$, P=0.041), no significant difference in herb cover ($F_{1/4} = 3.4$, NS) and similar sedge cover ($F_{1/3} = 2.9$, NS). Similar results were obtained when comparing ground cover between all sites (Table 10b; Fig. 14b). Woodland sites had about 4 times more grass cover than Riparian sites, and Riparian sites had about twice the amount of herb cover. No sedges were recorded in Woodland sites. Mine sites had similar grass (all > 50%, $F_{3/8} = 0.21$, NS) and herb cover ($F_{3/8} = 1.85$, NS), although both

Evaporation Pond sites had 4-6 times more herb cover than the WRD and PIT sites. The PIT site had about 3% sedge cover, and all other Mine sites had only trace amounts.

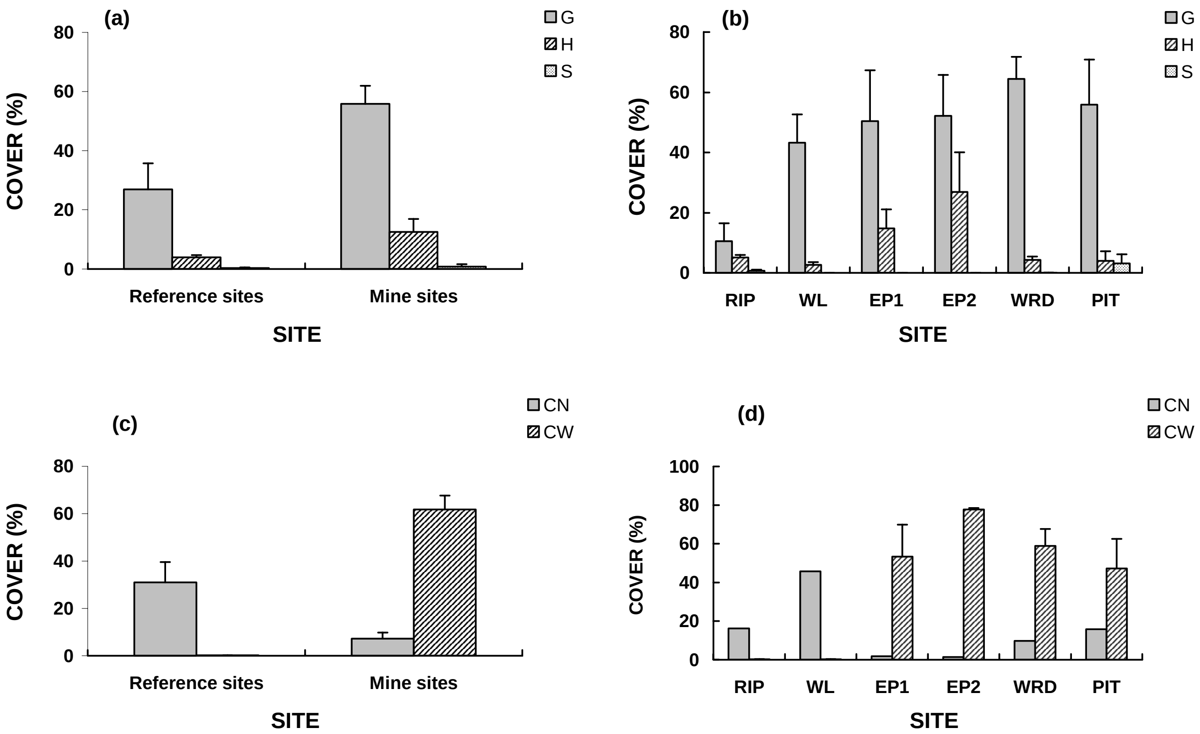


Figure 14 a-d Comparison between mean ground cover (%) of Grasses (G), Herbs (H) and Sedges (S) between (a) Reference sites and Mine sites, and (b) all Sites. RIP Riparian woodland; WL Eucalyptus dominated woodland; WRD Waste Rock Dump; PIT Mine Pit; EP1 & EP2 Evaporation Pond 1 & 2 respectively. Similarly for mean ground cover (%) of Native (CN) and Weed (CW) species for (c) Reference sites and Mine sites and (d) for all Sites. The mean ground cover of plants in 3 x 0.01ha plots/transect were first derived, and then averaged across the 3 transects/site. Vertical lines are standard errors. Nabarlek, September 2003.

There were significant differences in mean ground cover (%) between Reference sites and Mine sites and Plant Type (weed or native), but a significant interaction between the two (Table 4a; Fig. 14c). Reference sites had 4.4 times more cover of native grasses than Mine sites and, in contrast, Mine sites had 310 times more weed grass cover. Similar results were obtained when comparing the ground cover of natives and weeds between all sites (Table 4b; Fig. 14d). Woodland sites had about 3 times more cover of native species than Riparian sites, and both sites had about the same very low amounts of weed cover (= 0.2%). Most of the above location differences in ground cover of natives and weeds was due to differences between grasses and herbs: no weed grasses were found in Reference sites and, in contrast, Mine sites had on average 46.7% weed grass cover (Table 4a, Fig. 15a). Reference sites had 5 time more native grass cover than Mine sites, explaining the significant cross-over interaction (Table 4a). Woodland sites had 4 times more native grass cover than Riparian sites (Table 4b, Fig. 15b), and Mine sites had 8 times more weed ground cover than native cover (Fig. 15d).

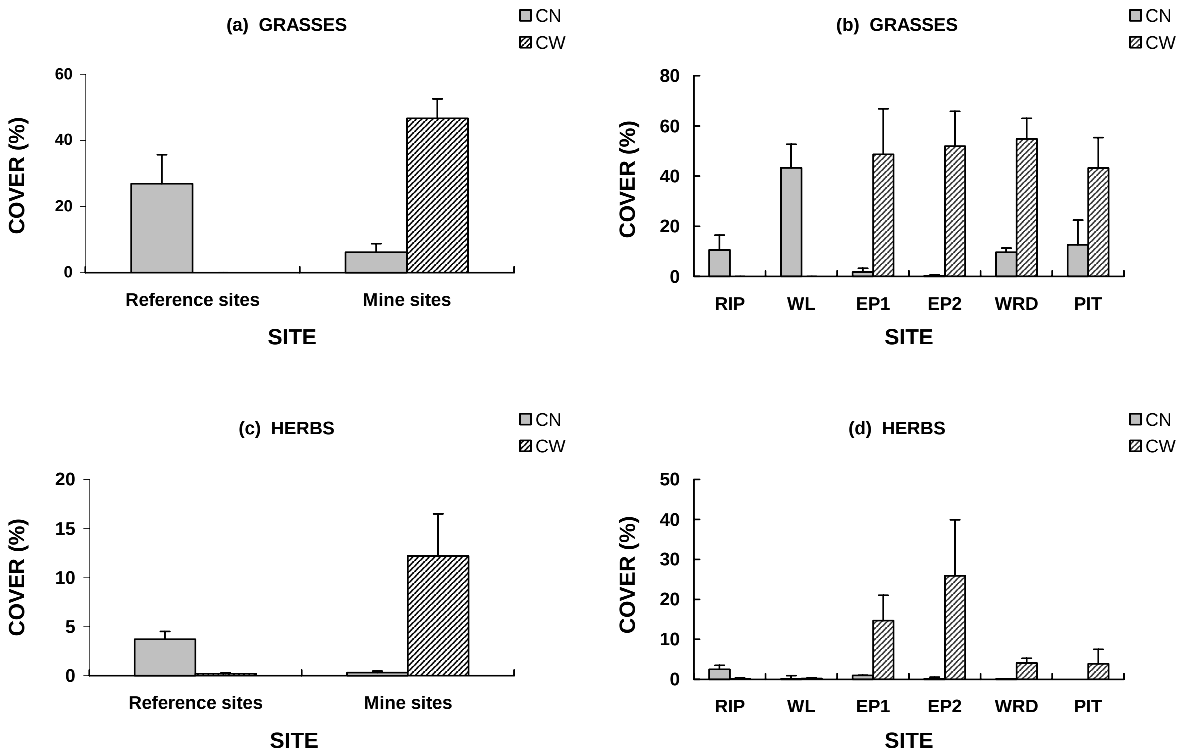


Figure 15 a-d Comparison between mean ground cover (%) of Native and Weed grasses between (a) Reference sites and Mine sites, and (b) all Sites. RIP Riparian woodland; WL Eucalyptus dominated woodland; WRD Waste Rock Dump; PIT Mine Pit; EP1 and EP2 Evaporation Pond 1 and 2 respectively. Mean ground cover (%) of native and weed herbs for (c) Reference sites and Mine sites, and (d) for all Sites. The mean ground cover of plants in 3 x 0.01ha plots/transect were first derived, and then averaged across the 3 transects/site. Vertical lines are standard errors. Nabarlek, September 2003.

On average there was no significant difference in herb cover between Reference sites and Mine sites, nor in the cover of weeds and natives across both locations. However, there was a significant interaction between the two because Mine sites had 61 times more herb cover than Reference sites, and Reference sites had 12 times more native herb cover than Mine sites (Table 4a, Fig. 15c). Both Reference sites had similar very low amounts of weed herb cover (0.2%), and Riparian sites had twice as much native herb cover than Woodland sites (Table 4b, Fig. 15d). Both Evaporation Pond sites had 4-6 times more herb weed cover than the WRD and PIT sites, and the cover of native herbs was very low across all Mine sites (0.03 – 1.0%; Fig. 15d).

4.1.2.3 Biomass and fuel loads

There was a significant difference in mean ground cover biomass between Reference sites and Mine sites, and between Plant Type (grasses, herbs & sedges). However, there was a significant interaction between the two (Table 4a): Mine sites had twice as much biomass of grasses (Fig. 16a), 21 times more biomass of herbs (Fig. 16c), and similar amounts of sedges.

Similar results were obtained when comparing ground cover biomass between all sites (Table 4b; Fig. 16b): Woodland sites had 10 times more grass biomass than Riparian sites ($F_{1/4}$ = 7.48, P=0.052) and a similar biomass of herbs (Fig. 16d; both Evaporation Ponds had greater grass biomass than other Mine sites but this was not significantly different; no sedges were recorded in Woodland sites; Riparian sites had 7 times more sedge biomass than that for herbs; and Mine sites had similar biomass of grasses and herbs ($F_{3/8}$ = 0.54, NS; $F_{3/8}$= 0.60, NS; respectively). The PIT site had most sedge biomass (86 kg.ha^{-1}), whilst all other Mine sites had only trace amounts.

Grasses contributed most to ground cover biomass and, hence, the four most dominant species were analysed for differences between location. These are: native Black Spear grass (BSG: comprising two species *Heteropogon triticeus* for WL & *Heteropogon contortus* for all other sites; Plates 5a, 6d); Mission grass weed (MG: comprising both the perennial & annual species, *Pennisetum polystachion* & *P. pedicellatum*, respectively; Plates 4d, 5c&d); Para grass weed (PARA: *Urochloa mutica*; Plates 5b&c); and Rhodes Feather Top weed (RFT: *Chloris virgata*). Rhodes Feather Top was deliberately introduced in 1994 for revegetation. There was no difference in grass biomass between sites, a significant difference between species, and a significant interaction between the two (Table 4a, Fig. 17a): the interaction is because no weed grasses were found on Reference sites. There were similar biomasses of Black Spear grass between Reference sites (2.5 tonnes.ha^{-1}) and, Reference sites in turn had about 90 times more Black Spear grass biomass than Mine sites. Across the Mine sites Mission grass had the most biomass (3.9 tonnes.ha^{-1}), and Para grass and Rhodes Feather Top had similar biomasses (0.5 tonnes.ha^{-1}).

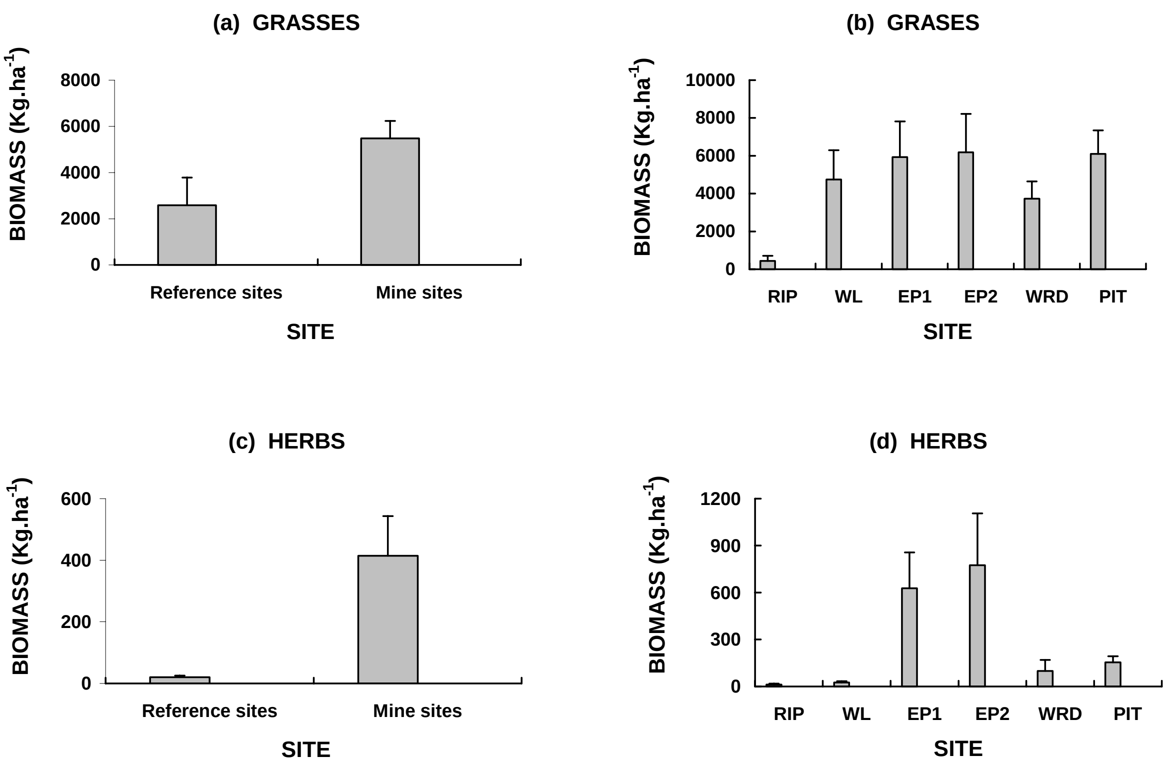


Figure 16 a-d Comparison between mean above ground biomass (ODW, kg.ha^{-1}) of grasses between (a) Reference sites and Mine sites, and (b) all Sites. RIP Riparian woodland; WL Eucalyptus dominated woodland; WRD Waste Rock Dump; PIT Mine Pit; EP1 & EP2 Evaporation Pond 1 & 2 respectively. See Appendix 9.2 for method of estimating biomass. Mean biomass of ground cover plants in 3 x 0.01ha plots/transect were first derived and then averaged across the 3 transects/site. Vertical lines are standard errors. Nabarlek, September 2003.

The differences in biomass of dominant grass species reflect local environmental differences as much as mining history (Fig. 17b). For example, no Black Spear grass was found on the Evaporation Ponds transects, and no Para grass was found on EP2 or the PIT sites. Most biomass of Mission grass was found in the EP2 and PIT sites (about 5 - 6 tonnes.ha^{-1}), followed by the EP1 and WRD sites (about 3 tonnes.ha^{-1}). Because of such high fuel loads, all Mine sites are at extreme risk of uncontrolled fire. A small amount of Para grass biomass was estimated for the WRD site (0.005 tonnes.ha^{-1}), none on any other Mine site, and the most biomass estimated was for EP1 (2.2 tonnes.ha^{-1}).

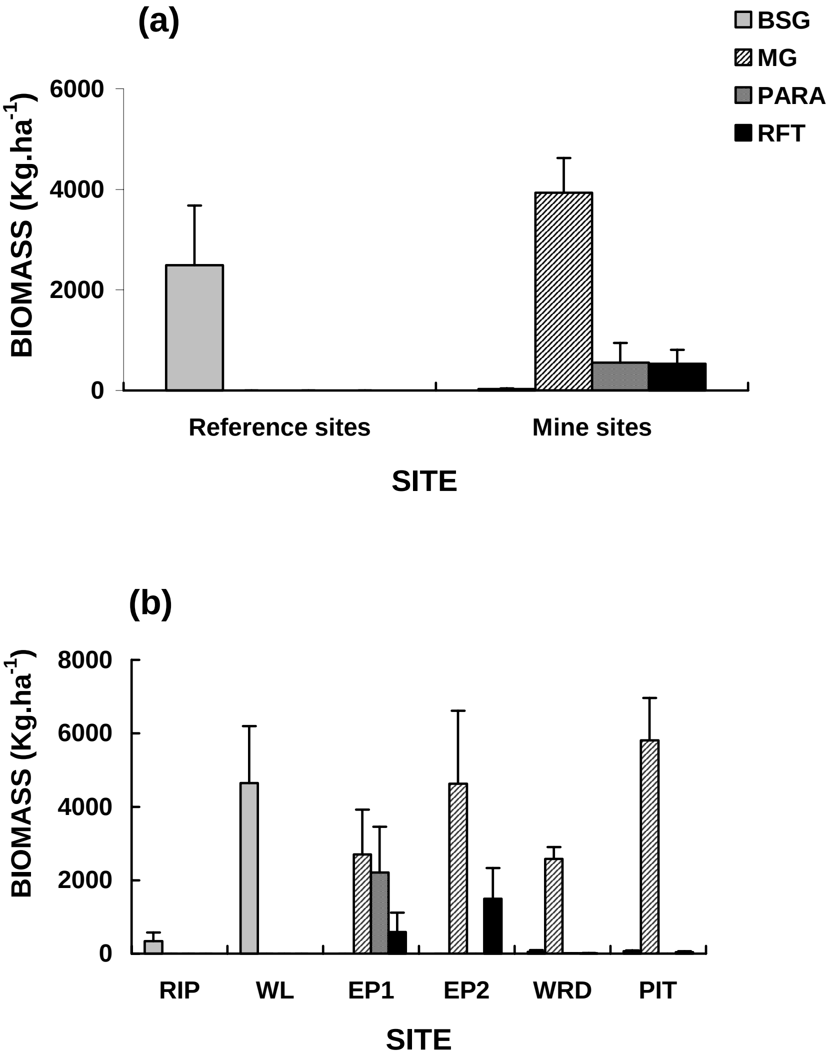
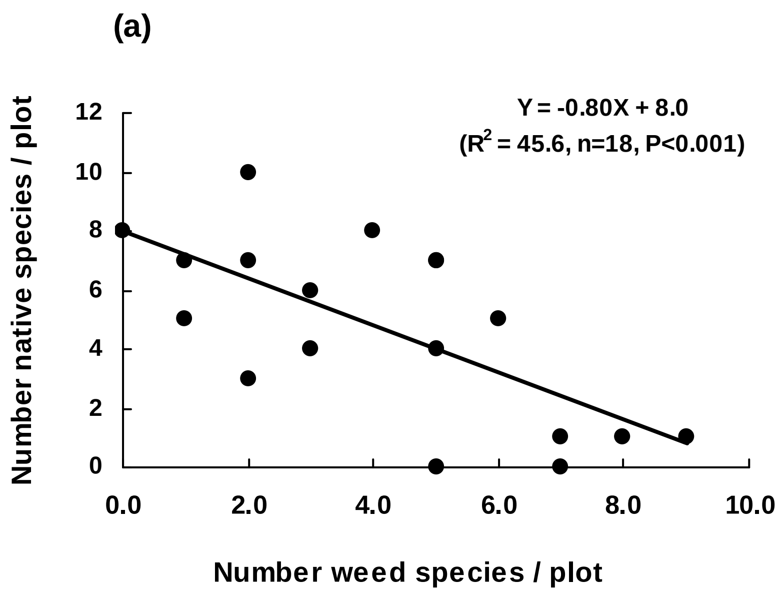


Figure 17a & b Comparison between mean biomass (kg.ha^{-1}, ODW) of four dominant grass species for (a) Reference sites and Mine sites, and (b) all Sites. WRD Waste Rock Dump; PIT Mine Pit; EP1 & EP2 Evaporation Pond 1 & 2 respectively; BSG (Black Spear Grass comprise two species, *Heteropogon triticeus* for WL & *Heteropogon contortus* for all other sites); MG (Mission Grass comprise both the perennial & annual species, *Pennisetum polystachion P. pedicellatum* respectively); PARA (Para Grass, *Urochloa mutica*); RFT (Rhodes Feather Top, *Chloris virgata*). The mean biomass of 3 x 0.01ha plots/transect were first derived, and then averaged across the 3 transects/site. Vertical lines are standard errors. Nabarlek, September 2003.

4.1.2.4 Key plant relationships

Across all sites and plant types (grasses, herbs & sedges) there was a significant negative relationship between the number of native ground cover species and the number of weed species found on transect plots (Fig. 18a): the more weed species the less native species.

Although the relationship is only correlative, it nevertheless suggests that weeds may exclude native species on the minesite. A similar relationship was found between the cover of weeds and natives in transect plots (Fig. 18b).



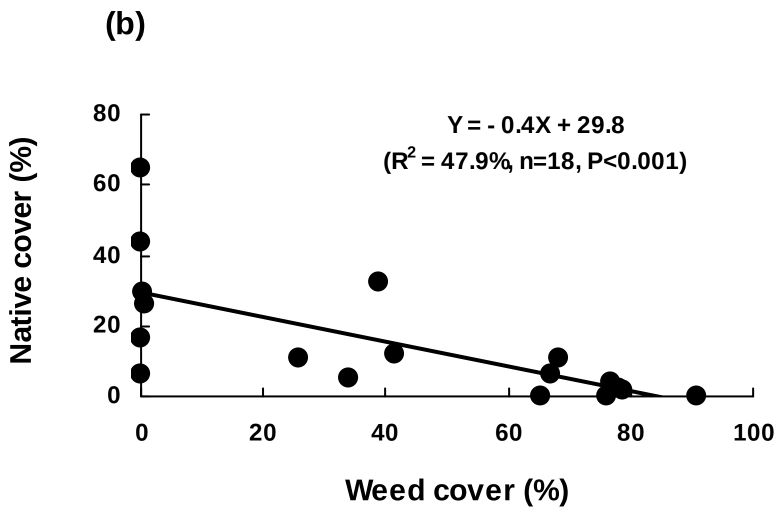


Figure 18 a & b The negative regression relationship between (a) the number of native and weed species found in plots across all sites, and (b) the cover of native and weed species found in plots across all sites. Mean cover values (%) of 3 x 0.01ha plots/transect were first derived, and then averaged across the 3 transects/site. Nabarlek, September 2003.

Additionally, a negative linear relationship was found in transect plots between the percentage ground cover of weeds and the total density of trees and shrubs (Fig. 19), but only when one outlier was excluded. Data from Transect 6 of EP1 are excluded from analysis because it is the only location with the co-occurrence of high Para grass (~90% cover) and Melaleuca abundance. Similar co-occurrences are found on the Magela floodplain and Mary River wetlands. Although this relationship is also only correlative, it nevertheless suggests that, with the exception of Para grass, weed abundance could be suppressed on the minesite by successful succession from shrub-grassland to woodland or forest. Para grass may require continual intervention control *ad infinitum.*

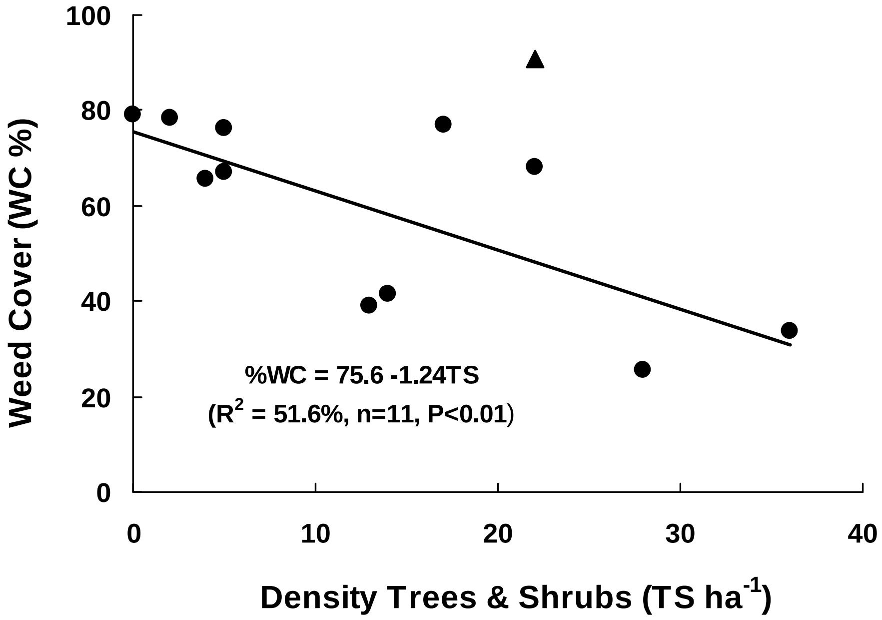


Figure 19 The negative relationship between ground cover (%) of weeds and the total density (ha^{-1}) of trees and shrubs. Mean attribute values of 3 x 0.01ha plots/transect were first derived, and then averaged across the 3 transects/site. Data from Transect 6 of EP1 is excluded from analysis (triangle), representing the co-occurrence of the highest cover of Para grass (90%) and density of Melaleuca trees (see text). Nabarlek, September 2003.

4.1.2.5 Litter, rocks & bare ground

There was a significant correlation between the mean percentage cover of logs and sticks (R=0.900, n=18, P<0.001) and, hence, their values were added. There were no significant differences between sites and the cover (% cover/0.01ha plot/transect) of bare ground ($F_{5/12}$ = 1.99, NS), litter ($F_{5/12}$ = 1.66, NS) and logs-sticks ($F_{5/12}$ = 1.71, NS). However, in contrast, there was a significant difference between sites in the cover of exposed rocks ($F_{5/12}$ = 4.90, P<0.011): there was 22 times more rock cover on Mine sites than on Reference sites ($F_{1/6}$ = 6.96, P=0.017; Fig. 22a). Within Mine sites, most exposed rocks were found on the PIT and WRD sites (Fig. 22b).

4.1.2.6 Seedling density & size structure

All woody seedlings were recorded in the 50 x 1m^2 transects. Substantial numbers of woody plants that were less than 10 cm high and that were not reports were observed on the Reference sites (RIP: 49 $\pm$ 23 SE seedlings per transect; WL: 13 $\pm$ 6 seedlings per transect). No woody seedling species (non-resprouting plants < 10 cm high) were found in the 50 x 1 m^2 transects at any of the EP1, EP2, PIT or WRD sites. At both Reference sites at least six species were identified based on leaf morphology, and the number of species could be greater if eucalypt seedlings that appeared similar were actually different species.

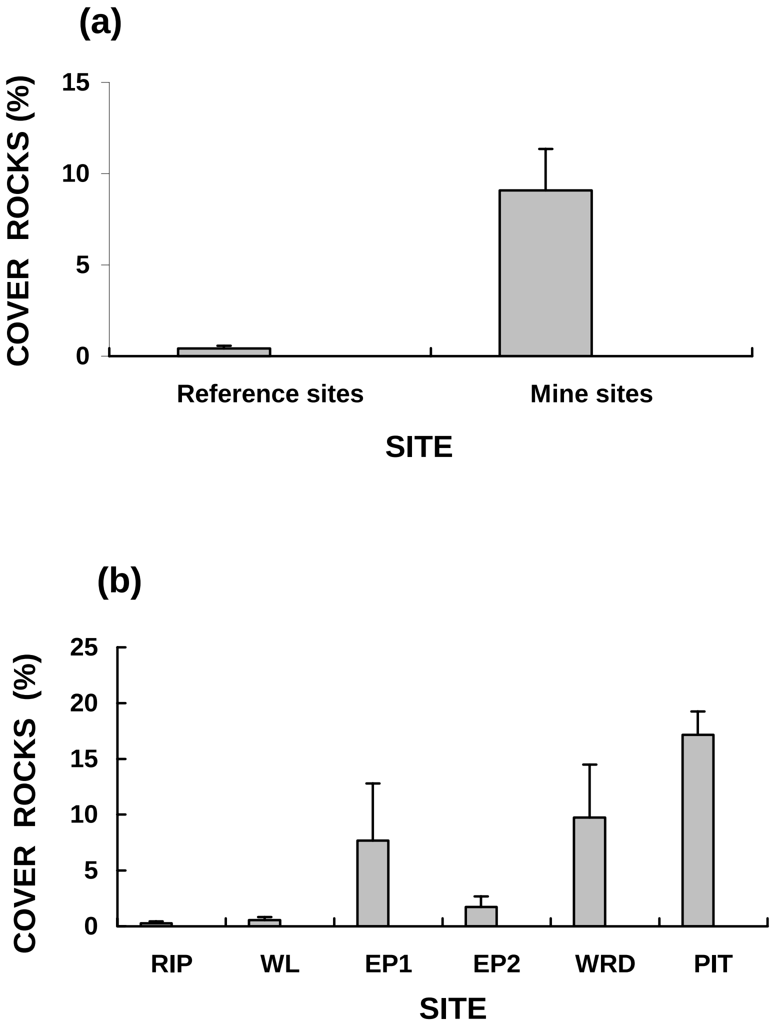


Figure 20 a & b Comparison between mean Rock cover (%) for (a) Reference sites and Mine sites, and (b) all Sites. RIP Riparian woodland; WL Eucalyptus dominated woodland; WRD Waste Rock Dump; PIT Mine Pit; EP1 Evaporation Pond 1; EP2 Evaporation Pond 2. The mean cover of rocks in 3 x 0.01ha plots/transect were first derived, and then averaged across the 3 transects/site. Nabarlek, September 2003.

4.2 Soil properties

With respect to most soil properties the two Reference sites were similar, the two Evaporation Pond sites were similar, and the Waste Rock Dump and the Pit sites were similar (Appendix 9.9). T-tests were carried out to compare these pairs sites (Table 5). Evaporation Pond 2 had higher (t-test, 2 tailed, equal variance; n=3, df =5, $p<0.05$) manganese, sodium, copper and iron concentrations and a higher cation exchange capacity (CEC). The Waste Rock Dump and Pit sites had similar soil characteristics. The only significant differences were that the Pit site had higher sodium and chloride concentrations (t-test, 2-tailed, equal variance; n=3, df =5, $p<0.05$). The two Reference sites differed in that the Woodland site had higher organic carbon, slightly higher potassium, slightly lower chloride, higher manganese, lower iron and a higher Ca:Mg ratio than the Riparian forest site (t-test, 2 tailed, equal variance; n=3, df =5, $p<0.05$). However, in most attributes the pairs of sites were similar so in Table 5 the average values for the six transects on Reference sites, the six Evaporation Pond transects and the six transects from the other rehabilitated areas are presented.

Table 5 Comparison of soil properties of the unmined reference sites, evaporation pond rehabilitation sites and the waste rock dump/pit (WRD/Pit) rehabilitation sites. See Appendix 9.5 for details of chemical tests. Nabarlek, September 2003. (One way ANOVA; Grouping: RIP & WL, EP1 & EP2, WRD & Pit; n = 6, df. = 17) (Post hoc Tukey's test, p<0.05, the same letter in two columns indicates that the means of those columns are not significantly different).

	Unmined		Evap. Pond		WRD/Pit		1 way ANOVA	Tukey's test
	Mean	stdev	Mean	stdev	Mean	stdev	P value	
pH (1:5 Water)	6.2	0.1	6.2	0.1	6.1	0.2	0.604	
pH (1:5CaCl2)	5.6	0.1	5.7	0.2	5.6	0.3	0.504	
Organic Carbon %	1.1	0.6	2.6	1.0	1.4	0.7	0.006	a b a
Nitrate mg/kg	0.8	0.3	4.0	6.6	2.7	3.1	0.444	
Phosphorus (Colwell) mg/kg	< 5	-	15.4	10.8	13.6	5.1	0.045	a b ab
Sulfate mg/kg	3.1	0.5	21.2	14.2	9.0	8.5	0.015	a b ab
Potassium Meq/lOOg	0.09	0.04	0.45	0.12	0.20	0.04	0.000	a b a
Calcium Meq/lOOg	2.7	1.0	10.1	5.6	1.3	0.4	0.000	a b a
Magnesium Meq/lOOg	0.9	0.3	9.2	5.8	5.8	2.4	0.004	a b ab
Sodium Meq/lOOg	0.03	0.02	0.08	0.05	0.03	0.01	0.013	a b a
ESP %	1.2	1.4	0.4	0.1	0.4	0.1	0.222	
C.E.C. Meq/lOOg	4	1	20	11	7	3	0.002	a b a
Ca:Mg Ratio	3.3	1.4	1.2	0.3	0.2	0.1	0.000	a b b
Chloride mg/kg	9	1	22	8	15	9	0.023	a b ab
E.C. dS/m	0.03	0.00	0.10	0.04	0.05	0.02	0.001	a b a
E.C. (Sat.Ext) dS/m	0.4	0.1	1.1	0.5	0.6	0.2	0.001	a b a
Manganese mg/kg	47	32	103	9	15	7	0.000	b c a
Iron mg/kg	28	15	104	48	53	40	0.010	a b ab
Copper mg/kg	0.5	0.2	2.5	1.1	0.7	0.5	0.000	a b a
Zinc mg/kg	0.3	0.2	1.1	0.3	0.6	0.3	0.000	a b ab
Boron mg/kg	0.2	0.0	0.4	0.1	0.2	0.1	0.004	a b a

The soil pH was slightly acid and very similar at all the sites. In most of the other attributes the Evaporation Pond sites varied considerably from the unmined sites and the Waste Rock Dump and Pit sites were intermediate or similar to the unmined sites. Soil organic carbon was 2.5 times higher in the evaporation pond soil than at the unmined sites. Soil organic carbon provides cation exchange sites and the CEC was also higher at the Evaporation Pond sites.

Of the major nutrients, nitrate concentrations were consistently low in the soil from the unmined sites but highly variable at the rehabilitation sites. Phosphorus levels were not detectable in any of the soil samples from the unmined transects (< 5 mg/kg). They were significantly higher in the soil samples from the Evaporation Pond transects with a mean value of 15 mg/kg and levels as high as 29 mg/kg at two of the transects. Sulphate and potassium levels were also higher at the evaporation pond sites that at the unmined sites with average concentrations being 7-fold and 5-fold higher.

Most other cations and metals (calcium, magnesium, sodium, iron, copper, zinc, boron) were all in significantly higher concentrations in the evaporation pond soil samples than in soil samples from the unmined site (Table 5). Manganese concentrations were similar between the

WL site and the evaporation pond sites, and similar between the RIP site and the other rehabilitation sites (Appendix 9.4 and 9.5). The WRD and PIT rehabilitation areas had similar levels of calcium, sodium and copper to the unmined sites and had concentrations of magnesium, iron and zinc that were intermediate between those of the evaporation pond and unmined site samples.

Chloride and electrical conductivity (EC) values were higher in the evaporation pond soil samples but the highest EC values at any transect was only 0.15 dS/m (Appendix 9.4). The exchangeable sodium percentage of cations (ESP) was similar at all sites and 1.2% or less. The ratio of calcium to magnesium cations was low at the WRD and PIT sites and significantly higher in the unmined soils.

Metal concentrations in the soil were also measured using a harsh concentrated nitric and perchloric acid digest. The acid extractable concentrations of magnesium, lead, thorium and uranium were all elevated in the soil samples from the mine rehabilitation areas (Table 6). However, although the magnesium levels were extremely high in the evaporation pond sites much of this magnesium is not immediately available to plants. The exchangeable magnesium in the Evaporation Pond soils averages 1,119 ppm, whereas the acid extractable magnesium at those sites averages 15,107 ppm.

Table 6 Summary of t-tests comparing soil metal properties between Reference sites and Mine sites. Bold text highlight significant differences. See Appendix 9.6 for details of metal tests and measurement units. Nabarlek, September 2003.

	T-tests; Grouping: Reference sites cf Mine sites Group 1: Reference Group 2: Mine								
Variable	Mean 1	Mean 2	t-value	df	p	Valid N 1	Valid N 2	Std.Dev. 1	Std.Dev. 2
Mg	**515.9**	**29228.3**	**-4.141**	**16**	**0.001**	**6**	**12**	**226.5**	**16725.0**
Mn	649.1	492.9	0.715	16	0.485	6	12	542.4	379.2
Pb	**6.0**	**15.9**	**-2.691**	**16**	**0.016**	**6**	**12**	**2.8**	**8.7**
Th	**3.5**	**14.8**	**-3.506**	**16**	**0.003**	**6**	**12**	**1.5**	**7.7**
U	**1.6**	**135.9**	**-2.716**	**16**	**0.015**	**6**	**12**	**0.7**	**119.3**

4.3 Soil-plant relationships

Table 7 summarises the results of the Factor Analysis, highlighting significant variable loadings in the first two Principle Components (factors) of both the vegetation and soil axes. Soil Nitrogen and pH do not make important contributions to either of the soil PCs. Lead and Thorium make important positive contributions to the soil PC2 only. All other soil variables make important positive contributions to the soil PC1. Hence, poor soils have positive PC1 values. The cover of weeds makes an important negative contribution to the vegetation PC1 axis and, in contrast, all canopy-related attributes make significant positive contributions with the exception of shrub height, which makes a positive contribution to the vegetation PC2 along with the cover of sticks. Hence, with respect to the vegetation PC1, positive values reflect good vegetation characteristics with the best conditions found on Reference sites.

The PC1 vegetation factor scores (Y) for each transect were plotted against corresponding PC1 soil factor scores (X), and the scatter examined for structure. In essence, the ordination plot characterises soil-plant relationships for all sites along a successional gradient, ranging from “poor vegetation-poor soil” sites found on the Evaporation Ponds areas to “good vegetation-good soil" sites found on reference or analogue areas. Note that the multivariate soil-plant space "good vegetation-poor soil" does not, nor should not, exist. Results show that all Mine sites lie along a successional trajectory, in terms of soil and vegetation development, towards the natural Reference sites. The gradient reflects significant site differences in soil and plant condition (Fig. 21a). Although sites are variable, EP2 has the poorest soil development factor score and, hence, poorest vegetation condition in comparison to Reference sites (i.e. they are the least successful). The best Mine sites in terms of soil and vegetation development (& hence revegetation success) are the WRD sites followed by the Pit sites. Somewhere between the two lies EP1.

Most of the variance in the vegetation PC1 is explained by total canopy cover and tree density (R^2 ~ 80% for both, see Fig 22a&b). Both tree density and total canopy cover have zero values at a vegetation PC value of -1.0. Weed cover was also a significant but negative contribution to the vegetation PC axis, and the relationship is nonlinear and so it's effect may be underestimated in this model (Fig. 22c): a threshold vegetation PC value exists for weeds, all mine sites had extensive weed cover and so had negative PC values and, in contrast, all reference sites with zero to trace amounts of weed cover had positive values. The most significant and positive contributions to the soil PC axis were the levels of nutrients and salts in the soil, reflected in soil EC values (Fig. 22d): in general mine sites had very high salt and nutrient levels, clustered between soil PC values of -0.5 to -1.0.

In summary, a useful rapid and cost-effective means of measuring total canopy cover, such as remote sensing captures, may provide a useful complementary tool to help monitor revegetation success. Nevertheless, ground-based vegetation surveys are still required, but because of large sampling errors associated with under sampling variable mine sites, perhaps less frequently.

5 Discussion

5.1 Rehabilitation objective & indicators for revegetation success

The original goal of the Nabarlek revegetation program was to return mined areas "to a self sustaining woodland community that blends in with the surrounding environment" (Prendergast et al 1999). Hence, given the emphasis on "woodland, self-sustaining and blending", appropriate revegetation success indicators could include the following:

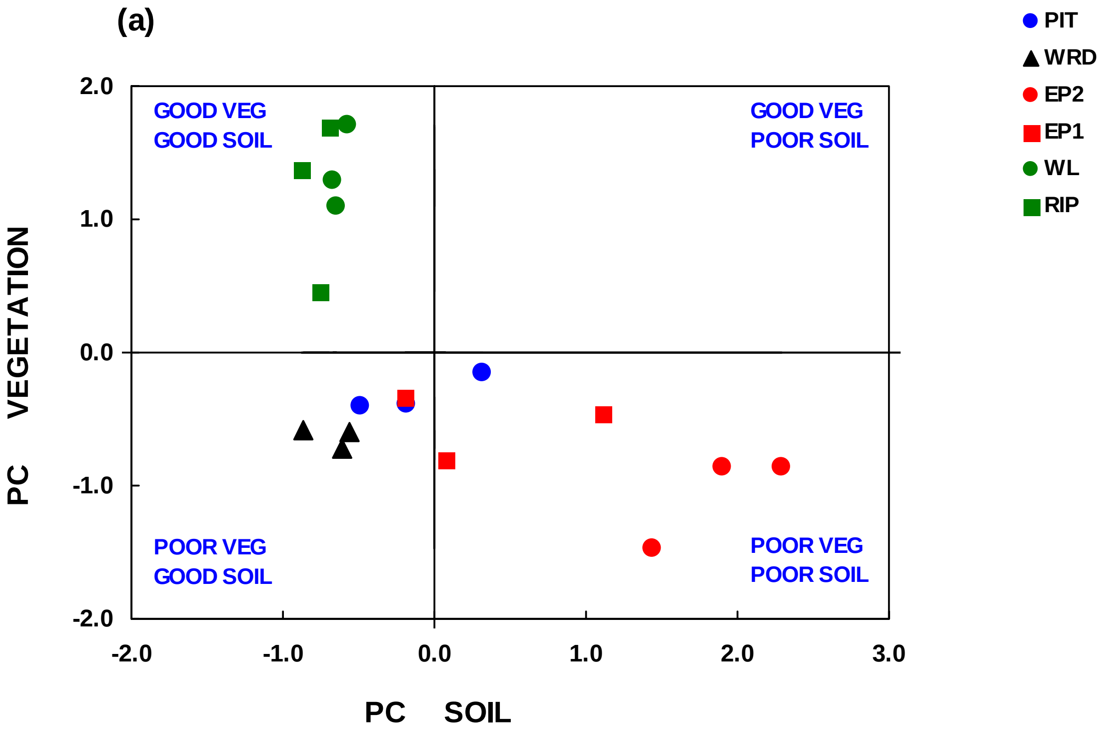
- The density of trees (> 2m height) and shrubs (>0.1m & <2m height) with a size distribution and species composition reflecting trajectory towards analogous woodland (riparian or eucalyptus dominated).
- The vigour, health, rates of growth or productivity of canopy species (indexed by rates of change of dbh or height).
- The density of mature trees in relation to time since revegetation.
- The density of woody seedlings (<0.1m height) and saplings (tree shrubs) as an index of tree recruitment.
- Native species richness and abundance of canopy and ground cover species.
- The absence or low occurrence of weeds.
- Fuel load (biomass) as an index of fire risk.

- An array of chemical and physical soil condition indices related to soil development and nutrient cycling.

Table 7 Summary of variable loadings for Factor Analysis of vegetation characteristics and soil properties. Loadings with bold highlight > 0.70. Varimax rotation used, PC1 and PC2 are Principle Components 1 and 2 respectively. Nabarlek, September 2003.

SOIL			VEGETATION		
Variable	**PC 1**	**PC 2**	**Variable**	**PC 1**	**PC 2**
pH	-0.274	-0.678			
OC%	**0.898**	0.094			
Nitrogen	0.589	0.452			
Sulfate	**0.829**	0.292	Cover natives	0.687	0.136
P	**0.701**	0.575	Cover weeds	**-0.885**	0.080
K	**0.924**	-0.024	Bare ground	0.482	-0.260
Ca	**0.921**	-0.246	Litter	-0.370	0.281
Mg	**0.863**	0.339	Logs	0.083	0.781
Na	**0.883**	-0.018	Sticks	-0.085	**0.877**
Cl	**0.707**	0.122	Rocks	-0.479	0.352
EC	**0.933**	0.168	dbh	**0.834**	-0.091
Cu	**0.926**	0.005	Cover trees	**0.860**	-0.026
Zn	**0.843**	0.190	Cover shrubs	**0.778**	0.162
Mn	**0.706**	-0.523	Density trees	**0.827**	-0.075
Pb	0.007	**0.895**	Density shrubs	**0.889**	-0.135
Th	-0.114	**0.857**	Height trees	**0.757**	0.160
U	**0.740**	0.590	Height shrubs	0.006	**0.780**
Explained V	9.635	3.500	**Explained V**	5.953	2.367
Prop Total	0.567	0.206	**Prop Total**	0.425	0.169

Although all vegetation and soil characteristics are intercorrelated to varying degrees, the ordination model shows that differences between sites may reflect different stages of successional development (or lack of successional development) towards analogue conditions. If so some Mine sites (e.g. EP2) appear to have developed inertia along the successional trajectory pathway, most likely due to a combination of factors such as poor soil development due to waterlogging and mine-reflated chemicals such as salts, and poor vegetation development due to the occurrence of fire, weeds or lack of early tree establishment. Nevertheless, with respect to choice of indicators of revegetation success, our preliminary results suggest that most of the success indicators listed above would be reflected in the extent of native canopy and ground covers (see below).



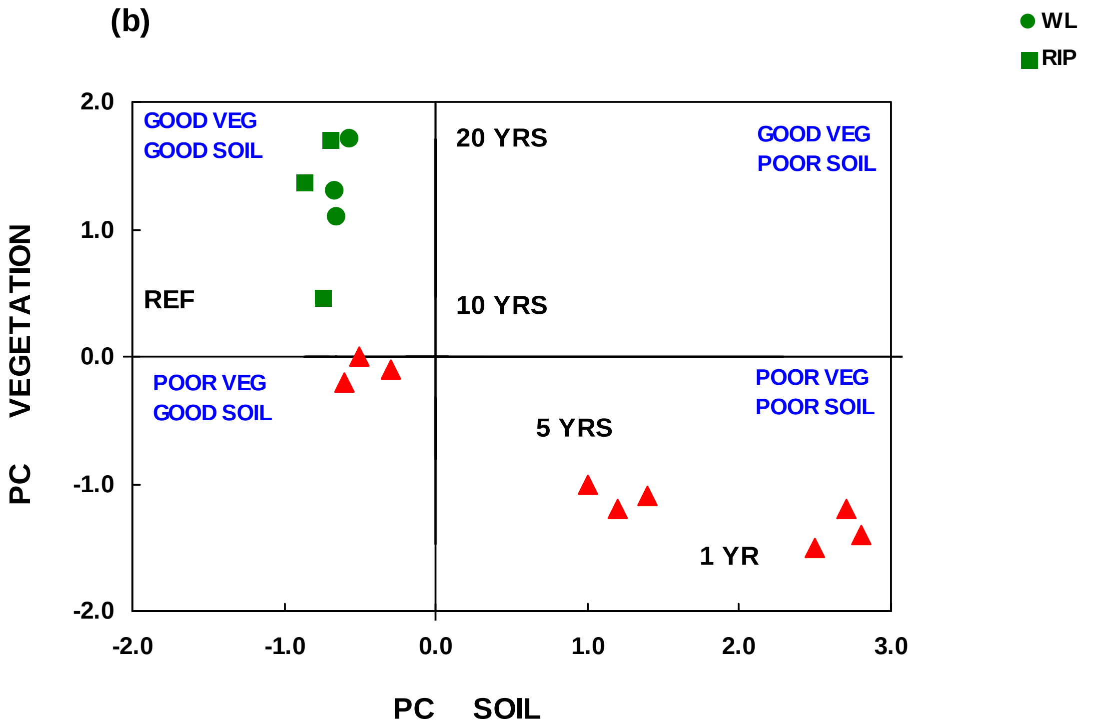


Figure 21 a & b. (a) Ordination (Factor Analysis) of plant-soil relationships across all sites/transect. The Vegetation PC axis is the 1st Principle Component (PC) after varimax rotation and, similarly, for the Soil PC. REF is Reference or analogue site. Tree density is zero where Vegetation PC = -1.0. (b) Hypothetical model showing succession trajectory of rehabilitated mine sites towards analogue conditions after 1, 5, 10 and 20 years, and associated soil-plant characteristics. Sites may have progressed at different rates since revegetation because of inherent variation in site conditions.

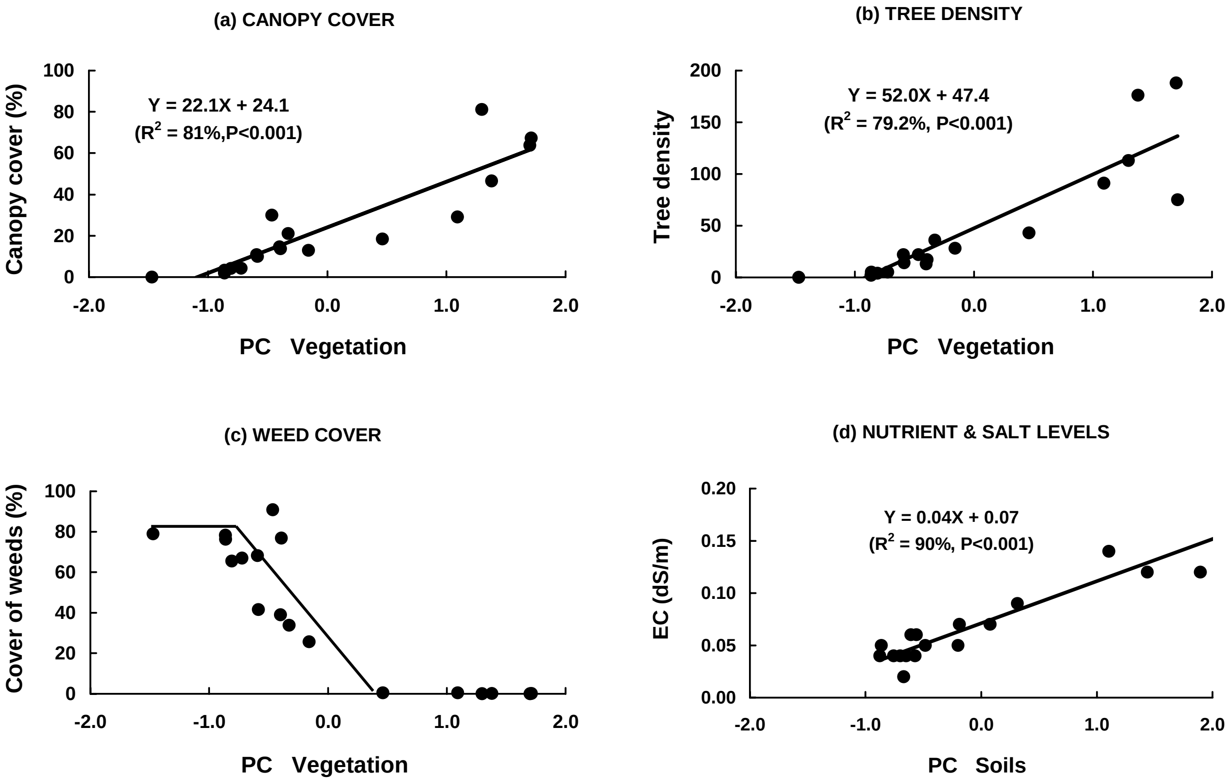


Figure 22 a-d Regression relationships between the Vegetation PC axis and: (a) canopy cover (mean % cover/0.01ha plot/transect); (b) tree density (mean numbers/plot/transect); (c) weed cover (mean % cover/plot/transect); and (d) between the Soil PC axis and nutrient and salt levels reflected in EC values (dS/m, mean/transect from three subsamples). Nabarlek, September 2003.

5.2 Development of monitoring methods

Rehabilitation success has been monitored largely in the past by following vegetation development using traditional quantitative measures of soil and plant characteristics. This approach relies on plant composition data and an array of soil property measures as indicators of successful revegetation. However, Tongway (2000) argues that these methods are uninformative with respect to assessment of critical ecosystem processes and functions. He suggested using Ecosystem Function Analysis (EFA) as an alternative method to monitor and assess ecosystem rehabilitation success. EFA was originally developed for assessment of rangeland condition over vast areas, is well described in the literature, and has generated much debate about it’s role in assessing rehabilitation of mine sites that encompass much smaller areas than continental landscapes (Corbett 1999). EFA incorporates the following three components to compare indicator values of rehabilitated sites with analogue or reference sites, and which Tongway et al (1997) argue can be used to track ecosystem development trajectories: (1) Landscape Function Analysis (LFA); (2) Vegetation development; and (3) Habitat complexity. The backbone of the EFA methodology is the LFA; it is a rapid field procedure that assesses a site in terms of the distribution, regulation and use of vital resources such as water and nutrients. The following soil and water indicators are used in LFA: (1) soil stability; (2) infiltration; and (3) nutrient cycling. Tongway (2001) argues that these LFA indicators reflect a wide range of physical, chemical and biological processes, that can all be related to the species composition and growth rates of vascular plants, and to the development of ecological niches for fauna. However, despite the above attractions, the method has been much criticised because of its qualitative nature and, hence, likely inconsistency between observers. The most significant criticism is that generic assessment models may have little role for rehabilitated mine sites that often require more comprehensive, detailed, site-specific knowledge obtained by direct measurement. Hence, no further validation of the methodology is warranted at Nabarlek because direct measurement of soil and vegetation characteristics are now available to assess revegetation success.

As stated in the previous Section (5.1), most indicators of revegetation success may ultimately be reflected in the extent of native canopy cover, itself correlated to stand density. Most of the variance in the vegetation component of the multivariate model used to assess revegetation success was explained by either tree density or total canopy cover (R^2 ~ 80% for both). This suggests that a rapid and cost-effective means of measuring total canopy cover from high resolution remote sensing images may provide a powerful complementary tool to help monitor revegetation success at "whole of landscape scales" and at more regular intervals. Nevertheless, even if many of the ground-based revegetation success indicators can be teased out of satellite images, such as the biomass of grassy weeds and the cover and height of dominant canopy species, detailed ground surveys are still necessary to obtain a matrix of attributes for robust characterisation. For example: the species composition and structure of vegetation, particularly for reference sites; longitudinal data on growth and survival rates of canopy species; information on new weed introductions that are initially at low occurrence and so difficult to detect even from high resolution satellite images; and key soil properties. However, detailed ground surveys may only need to be undertaken at critical benchmark time intervals after commencement of revegetation (e.g. annually for the critical first 1-5 years and then at the 10y, 15y and 20y marks). Remote sensing and ground survey methods, therefore, are not mutually exclusive but complementary parts of the monitoring and assessing process.

5.3 Characterisation of vegetation & soils on Nabarlek & adjacent reference sites

5.3.1 Soils

There is no indication that the mining rehabilitation process has affected the soil pH, it is in a favourable range for plant growth and is the same as the surrounding soils. At this pH aluminium toxicity would not be an issue.

The Evaporation Pond sites are tending to retain nutrients, and nutrient and salt levels are generally higher than at the other sites, reflected in their EC levels. The unmined sites, WRD/PIT sites and EP sites had mean EC values of 0.03, 0.05 and 0.10 dS/m respectively (Table 5), levels unlikely to impact on plant growth. However, soil salinity levels may exhibit seasonal trends and, hence, these results will be re-examined as part of the CDU Honours project.

Nitrate levels are extremely low in all of the soil samples as even a level of 500 mg/kg is considered very low in an agricultural soil (Bruce & Rayment, 1982). However nitrogen may also be present in other forms and may be bound in organic matter and microbial biomass. In the unmined vegetation soil phosphorus at less than 5 mg/kg is also deficient for plant growth and would be limiting growth. Much of the P at these sites would be bound into the living vegetation. The phosphorus levels at the rehabilitated sites are still low but would be adequate for many species (Landon 1991). The higher levels of phosphorus in the Evaporation Pond sites in particular may be a factor in encouraging growth of grasses and legumes. Exchangeable potassium was very low in the native vegetation but moderately available in the rehabilitation area soils (Bruce & Rayment 1982). Sulphate was very low in the unmined vegetation, highly available in the evaporation pond soil and low to medium in the soils of the other rehabilitation sites.

Calcium levels were high (> 10 mg/kg; Landon 1991) in the evaporation pond and low at the other sites. The Ca:Mg ratio can also be important, an imbalance can result in phosphorus, manganese or calcium deficiency. A level of 3 to 5:1 is the normal range, the very low ratio in the WRD and PIT sites could result in possible phosphorus and calcium deficiency. Magnesium is moderately available at the unmined site but present at high concentrations (> 4 mg/kg; Landon 1991) at the rehabilitation sites. Iron concentrations would not limit plant growth. Manganese levels of greater than 50 mg/kg are considered high and manganese can be toxic but this tends not to be a problem when the soil pH is above 5.5 (Landon 1991). Zinc availability is low at the unmined sites and moderate at the other sites (Bruce & Raymont 1982). Copper availability is moderate in all of the sites (Bruce & Rayment 1982). Boron concentration is very low in all of the soil samples (Bruce & Rayment 1982).

If a high proportion of the cations consisted of sodium ions this can result in poor soil structure, however the exchangeable sodium percentage was low at all of the sites. Chloride concentrations were also low and would not directly affect plant growth.

Soil organic matter is important for providing cation and anion exchange sites and thus assisting to retain nutrients in the soil. It was low in the unmined, WRD and PIT sites but was high in the evaporation pond soils (Bruce & Rayment, 1982). Organic matter, along with the clay composition of the soil is important in providing cation exchange capacity in the soil and retaining cation nutrients. The CEC of the soil from the unmined sites was very low, the Evaporation Pond sites was moderate and the other rehabilitation sites had low CEC.

5.3.2 Vegetation

Vegetation characteristics on Eucalyptus woodland and Riparian forest reference sites adjacent to the minesite reflected natural local environmental conditions (e.g. soil, topography, hydrology & fire history). Our reference or analogue sites were used to compare the success of vegetation development on rehabilitated areas across the minesite. Examination of the Quickbird remote sensing capture (September 2003) indicates that our reference sites typify the surrounding landscape and, are in “healthy” condition themselves (i.e. basically weed free). Overall, 49 canopy species were recorded (including 10 *Eucalyptus* and *Corymbia* spp, two *Melaleuca* spp, *Pandanus spirolis* and 11 *Acacia* spp), and 85 ground cover species. Of the latter, 41 (44.2%) were grasses, 43 herbs (50.6%) and 4 (5.2%) sedges. Of the grasses, 15 species (36.6%) are classified as weeds, and that for herbs 19 (44.2%). No weed sedges were recorded. Overall, ground cover comprised 40% weed species, nearly all occurring on the minesite: small amounts of herb weeds were found on the Woodland site, and no grass weeds were found at either reference site.

Reference sites had: twice as many canopy species; 13 times more trees which were twice as tall and thick; 3.5 times more shrubs; and 5 times more canopy cover. The regression relationships developed to predict the density of trees and shrubs from their canopy cover (%) estimated from ground surveys may be used to indirectly estimate stand density from estimates of canopy cover made from remote sensing captures, and this will be explored further.

Ground cover vegetation on reference sites and mine sites were also characterised and compared. About 2.5 times more native species were found on Reference sites than on Mine sites, and 4.8 times more weed species were found on Mine sites. No grass weeds were found on Reference sites, which had twice as many native grass species than did Mine sites. Mine sites had twice as many weed grass species than native grass species. Similar results were found for herbs. In contrast to Reference sites, Mine sites had twice as much ground cover of grasses and similar covers of herbs and sedges. However, Reference sites had 4.4 times more ground cover of native species than Mine sites and, in contrast, Mine sites had 310 times more weed cover than Reference sites. No grass weeds were found on Reference sites and, in contrast, Mine sites had on average 46.7% cover of grass weeds. Mine sites had 61 times more herb cover than Reference sites, but Reference sites had 12 times more native herb cover than Mine sites.

Mine sites had twice as much biomass of grasses than Reference sites, 21 times more biomass of herbs and similar amounts of sedges. Grasses contributed most to ground cover biomass and comprised four dominant species: native Black Spear grass (two species; *Heteropogon triticeus* for Eucalyptus woodland & *Heteropogon contortus* for all other sites); Mission grass weed (comprising both the perennial & annual species, *Pennisetum polystachion* & *P. pedicellatum*, respectively); Para grass weed (*Urochloa mutica*); and Rhodes Feather Top weed (*Chloris virgata*). Although there were similar amounts of grass biomass between Reference sites and Mine sites, there were extreme differences in the contributions from native and weed species. Reference sites had similar biomasses of native Back Spear grass, although from two different species (2.5 $t.ha^{-1}$). In contrast, Reference sites had 90 times more native Black Spear grass biomass than Mine sites and no grass weeds. On Mine sites Mission grass had the most biomass (3.9 $t.ha^{-1}$), followed by Para grass and Rhodes Feather Top grass with similar biomasses (0.5 $t.ha^{-1}$). These biomass estimates are comparable to estimates derived for the same or similar species in other localities (e.g. Cull & Ebersohn 1969, Butler & Fairfax 2003, Douglas & O'Connor in press).

There were no differences in the cover of litter, bareground, logs and sticks between Reference and Mine sites, suggesting that soil organic carbon should not be a limiting factor to plant growth. In contrast, however, there was 22 times more rock cover on the minesite than on Reference sites, mostly on the Pit and Waste Rock Dump sites.

The negative correlation found between the number of native ground cover species and the number of weed species across all sites underpins the contrast between the natural analogue sites and the minesite in terms of vegetation condition. However, with the exception of Para grass and paperbark trees, the negative correlation found between the ground cover of weeds and the total density of trees and shrubs on the minesite, in combination with much experimental research, suggests that weeds could be eventually suppressed by successful succession of vegetation from shrubland-grasslands to woodland.

There was substantial seedling establishment in the unmined native reference sites with many woody shrub and tree species represented as seedlings. However, seedling densities of woody species were considerably less on the rehabilitated minesite. This suggests that woody plant density is unlikely to increase in the short term and may well decrease as a result of woody plant losses due to fire.

All results are summarised in Figure 23 (less the presence/absence results for woody seedlings). Basically, for revegetation to be assessed as being successful, the minesite vegetation would now need to be dominated by a lot more mature trees and a lot less weeds.

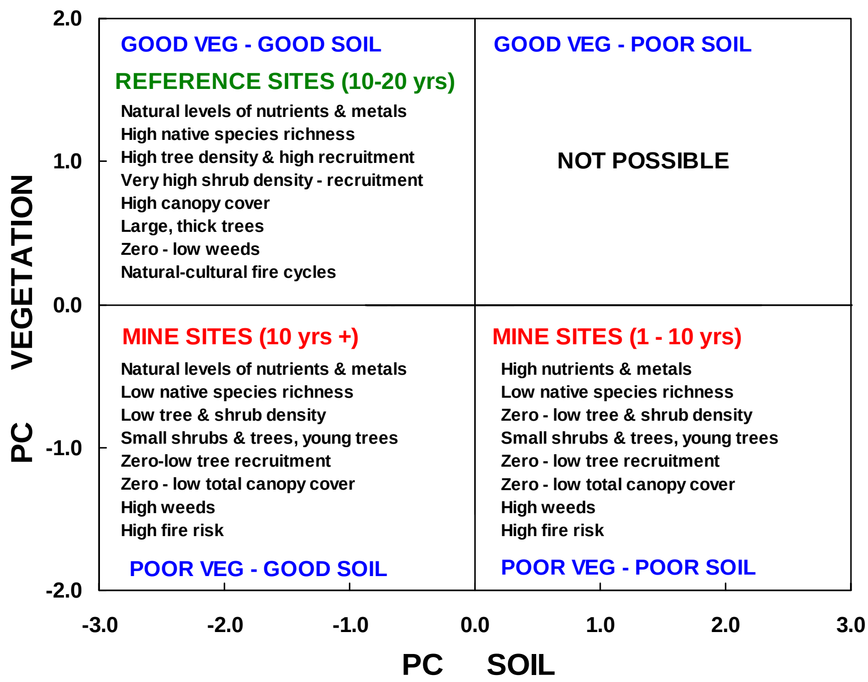


Figure 23 Vegetation and soil characteristics associated with the hypothetical Principle Components model (Fig. 22b), showing a possible successional trajectory pathway of the rehabilitated mine sites towards analogue conditions after 1, 5, 10 & 20 years.

5.3.3 Soil-plant relationships

A multivariate statistical model was developed to explore soil-plant relationships across all sites as a tool to help simplify and assess revegetation success, whilst still using all complex intercorrelated soil and plant attribute variables. All Mine sites sampled lie along a successional trajectory, in terms of soil and vegetation development, towards the natural Reference sites. The graphical model characterises soil-plant relationships for all sites, ranging from "poor vegetation-poor soil" sites to "poor vegetation-good soil" sites on the minesite, towards "good vegetation-good soils" sites that characterise reference sites. Although eight years has elapsed since Nabarlek was revegetated, half the mine sites sampled in September 2003 were classified as "poor vegetation-poor soil" sites according to the model and, hence, unsuccessful with respect to revegetation success. Although the other half of mine sites were classified as "good soil-poor vegetation sites", they may remain classified as such because of poor vegetation development (i.e. low tree density, intermediate shrub density, high weed biomass & cover, high fire risk). To break free and cross the threshold to self-sustaining vegetation communities analogous to reference sites would likely require significant management intervention. It should be emphasised, however, that whilst this model is encouraging in terms of reducing the complexity of assessing revegetation success, it can only highlight key hypotheses to test by well-designed experiments.

However, additional wet season data are needed to enhance this model. Such data will include information on proneness to water logging, additional species phenology data, the canopy cover of deciduous trees, another sample of woody seedlings and, will likely include many annual ground cover species not recorded in the dry season.

5.4 Predicting successional processes

No disturbed sites in the Alligator Rivers Region have been systematically revegetated, assessed and monitored over decadal time scales and, hence, there is little knowledge with which to predict vegetation succession at Nabarlek. Additionally, the literature offers little guidance as to what succession model to use on rehabilitated sites in general. Nevertheless, there is knowledge and experience gained from revegetation efforts on other minesites in northern Australia (e.g. Weipa), spanning decades, and which may be applicable to Nabarlek and Ranger. For example, the most successful (or least unsuccessful) revegetated sites on Nabarlek are the Pit and Waste Rock Dump areas: they appear to have reasonable shrub cover and a few more trees than other parts of the minesite. Nevertheless, by today's standards after eight years, tree density and seedling recruitment would be classed as insufficient with respect to attaining self-sustaining woodland communities within a reasonable timeframe. Additionally, comparison of 1:25,000 aerial photos taken in 1982 and 2002 show that these sites include also large patches of undisturbed pre-mining vegetation and, hence, should not be included in any assessments, even qualitative ones (Plates 1a & b). Our sample transects, however, were deliberately chosen to encompass only rehabilitated areas on the minesite (see Plate 1a). The "healthier-looking" sites in the Pit and Waste Rock Dump areas are basically acacia shrubland with a dense grass weed understorey. Hence, they may complete their succession and die out, as our seedling recruitment data suggests, with no trees to replace them because few trees exist. Additionally, with the current high fuel loads of weed grasses, even maintenance of existing shrubland is at risk from uncontrolled fire (Plate d).

One valuable lesson that could be learnt from Nabarlek for assessment of revegetation success at Ranger is the necessity of establishing strategic experimental monitoring plots of sufficient size (e.g. 1ha), run over decadal time frames, as true reference areas to gauge the success of successional development over critical time intervals (5y, 10y, 15y & 20y; Carl Grant, pers. comm.). Traditionally, natural analogue sites are selected to reflect the character of successional end points, the desired vegetation state, but provide little information on how to get there. It is only half the story, hence the necessity of large plot experiments over time. However, because of costs, such landscape-scale experiments require a robust and efficient design in the first place (i.e. *a priori* hypotheses to test), one that embraces the principles of balanced treatment combinations and adequate replication. Even analogue sites are ecologically dynamic and so need to be adequately replicated to capture natural spatial and temporal variability. Rehabilitated minesites, and even natural landscapes, are open systems subject to disturbances such as fire and weeds and, hence, unpredictable nonequlibrium dynamics. The danger for successional plant communities is that they may collapse into irreversible states, requiring costly management intervention, and this is certainly confirmed by experience. In contrast, however, climax states are more resilient and, hence, robust to disturbance.

In summary, landscape-scale experiments should provide the necessary information to model and predict successional processes of revegetated mine sites and surrounding landscapes at key time intervals. Major advantages of this approach are that such information would be specific to that site and yet would contribute to generic knowledge for application to other rehabilitated minesites with similar environments.

Some experimental revegetation field trials were established at Ranger over 10 years ago and the monitoring results have been reviewed by Reddell and Zimmermann (2002), providing much useful information with implications for successful revegetation at both at Ranger and Nabarlek. For example, they conclude that: fire can be beneficial but depending on type of fire and successional stage of vegetation; high density, aggressive acacia species inhibit performance of framework establishment species; and that native grasses have potential use in revegetation at Ranger. The other side of the ARRTC Key Knowledge Need coin “what can we learn from Nabarlek for Ranger” is “what have we learned from Ranger for Nabarlek”, demonstrating the utility of adaptive, experimental management (see Holling 1978).

5.5 Preliminary assessment of revegetation success

The few examples of minesite revegetation in the wet-dry tropics of Australia that may be relevant to Nabarlek are Weipa, Groote Eylandt and Gove, and these will be reviewed to assess revegetation benchmarks against time since rehabilitation. Nevertheless, Alcoa’s rehabilitation objective in Western Australia’s jarrah forests is most relevant in terms of what can be achieved given adequate levels of investment and planning. They aim to restore a self-sustaining forest ecosystem to enhance or maintain water, timber, recreation and conservation values. Their completion criteria suggests that ecosystem resilience can be obtained in less than five years, and that a sustainable integrated landscape with landuse can be obtained in 10-15 years (Carl Grant, pers. comm.).

Eucalypts are a favoured establishment species on many rehabilitated minesites across Australia and, with respect to benchmarking revegetation success in years since rehabilitation, they generally take between 5-10 years to produce seed although there would be large site-specific variation. The preliminary results reported that characterises soils and vegetation on the Nabarlek minesite, in comparison to adjacent analogue sites, demonstrates that revegetation has been largely unsuccessful in relation to the original goal of “blending in with the surrounding woodland”, and to experience on other revegetated minesites at the 5, 10 and 15 year benchmarks. The overall vegetation on the minesite is characterised by grassy weeds, high fire risk, a senescing acacia shrubland nearing the end of their life, and very little woody recruitment because of a low density of necessary mature trees (a “vortex of unsustainability”). The latter point suggests that woody plant density is unlikely to increase in the short term and may decrease as a result of losses due to fire. Additionally, the Evaporation Ponds may have poor soil development in terms of seasonally high nutrient and salt levels and, most likely suffers from seasonal waterlogging. Such poor soil conditions will inhibit growth and survival of woodland plant species, ultimately reflected in poor vegetation development.

Our quantitative assessment, however, simply supports the view by Prendergast et al (1999) and delegates at the Nabarlek Rehabilitation Workshop in 2000 (Klessa 2001), that progress in revegetation at the five-year benchmark was unsatisfactory. The catalyst for the 2000 Nabarlek Rehabilitation workshop was disagreement by Prendergast et al (1999) with the optimistic assessment by Adams Ecological Consultants that revegetation on Nabarlek was progressing satisfactorily at the five-year benchmark (Adams & Hose 1999). The key workshop findings were that: further revegetation work is required if succession to a woodland community is to be achieved; grasses and weeds dominated ground cover on up to 50% of the minesite; appropriate indicators of revegetation success need to be identified (and accepted by stakeholders - our comment); and an active management plan is needed to address issues such as fire management, weed and feral animal control, erosion control and contaminant transport. Specific recommendations were: bush tucker plants should not be planted on site; preventative fire management should be implemented for revegetated areas for at least the first five years; fire breaks should be maintained; a weed control strategy should be developed; and feral animals should be excluded from the site (Klessa 2001). In support of research needed to address some of these issues, the Supervising Scientist part-funded an Australian Centre for Mining Environmental Research (ACMER) study on Ecosystem Function Analysis (EFA) at Nabarlek (see section 5.2). The following specific research and management needs were identified by the workshop for consideration:

1 More information is required to assess revegetation, particularly during the early stages of development.

2 Amongst the secondary revegetation criteria which might be used to gauge success are species abundance, recruitment, competition, inflorescence, vigour, fire tolerance, weed density and soil C:N ratio.

3 Raw data used by Adams Ecological Consultants (Adams & Hose 1999), used to assess revegetation at Nabarlek in 1996 as being successful, be obtained.

4 Aerial photography be used to delineate upland and run-on zones (which favour Melaleuca establishment) as a tool to assess revegetation success over the whole site.

5 A survey should be conducted to collate a weed list for Nabarlek, which should include both disturbed and undisturbed areas.

6 A weed control strategy should be developed for problematic species as defined under NT legislation and, which pose problems (fuel load & competition) to the successful establishment of trees and shrubs on site.

7 Grasses should be managed appropriately to reduce fuel load and competition with trees.

With respect to (1) and (2) above, current ***eriss*** research hopes to close these information gaps. With respect to (3), further attempts should be made to obtain the raw data collected by Adams Ecological Consultants, although the preliminary assessment of revegetation success reported here supersedes it. Such data, however, would provide the only baseline with which to measure successional rates of vegetation change since revegetation commenced eight years ago. With respect to (4), sequential aerial photography have been obtained for Nabarlek but the delineation of upland and run-on zones to assess revegetation success over the whole site has, as far is known, not been done. However, ***eriss*** has created a 2m DEM of Nabarlek to simulate soil erosion and sediment transport across the minesite over time using landform evolution modelling (Lowry et al in press), which will be matched to current vegetation patterns. Recommendations (8) and (9) are currently being addressed by Demed land management rangers as part of the Mining Management Plan (see section 5.6), with support from the NLC Caring for Country Unit, ATSIC and Pioneer (Wolff, pers. comm). The most challenging recommendation is (7); our preliminary results show that fuel loads across the minesite from weed grasses (principally Mission grass) remain extremely high and, hence, so too the potential risks to native seedling growth and survival through both competition and fire hazard. The replanting efforts by Demed (see below) are obviously at extreme risk from uncontrolled fires on the minesite.

Increasing the amount of native canopy cover with revegetation plots may be the best long-term strategy to suppress weed grass cover and to reduce fire risk. However, at current levels of investment, Demed have replanted only 2.8% of the rehabilitated Evaporation Ponds areas over a few years. Additionally, they do not have the resources to manage abundant weed grasses across the entire minesite, principally Mission grass. Their pragmatic and practical weed control strategy is to focus on containment of new weed introductions at low occurrence (see section 5.6).

5.6 Demed vegetation management

Demed (Nabarlek Association) have an active land management program at Nabarlek, involving replanting native canopy species from tube stock, feral animal and weed control and fire management. Only weed control and revegetation are discussed here.

Weed control

In October 2003 the Demed land management facilitator (Danyel Wolff) approached ***eriss*** to review their strategic weed management plan (Wolff 2003). The review was carried out by Dave Walden, who leads the ***eriss*** ecological risk assessment project for weeds in the ARR. The objectives of their management plan are to:

- determine the distribution of invasive plant species that pose an environmental threat to minesite rehabilitation areas and ecosystems, and surrounding ecosystems;
- prioritise weeds of greatest impact and target these first;
- control weeds at major access points;
- minimise vectors of dispersal such as vehicle traffic and feral animals; and
- control plants that compete with the establishment of tubestock in rehabilitation areas.

The broad weed control strategy adopted by Demed is to revegetate with favourable canopy species, containment, and control of new aggressive weed species that have the potential to become major problems (Fig. 24). Many weeds on Nabarlek, such as Rhodes Feathertop grass and Para grass, were apparently deliberate introductions during revegetation. The ***eriss*** review concludes that the Demed weed management strategy is both pragmatic and practical given current resources and other competing regional land management priorities, and could be enhanced by broadly adopting the principles and guidelines that underpin the Kakadu and National weeds management strategies (Thorp 1999; Weeds of National Significance: Guidelines for Developing Weed Strategies).

Revegetation

Demed have provided access to data records associated with their revegetation program, which includes GPS locations of revegetation plots, number and species planted and date of planting. This is sound data with which to monitor progress of their program. Most of the replanting effort is distributed along the northern section of EP1 and EP2 (Fig. 24), the minesite areas requiring most attention. A total of 50 revegetation plots have been established to date, approximately 20m in diameter, comprising about 3% of the Evaporation Ponds area. The rate of revegetation towards analogue conditions, assuming that plot plants survive, will depend on initial coverage of the rehabilitated area. A first-cut effort analysis shows that to achieve a 25% coverage of the ponds area would require eight times the current effort (400 plots) and, hence, associated costs.

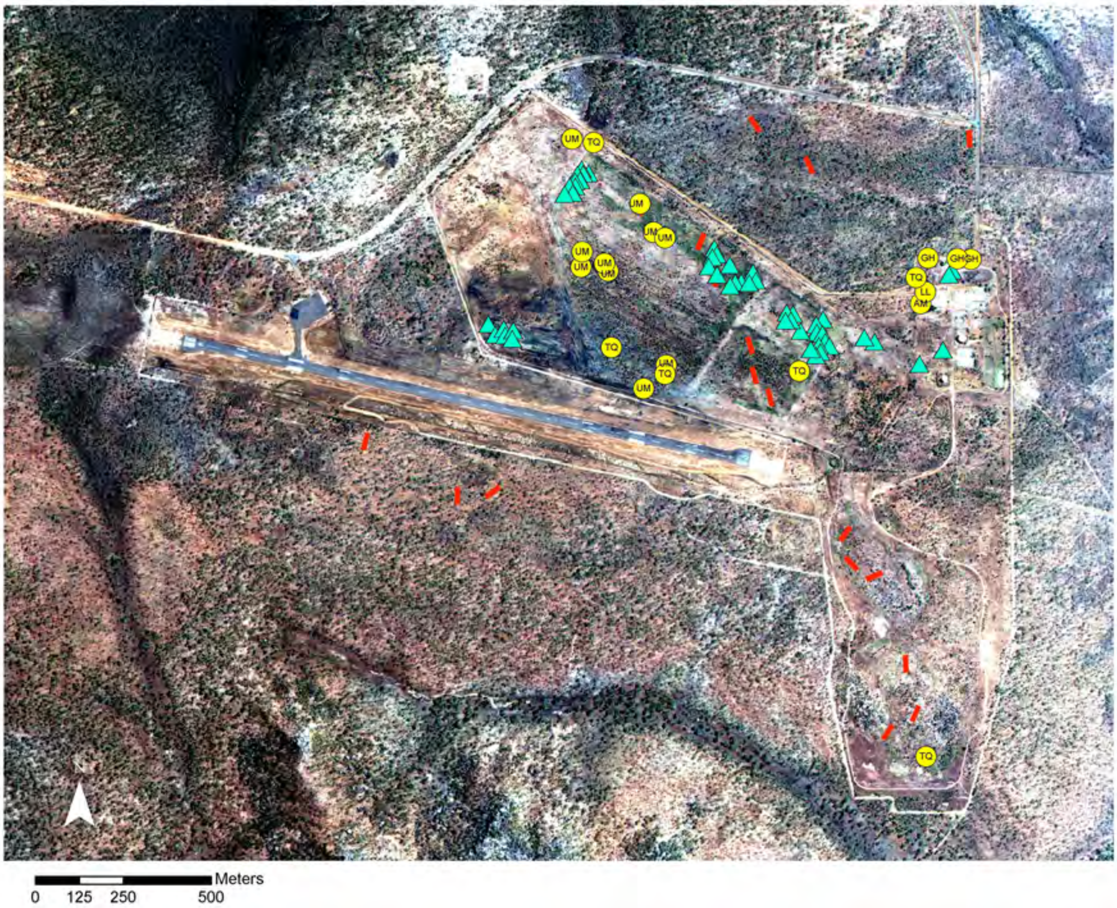


Figure 24 Quickbird satellite image (October 2003) showing location of Demed revegetation plots (blue triangles) and targeted weed control sites (yellow circles) in relation to sample transects (red). AM = African Mahogany (*Khaya senegalensis*); UM = Green Panic (*Urochloa maxima*); TQ = Grader Grass (*Themeda quadrivalis*); GH = Donkeys Dick (*Gmelina hysterix*); LL = Coffee Bush (*Leucaena leucocphala*).

6 Recommendations

6.1 Future research

In addition to current research activities centred on monitoring and assessment of revegetation success, knowledge is required also in the following areas, some of which have already commenced in collaboration with Charles Darwin University through postgraduate studies (see Appendix 9.6.1 & 9.6.2):

1 soil factors affecting growth & survival of framework species;

2 soil seed bank, especially weeds;

3 fire resistance & selection;

4 integrated fire & weed management; and

5 predicting vegetation succession & time scales.

We recommend that research in these areas be supported by the Nabarlek MTC stakeholders.

6.2 Future management

Whatever management option is adopted by Nabarlek stakeholders with respect to revegetation at the year 9 benchmark, a positive and key outcome would be the continued engagement with, and participation by, local indigenous communities in seeking sustainable solutions. Demed have demonstrated incredible initiative and drive in seeking solutions through active weed, fire and revegetation programs at Nabarlek, and MTC stakeholders could tap into this enthusiasm.

Table 8 outlines some possible management options for the Evaporation Ponds (EP2) area, ranging from continuing with the status quo to reconstruction and revegetation of the landform. They serve only as starting points for further discussion by stakeholders if required, and do not include all issues and options.

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Table 8 Matrix of possible revegetation management options for the northern half of EP2 at Nabarlek, with associated (& speculative) benefits, ranked costs and risk level. EP2 covers 35% of the area of the rehabilitated mine site.* The high value of Demed community participation in rehabilitation programs is assumed in the Benefits column of all options.

Option	Final landscape?	Issues	Benefits*	$ Cost	Risk level
1. Continue Demed revegetation program at same level.	Weed swamp fringed by paperbarks, with small number of native reveg islands along northern margin of EP2.	No match with adjacent analogue sites. Few trees, high salt levels may inhibit growth paperbarks?; waterlogging problem for establishment & growth of natives?; high fuel load of weed grasses, fire risk high.	Great start	Minimum of all options	High – fire & salt
2. Continue Demed revegetation program at a higher level of effort.	Less weed swamp but larger number of native reveg islands throughout northern section of EP2.	No match with adjacent analogue sites. More patches of trees, high salt levels inhibit growth & establishment of paperbarks & other natives?; waterlogging problems?; high but less fuel load of weed grasses, fire risk less but still high?	Depends on levels of research investment & reveg effort.	$ cost will scale up depending on effort vs area coverage, & time scale of reveg goal	High – fire & salt, but scaled down with greater effort?
3. Construct a freshwater wetland (paperbark swamp-sedgeland).	Melaleuca swamp-sedgeland-grassland (capitalises on existing hydrology-soil constraints).	No match with adjacent analogues; high salt levels may inhibit establishment & growth of paperbarks & other natives?; waterlogging?; high but less fuel load of weed grasses, fire risk less but still high?; need to flush & maintain water in dry; offsite impacts?; requires hydrological engineering?	New diverse habitat, match with regional analogues; depends on levels of research investment.	High?	High – salt? Para grass weed colonisation high.
4. Construct landscape mosaic of Eucalyptus woodland & paperbark wetlands.	Eucalyptus woodland – paperbark swamp (riparian) mosaic.	Match with adjacent analogues. Issues as for 3 above. Location of patch/island type depends on topography & soils.	Requires less effort & costs than 3 & 4?	Costs high, between options 2 & 3?	Same risks 2 & 3?
4. Start again: develop new landform & revegetate.	Pre-mining landscape of Eucalyptus woodland.	Difficult to defend costs on practical & pragmatic basis, & loss of rehab time due to re-setting time scales.	Maximum.	Highest – prohibitive?	Highest – construction works will spread weeds.

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9 Appendices

9.1 Spatial data for Nabarlek

9.1.1 Summary table of GPS coordinates for all vegetation transects (WGS84 UTMS or GDA94 UTMS)

Transect Name	Position on transect					
	0m	10m	20m	30m	40m	50m
T1	317813.33 E	317813.46 E	317813.92 E	317815.39 E	317814.61 E	317815.72 E
	8639829.47 N	8639809.82 N	8639808.70 N	8639797.66 N	8639789.57 N	8639779.20 N
T2	317349.08 E	317354.32 E	317357.61 E	317362.11 E	317365.86 E	317370.26 E
	8639751.31 N	8639741.75 N	8639732.16 N	8639723.03 N	8639713.6 N	8639705.16 N
T3	317190.66 E	317196.34 E	317201.69 E	317206.84 E	317211.98 E	317218.56 E
	8639866.51 N	8639857.96 N	8639849.60 N	8639841.30 N	8639832.45 N	8639824.93 N
T4	317105.66 E	317102.69 E	317099.82 E	317096.77 E	317093.93 E	317090.81 E
	8639430.32 N	8639420.71 N	8639411.02 N	8639401.86 N	8639391.86 N	8639382.19 N
T5	317060.24 E	317056.87 E	317052.93 E	317049.94 E	317045.16 E	317041.24 E
	8639534.10 N	8639524.77 N	8639515.53 N	8639506.82 N	8639497.25 N	8639488.07 N
T6	316905.39 E	316900.20 E	316894.54 E	316888.46 E	316882.62 E	316876.85 E
	8639627.23 N	8639618.82 N	8639610.62 N	8639602.75 N	8639594.75 N	8639586.51 N
T7	317632.13 E	317633.00 E	317633.06 E	317633.46 E	317634.46 E	317634.98 E
	8638331.83 N	8638322.03 N	8638312.14 N	8638302.63 N	8638292.73 N	8638282.06 N
T8	317670.86 E	317666.19 E	317658.55 E	317658.55 E	317654.94 E	317651.54 E
	8638187.60 N	8638177.89 N	8638159.60 N	8638159.60 N	8638150.24 N	8638140.91 N
T9	317596.90 E	317591.29 E	317585.74 E	317580.10 E	317574.29 E	317568.67 E
	8638133.05 N	8638125.35 N	8638116.19 N	8638108.56 N	8638100.42 N	8638092.01 N
T10	317520.73 E	317529.27 E	317538.84 E	317547.98 E	317557.33 E	317566.36 E
	8638549.11 N	8638552.61 N	8638556.84 N	8638560.69 N	8638564.75 N	8638568.20 N
T11	317496.46 E	317488.97 E	317482.09 E	317474.79 E	317467.39 E	317460.61 E
	8638576.79 N	8638583.80 N	8638590.63 N	8638597.36 N	8638604.32 N	8638611.25 N
T12	317446.43 E	317452.83 E	317458.45 E	317464.14 E	317470.25 E	317475.91 E
	8638658.34 N	8638665.68 N	8638674.24 N	8638681.91 N	8638690.10 N	8638698.44 N
T13	317253.96 E	317251.69 E	317248.98 E	317246.38 E	317470.25 E	317241.08 E
	8639042.01 N	8639051.64 N	8639061.14 N	8639071.85 N	8638690.10 N	8639090.66 N
T14	317209.28 E	317206.73 E	317204.31 E	317201.79 E	317199.39 E	317196.46 E
	8639104.72 N	8639114.18 N	8639124.35 N	8639133.67 N	8639142.58 N	8639152.84 N
T15	317197.6 E	317194.96 E	317192.55 E	317189.54 E	317186.71 E	317183.85 E
	8639191.25 N	8639201.48 N	8639211.35 N	8639220.85 N	8639230.04 N	8639239.08 N
T16	316358.68 E	316358.84 E	316358.21 E	316358.87 E	316359.38 E	316358.72 E
	8638812.77 N	8638803.38 N	8638793.40 N	8638783.22 N	8638773.97 N	8638762.48 N
T17	316103.29 E	316101.50 E	316097.97 E	316095.90 E	316093.01 E	316091.29 E
	8638964.38 N	8638952.76 N	8638944.48 N	8638934.54 N	8638924.58 N	8638915.65 N
T18	316478.63 E	316471.31 E	316463.75 E	316454.21 E	316447.14 E	316439.10 E
	8638812.89 N	8638807.70 N	8638802.74 N	8638795.30 N	8638790.16 N	8638784.17 N

9.1.2 Summary of areas (ha) of sample strata (see Fig. 1) used in vegetation surveys at Nabarlek, September 2003

Code	Spatial feature	Perimeter (m)	Area (ha)	% Area
EP2	Evaporation Pond 2	1989.3	25.14	34.8
SRP	Stockpile Runoff Pond	796.9	3.94	5.5
EP1	Evaporation Pond 1 (tailings)	955.4	5.64	7.8
PIT	Mine Pit	842.0	3.98	5.5
WRD	Waste Rock Dump	1204.3	7.89	10.9
SS	Surplus Materials Stockpiles	983.3	5.62	7.8
SS	Surplus Materials Stockpiles	1621.6	14.62	20.2
OR	Ore Stockpile / Bogum stockpile	931.2	5.38	7.5
W	Woodland reference area	-	Open	
R	Riparian reference area	-	Open	
	Total area mine sites		**72.10**	100

9.2 Plants on Nabarlek

9.2.1 Revised plant species list

Species highlighted by grey shading are classified as weeds. For trees and shrubs the year and source are indicated (Brennan 1992, Adams & Hose 1999 & this report 2003).

Grasses

Species	Common name
Alloteropsis semialata	Cockatoo grass
Aristida inequiglumis	Wire-grasses
Aristida sp. 1	Wire-grasses
Arthrostylis aphylla	
Bothriochloa bladhii	Forest bluegrass
Brachyachne convergens	Native couch
Chrysopogon fallax	Golden beard grass
Dactyloctenium aegyptium	
Dicanthium sericeum	Slender Queensland bluegrass
Dicanthium sericeum ssp. polystachion	Slender Queensland bluegrass
Dicanthium sericeum ssp. sericeum	Slender Queensland bluegrass
Digitaria gibbosa	Umbrella grass
Digitaria sp	
Echinochloa colona	
Eragrostis cumingii	
Eragrostis sp	Love grasses
Eriachne major	Wanderrie grasses
Eriachne sp. 1	Wanderrie grasses
Eriachne sp. 2	Wanderrie grasses
Heteropogon contortus	Black speargrass
Heteropogon triticeus	Giant speargrass
Imperata cylindrica	Blady grass
Panicum mindanaense	
Panicum trachyrhachis	
Paspallum scrobiculatum	Scrobic paspalum, kodo
Paspalum longifolium	
Poacea sp	
Rhynchospora sp.	
Schizachyrium fragile	Fire grass
Sorghum sp. 1	Sorghum
Sporobolus australasicus	Dropseed grasses
Sporobolus sp. 1	Dropseed grasses
Thaumastochloa sp.	

Grasses

Species	Common name
Themeda quadrivalvis	Grader grass
Andropogon gayanus	Gamba grass
Chloris gayana	Rhodes grass
Chloris inflata	Purple-top chloris, purple-top rhodes grass
Chloris virgata	Feather-top rhodes grass
Cynodon dactylon	Couch
Digitaria ciliaris	Umbrella grasses
Melinis repens	Red natal grass, Molasses grass
Panicum maximum	Guinea grass
Paspalum plicatum	
Pennisetum pedicellatum	Annual Mission Grass, Pennisetum
Pennisetum polystachion	Mission grass (perennial)
Setaria ssp. italica	Japanese millet
Seteria sp.1	Japanese millet
Sorghum sp 1	Sorghum
Themeda triandra	Kangaroo grass
Urochloa maxima	Green Panic
Urochloa mutica	Para grass
Whiteochloa sp. 1	

Herbs & Vines

Species	Common name
Allium cernum	Wild onion
Alysicarpus glumaceus	
ASCLEPIADACEAE (FAMILY)	
Blumea axillaris	Daisy
Blumea integrifolia	Daisy
Blumea saxatilis	Blumea saxatilis
Chamaecrista nictitans	
Colendia procumbens	
Cyanthillium cinereum	Vernonia
Drosera sp.	
Eriachne obtusa	Wanderrie grasses
Euphorbia schizolepis	
Euphorbia sp.1	
Evolvulus alsinoides	
Fuirena ciliaris	
Galactia tenuiflora	Snail flower
Gomphrena flaccida	Everlasting
Goodenia armstrongiana	Goodenia
Heliotropium sp.	

Herbs & Vines

Species	Common name
Heterachne abortive	
Ipomea ploymorpha	Ipomea ploymorpha
Ipomoea sp.	
Kailarsenia suffruticosa	
Ludwigia octovalvis	Willow primrose
Marsdenia trinervis	
Mullago pentaphylla	
Portulaca oleracea	
Psoralea badocana	
Pterocaulon serrulatum	
Ptilotus corymbosus	
Ptilotus sp	
Rhyncospora submarginata	
Sauropus ditissoides	
Spermacoce calliantha	
Tephrosia remotiflora	
Vigna vexillata	
Waltheria indica	Waltheria
Xenostegia tridentata	
Xyris cheumatophila	
Alysicarpus vaginatis	One-leaf clover, Buffalo clover
Buchnera sp.	
Crotalaria goreensis	Gamba pea
Desmodium tortuosum	Engorda-caballo, Florida beggarweed
Euphorbia heterophylla	
Euphorbia hirta	Snake weed, Asthma plant, Caustic plant
Hibiscus sabdariffa	
Hyptis suaveolens	Hyptis, Horehound
Macroptilium atropurpureum	Sirato, purple bean
Macroptilium lathyroides	Phasey bean
Malvastrum americanum	
Passiflora foetida	Stinking passion flower
Physalis minima	Wild gooseberry
Polycarpaea corymbosa	Oldman's cap, chinese herb
Scoparia dulcis	Bitterbroom, Broomweed, Licorice weed
Sebastiania chamaelea	Creeping sebastiana
Sida acuta	Flannel weed, Spiny Head Sida
Sida rhombifolia	Paddy's lucerne
Sida sp. 1	
Stylosanthes hamata	Caribbean stylo
Stylosanthes viscosa	Poorman's friend, Sticky Stylo
Tridax procumbens	Pigweed

Sedges

Species	Common name
Cyperus sp 1	
Cyperus sp 2	
Fimbristylis acicularis	
Fimbristylis sp.	
Leptocarpus spathaceus	
Scleria brownie	
Scleria sphacelata	
Tricostularia undulata	

Trees

Scientifc Name	Common Name(s)	Source		
		Brennan (1992)	Adams (1994-1996)	2003 survey
Aeschynomene americana	American vetch		X	X
Acacia A (poss *torulosa)*			X	
Acacia aulacocarpa		X		X
Acacia auriculiformis				X
Acacia B			X	
Acacia C			X	
Acacia D	Papuan wattle, northern black wattle		X	
Acacia difficilis		X	X	X
Acacia E			X	
Acacia F (poss *latescens)*			X	
Acacia holosericea	Silver-leaf wattle, wahroon		X	X
Acacia lamprocarpa				X
Acacia latescens				X
Acacia latifolia			X	
Acacia mimula			X	X
Acacia mountfordiae			X	
Acacia pallidifolia				X
Acacia sericoflora				X
Acacia simsii	Sims wattle		X	X
Acacia torulosa	Wrinkly-podded wattle			X
Asteromyrtus symphyocarpa	Asteromyrtus symphyocarpa	X		
Blepharocarya depauperata	Rose butternut			X
Brachychiton diversifolius		X		
Brachychiton paradoxum	Red-flowered kurrajong			X
Buchanania obovata	Green plum	X		X
Calytrix exstipulata	Turkey bush	X		X
Cochlospermum fraseri	Kapok tree	X	X	X
Cochlospermum sp.	Kapok tree			X
Corymbia bella		X		
Corymbia confertiflora	Broad-leaved carbeen	X		X
Corymbia disjuncta				X
Corymbia latifolia				X

Trees

Scientifc Name	Common Name(s)	Source		
		Brennan (1992)	Adams (1994-1996)	2003 survey
Corymbia polycarpa	Long-fruited bloodwood	X	X	X
Corymbia porrecta				X
Corymbia setosa	Rough-leaved bloodwood		X	X
Dolichandrone filiformis		X		X
Erythrophleum chlorostachys	Ironwood	X	X	X
Erythroxylum elliptica				X
Eucalyptus A			X	
Eucalyptus alba	Timor white gum			X
Eucalyptus B			X	
Eucalyptus bleeseri	Smooth-leaved bloodwood		X	X
Eucalyptus C			X	
Eucalyptus miniata	Darwin woollybutt		X	X
Eucalyptus tectifica		X		
Eucalyptus tetrodonta	Darwin stringybark		X	X
Ficus opposite	Sandpaper fig	X	X	X
Ficus racemosa			X	
Gardenia resinosa		X		
Gardenia schwarzii				X
Glochidion apodogynum				X
Glochidion disparipes		X		
Grevillea decurrens			X	
Grevillea heiosperma			X	
Grevillea pteridifolia	Fern-leaf grevillea; golden tree	X	X	X
Hakea arborescens	Yellow hakea	X	X	X
Jacksonia dilatata		X		X
Lophostemon lactifluus		X		
Melaleuca leucadendra	Broad-leaved tea-tree			X
Melaleuca nervosa	Paperbark	X	X	X
Melaleuca viridiflora	Broad-leaved paperbark	X	X	X
Pachynema complanatum	Small shrub <1m			X
Pachynema junceum	Small shrub <1m			X
Pachynema sphenandrum	Small shrub <1m			X
Pandanus spiralis	Spiral palm	X		X
Persoonia falcata		X		
Petalostigma pubescens	Quinine tree, bitter-bark	X		X
Petalostigma quadriloculare	Quinine bush			X
Planchonia careya	Cocky apple; billy goat plum	X		X
Pogonolobus reticulatus	Medicine bush			X
Premna acuminata	Firestick tree, vitex			X
Terminalia grandiflora		X		
Terminalia platyphylla		X		
Terminalia pterocarya		X		
Vitex glabrate		X		
Wrightia saligna	Milkwood	X		X
Xanthostemon paradoxus		X		
Syzygium eucalyptoides ssp. *bleeseri*	Native apple	X		X
Verticordia cunninghamii		X		X

Table A9.2.2 Matrix of tree and shrub species occurrence on vegetation transects plots (0.1ha) across all sites at Nabarlek, September 2003

Scientifc Name	Common name	RIP	WL	EP1	EP2	WRD	PIT
		Reference sites		Mine sites			
Acacia aulacocarpa							
Acacia difficilis		X				X	
Acacia holosericea	Silver-leaf wattle, wahroon					X	X
Acacia lamprocarpa		X					
Acacia latescens				X		X	
Acacia mimula			X	X		X	X
Acacia sericoflora				X			X
Acacia simsii ?	Sims wattle					X	
Acacia torulosa	Wrinkly-podded wattle						X
Aeschynomene americana	American vetch						
Buchanania obovata	Green plum	X	X			X	
Brachychiton paradoxus	Red-flowered kurrajong	X					
*Calytrix exstipulata**	Turkey bush						
Cochlospermum fraseri	Kapok tree		X				
Carissa lanceolata	Small shrub (<1m)	X	X				
Corymbia confertiflora	Broad-leaved carbeen	X	X		X	X	
*Corymbia latifolia**							
Corymbia polycarpa	Long-fruited bloodwood	X				X	X
Corymbia porrecta		X	X	X			
Corymbia setosa	Rough-leaved bloodwood				X	X	X
Dolichondrone filiformis		X					

Table 9.2.2 (cont.)

Scientifc Name	Common name	RIP	WL	EP1	EP2	WRD	PIT
		Reference sites		Mine sites			
Distichostemon hispidulus	Small shrub (<1m)	X	X	X		X	
Erythrophleum chlorostachys	Ironwood	X	X	X		X	
Erythroxylum elliptica	Small shrub		X				
Eucalyptus bleeseri	Smooth-leaved bloodwood		X				
Eucalyptus miniata	Darwin woollybutt						X
Eucalyptus tetradonta	Darwin stringybark	X	X			X	
Ficus opposita	Sandpaper fig	X	X	X	X	X	X
Gardenia schwarzii		X	X				
Grevillea pteridifolia	Fern-leaf grevillea	X	X	X			
Grevillea refracta	Check		X				
Hakea arborescens	Yellow hakea	X					
Jacksonia dilatata						X	
Melaleuca leucadendra	Broad-leaved tea-tree			X			X
Melaleuca nervosa	Paperbark	X		X	X		X
Melaleuca viridiflora	Broad-leaved paperbark	X					
Meleleuca nervosa	Paperbark			X			
Pachynema junceum	Small shrub (<1m)	X				X	
Pachynema sphenandrum	Small shrub (<1m)						
Pandanus spiralis	Spiral palm	X		X			
Petalostigma pubescens	Quinine tree, bitter-bark		X				X
Petalostigma quadriloculare	Quinine bush		X				
Planchonia careya	Cocky apple	X	X				
Pogonolobus reticulatus	Medicine bush, vine	X					
Premna acuminata	Firestick tree, vitex		X				
Syzygium eucalyptoides ssp. *bleeserii*	Native apple	X					
Terminalia ferdinandiana	Billy goat plum		X				
Verticordia cunninghamii		X					
Wrightia saligna	Milkwood		X				
Total		**24**	**21**	**12**	**4**	**15**	**11**

9.2.3 List of Establishment species and seed usage (Adams & Hose 1999), and information obtained from Demed (* location of application unknown, dose in kg)

Seed Usage		
Species	**Dolerite area (g)**	**Schist area (g)**
Acacia aulacocarpa	375	0
Acacia difficilis	1913	694
Acacia holosencea	56	816
Acacia latescens	0	2364
Acacia mimula	11315	4743
Acacia oncinocarpa	6146	2104
Acacia platycarpa	855	0
Acacia torulosa	4042	1771
Acacia tropica	800	620
*Alysicarpus vaginalis**	25kg	
Cochlospermum fraseri	1739	227
*Cynodon dactylon **	50kg	
Erythrophleum chlorostachys	23443	10363
Eucalyptus bleeseri	2345	1129
Eucalyptus clavigera	3610	1140
Eucalyptus ferruginea	460	0
Eucalyptus foelscheana	3391	0
Eucalyptus latifolia	8	0
Eucalyptus miniata	520	155
Eucalyptus (Corymbia) polycarpa	1476	96
Eucalyptus setosa	130	705
Eucalyptus tectifica	450	20
Eucalyptus tetrodonta	1536	664
Grevillea decurrens	1021	55
Grevillea parallela	213	8
Greviflea pteridifolia	1570	40
Hakea arborescens	742	0
*Heteropogon sp.? **		
Melaleuca nervosa	45	0
Melaleuca viridflora	1905	30
Owenia vernicosa (seeds)	200	0
Pandanus spiralis (seeds)	1820	300
Petalostigma pubescens	4537	1944
*Terminalia ferdinandiana**	400kg fruit	
Terminalia grandiflora	30	0
Wrightia saligna	2415	780
Area (hectares)	**75.5**	**29.5**

9.3 Method to derive above ground biomass ($kg.ha^{-1}$, ODW)

A rapid field method was developed to visually estimate biomass (ODW, kg) of dominant ground cover plants rather than using traditional methods which involve impossible amounts of time cutting, sorting and oven drying large numbers of samples. The principle behind indirect methods is that acceptable amounts of accuracy are sacrificed within each sample unit for significant gains in precision between sample units (i.e. more replication is possible). The methods developed here are similar to the Comparative Yield and Dry Weight Rank techniques used to estimate pasture biomass and composition by weight over large, inherently variable environments (see Haydock & Shaw 1975).

Four representative ground cover types were chosen to develop "biomass standards" for use across all sites. These were: (a) Riparian grass & sedge mix; (b) Para grass (*Urochloa mutica*); (c) Black Spear grass (*Heteropogon contortus*); and (d) Mission grass (*Pennisetum polystachion*). For each standard five $1.0m^2$ quadrats were visually chosen (based on height & 100% cover) to encompass a linear range of biomass between minimum (Q1) and maximum (Q5) amounts encountered. For example, if Q1 and Q5 were the least and most amounts of biomass encountered, respectively, then Q3 would be the middle value, Q2 would be mid-way between Q1 and Q2 and, similarly for Q4. For each quadrat a reference photograph was taken, the species composition recorded, the mean height obtained ,and all plants cut at ground level. After litter was removed the samples were bagged, weighed (wet weight, kg) with a field balance and taken to the laboratory to oven dry (80^oC for 72 hrs) and re-weighed (kg). Very large samples were sub-sampled after mixing to convert wet weight to dry weights. Table 9.3a-d summarises the regression equations predicting biomass (ODW, kg) from mean height of plants, and Figure 9.3a-d illustrates the strong relationships. The equations apply to a 100% cover of dominant plant types, and were then extrapolated to $50m^2$ sample plots of varying cover by re-scaling. Note that data were recorded in 2 x $50m^2$ subplots because of ease of visual cover estimation, and later pooled to provide data for $100m^2$ (0.01ha) plots used in all analyses.

The method developed to estimate biomass (ODW, $kg.m^{-2}$) of Passionfruit vine, ubiquitous across the mine site, was based on cover and not height because it's thickness was consistently about 2-10cm. Table 9.3e summarises the regression equation developed to predict dry weight ($kg.m^{-2}$) of Passionfruit vine from cover (%) in a $1.0m^2$ quadrat. The equation for a $1.0m^2$ quadrat was then extrapolated to the $50m^2$ subplots.

Table A9.3 a-e Summary of regression equations predicting biomass (W, kg ODW) from mean height (H, m) of 100% ground cover dominated by (a) Riparian grasses & sedges, (b) Para grass (*Urochloa mutica*), (c) Black Spear grass (*Heteropogon contortus*) and (d) Mission grass (*Pennisetum polystachion*). (e) Regression equation predicting biomass (W, $kg.m^{-2}$ ODW) of Passion fruit vine (*Passiflora foetida*) from ground cover (C, %).

Standard	Equation	n	R	%R^2	P
(a) Riparian grasses & sedges	W = 0.06 + 0.60H	3	0.9999	99.9	0.03
(b) Para grass	W = 0.12 + 1.16H	5	0.9777	95.6	0.005
(c) Black Spear grass	W = -0.07 + 1.38H	5	0.9940	98.8	0.001
(d) Mission grass	W = 0.01 + 0.75H	5	0.9899	98.0	0.002
(e) Passionfruit Vine	W = 1.91 + 2.26C	5	0.9985	99.7	0.001

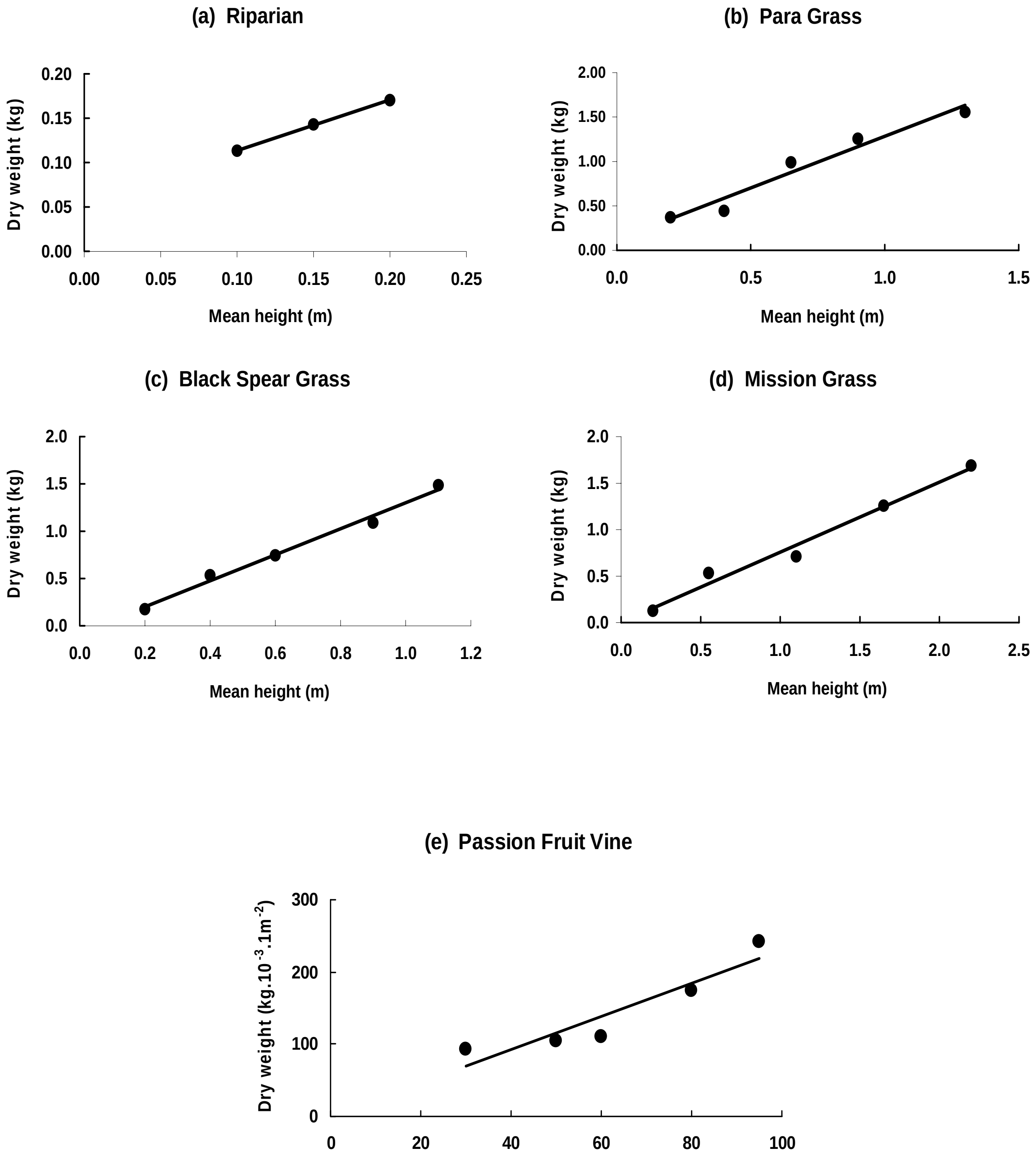

Figure A9.3 a-e Regression lines predicting biomass (ODW, kg) from mean height (m) of 100% ground cover dominated by (a) Riparian grasses & sedges, (b) Para Grass (*Urochloa mutica*), (c) Black Spear Grass (*Heteropogon contortus*) and (d) Mission Grass (*Pennisetum polystachion*). (e) Regression line predicting biomass of Passion Fruit Vine *(Passiflora foetida*) (ODW, $kg.m^{-2}$) from ground cover (%) in $1.0m^2$ quadrats.

9.4 Results of soil chemical analyses for all sites (September 2003) – Incitec Pivot Ltd

Site	RIP	RIP	RIP	WL	WL	WL	WRD	WRD	WRD	PIT	PIT	PIT	EP1	EP1	EP1	EP2	EP2	EP2
Sample (transect)	1	2	3	16	17	18	7	8	9	10	11	12	13	14	15	4	5	6
Colour (Munsell)	Brown	Brown	Brown	Grey-brown	Brown	Brown	Grey-brown	Grey-brown	Grey-brown	Grey-brown	Grey-brown	Grey-brown	Grey	Brown	Brown	Brown	Grey-brown	Grey-brown
Texture	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam
pH (1:5 Water)	6.3	6.3	6.1	6.3	6.3	6.1	6.3	6.4	6.1	6.2	6.1	5.7	6.3	6.2	6.4	6.2	6	6.1
pH(1:5CaCl2)	5.7	5.5	5.5	5.7	5.8	5.5	5.9	5.9	5.5	5.6	5.5	5.2	5.8	5.6	6.1	5.7	5.5	5.7
Organic Carbon %	0.8	0.6	0.5	1.4	1.1	2.0	1.3	0.7	1.1	1.1	1.4	2.7	2.0	1.4	3.0	2.2	3.1	4.1
Nitrate Nitrogen mg/kg	1.0	< 0.5	< 0.5	0.8	0.9	1.3	< 0.5	< 0.5	1.1	0.7	6.6	6.6	0.6	0.9	< 0.5	1.0	17.2	3.7
Sulfate Sulftur (MCP) mg/kg	2.5	3.3	3.8	2.8	2.9	3.0	2.3	1.7	13.0	4.8	8.1	24	12	12	11	25	48	19
Phosphorus (Colwell) mg/kg	< 5	< 5	< 5	< 5	< 5	< 5	13	17	9	11	9	22	7	< 5	10	12	29	29
Potassium (Amm-acet.) Meq/lOOg	0.09	0.06	0.04	0.12	0.12	0.14	0.24	0.16	0.15	0.18	0.24	0.22	0.44	0.21	0.51	0.47	0.52	0.53
Calcium (Amm-acet.) Meq/lOOg	2.8	3.1	0.85	3.1	2.7	3.9	1.9	0.9	1.1	1	1.3	1.5	3.8	3	12	14	17	11
Magnesium (Amm-acet.) Meq/lOOg	1.4	1.1	0.6	0.7	0.7	0.8	5.1	3.5	3.5	7.1	9.9	5.8	2.2	2.8	8.2	13	16	13
Aluminium (KCL) Meq/100g	-	-	-				-	-	-	-	-	-	-		0.26	-	-	-
Sodium (Amm-acet.) Meq/lOOg	0.025	0.03	0.06	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.03	0.05	0.04	0.025	0.03	0.07	0.13	0.11	0.14
Chloride mg/kg	11	9.9	10	8.3	7.6	8.6	11	7.1	< 4	15	25	25	18	15	35	17	17	30
E.C. dS/m	0.03	0.03	0.03	0.03	0.02	0.03	0.05	0.04	0.05	0.04	0.06	0.08	0.06	0.04	0.12	0.10	0.15	0.10
Copper (DTPA) mg/kg	0.32	0.65	0.2	0.56	0.72	0.55	0.27	0.11	0.74	1	0.65	1.4	1.3	1.8	1.4	3.4	3.2	3.8
Zinc(DTPA) mg/kg	0.64	0.28	0.12	0.15	0.15	0.16	0.63	0.22	0.46	0.65	0.76	1.1	0.82	0.55	1.4	1.2	0.97	1.4
Manganese (DTPA) mg/kg	18	30	8.5	75	77	76	13	5.5	12	14	17	27	88	110	110	110	100	100
Iron (DTPA) mg/kg	25	47	47	13	15	23	28	15	56	41	48	130	68	53	81	100	140	180
Boron (Hot CaC12) mg/kg	0.19	0.2	0.26	0.16	0.14	0.19	0.18	0.13	0.19	0.23	0.26	0.46	0.33	0.23	0.49	0.39	0.45	0.55
Liming Estimate	-	-	-				-	-	-	-	-	2.2	-			-	-	-

t/hapH 6.0 t/ha																		
Liming Estimate t/ha pH 6.5 t/ha	1.2	1.2	1.2	1.7	1.7	2.8	1.7	1.2	2.2	2.8	2.8	3.4	2.2	1.7	2.2	2.8	4	3.4
Cation Exch. Cap. Meq/lOOg	4.3	4.3	1.5	4	3.5	4.8	7.3	4.6	4.8	8.3	11.5	7.6	6.5	6	21.1	27.6	33.6	24.7
Ca/Mg Ratio	2	2.8	1.5	4.3	4	5.1	0.37	0.26	0.31	0.14	0.13	0.26	1.7	1.1	1.5	1.1	1.1	0.85
E.C. (Sat.Ext) dS/m	0.4	0.4	0.4	0.4	0.2	0.4	0.6	0.5	0.6	0.5	0.7	0.9	0.7	0.5	1.4	1.2	1.8	1.2
Aluminium Saturation %															1			
Sodium % of Cations (ESP) %	0.58	0.77	4.1	0.55	0.63	0.46	0.3	0.48	0.46	0.33	0.45	0.51	0.38	0.5	0.3	0.47	0.33	0.57
Phosphorus Buffer Index (PBI-Col)	38.6*	37.9*	27.4*	52.1*	45.0*	60.6*	19	11	15	23	31	49	59	52.9*	75	87	77	82

9.5 Soil metal analysis for Reference and Mine sites (Sept 2003)

ICPMS analysis of Nabarlek soil samples

Charles Darwin University Environmental Chemistry Laboratory
Acid extractable concentrations in mg/Kg dry weight (concentrated nitric + perchloric acid)

Site & Transect	Mg	Mn	Pb	Th	U
T1 (RIP)	887	247	4.51	2.17	1.47
T2 (RIP)	663	266	3.59	1.92	0.64
T2 (RIP) duplicate digest	641	254	3.84	2.04	0.65
T3 (RIP)	307	74	3.39	2.60	0.96
T4 (EP2)	22700	696	11.40	9.76	154.00
T5 (EP2)	26800	532	9.82	10.30	317.00
T6 (EP2)	23300	495	11.30	8.20	336.00
T7 (WRD)	39900	235	11.30	23.10	21.20
T8 (WRD)	52300	210	14.10	23.30	22.50
T9 (WRD)	49000	209	18.10	21.60	78.70
T10 (PIT)	39000	179	28.00	19.20	171.00
T10 (PIT) duplicate digest	39700	165	28.30	19.90	180.00
T11 (PIT)	38500	184	26.90	22.30	117.00
T12 (PIT)	41400	191	33.30	22.00	293.00
T13 (EP1)	6520	659	9.55	5.83	33.00
T14 (EP1)	5720	934	9.55	6.65	55.80
T15 (EP1)	5600	1390	7.46	4.92	31.80
T16 (WL)	337	1060	7.16	4.51	1.89
T17 (WL)	531	1450	10.80	5.43	1.99
T18 (WL)	369	797	6.43	4.42	2.61
EP1 soil seedling trial	3590	368	7.71	5.51	19.70
RIP soil seedling trial	442	186	4.01	2.27	0.78
RIP duplicate digest	404	177	4.59	2.24	0.82
Quality Control					
Detection limit	0.7	0.070	0.040	0.170	0.002
Digest blank	<0.7	<0.070	<0.040	<0.170	0.003
spike addition	1010	97	9.67	9.67	9.67
spike recovered	974	98	10.60	8.90	8.74
IAEA soil-7 result	11300	666	61.4	6.34	1.22
Certified value* for total conc analysis	11300	631	60.0	8.20	2.60

9.6 Revegetation research MOU with Charles Darwin University

Attachment 1

Agreement for the Supply of Data

Important: The completed Schedule and Licence Conditions set out below will constitute a legal agreement between the Commonwealth of Australia ("the Commonwealth"), through the Supervising Scientist Division of the Department of Environment and Heritage, and you ("the Licensee") in relation to the data.

If you are entering into this agreement on behalf of a company or organisation, you warrant that you have the authority to do so.

The Schedule

Date: 24 February 2004

Commonwealth

The Commonwealth of Australia is represented by the Department of the Environment and Heritage (DEH). The contact details are:

Dr Max Finlayson, Director, Environmental Research Institute of the Supervising Scientist

Address: GPO Box 461, Darwin, NT, 0801

Telephone: (08) 8920104

Facsimile: (08) 89201199

Email Address: max.finlayson@deh.gov.au

Licensees

Charles Darwin University (CDU), for Dr Sean Bellairs & Judy Manning.

Telephone: (08) 8946 6070

Facsimile: (08) 8946 6847

Email Address: sean.bellairs@cdu.edu.au

Email Address: judymanning@octa4.net.au

University of Groningen (Netherlands) and Charles Darwin University (Stefanie Vink).

Telephone: 0011 31 503632224

Email Address: email: stefanievink@hotmail.com or s.n.vink@student.rug.nl

The Data

1. The following data belong exclusively to the nominated parties and will be shared as specified in this agreement:

(a) All remote sensing data is the exclusive property of DEH. Hence, DEH is to maintain sole responsibility for remote sensing and ground-truthing work.

(b) All vegetation recruitment/development data relating to laboratory and shade house soil microbial biomass and soil seed bank experiments are to be the exclusive property of CDU. Hence, CDU is to maintain sole responsibility for shade house and laboratory experiments investigating seedling growth and survival, soil stored seed, soil microbial biomass and nutrient cycling, in relation to soil and on-site vegetation characteristics.

2. The following data are subject to joint ownership and shared IP rights and will be used as specified in this agreement:

(a) Dry (August/September 2003) and Wet season (April 2004) vegetation data obtained on ground transects at Nabarlek mine-site and the two reference areas. Information includes:

- plant biodiversity data
- cover and density data for trees and shrubs in $10m^2$ transect plots
- cover data for all grass, herb and sedge species in $10m^2$ transect plots
- soil nutrient and metal analyses relating to transects and other areas
- relevant photographic coverage's

(b) Raw and processed data relating to ground transect surveys of vegetation attributes at Nabarlek mine-site and two reference areas, and used to characterise vegetation and assess re-vegetation success.

Use of Data

1. The data belonging to DEH will be used by the Licensee for research and training purposes and results will be incorporated into a Masters thesis (Stefanie Vink) and Honours thesis (Judy Manning). Stefanie Vink will specifically relate vegetation characteristics derived from the August/September (dry season) ground survey, and the soil nutrient and metal analyses, to soil factors affecting growth and survival of some native seedling species at Nabarlek. Judy Manning will specifically relate vegetation characteristics derived from the planned April 2004 (wet season) ground survey to "Soil seed bank, soil microbial biomass and nutrient cycling characteristics affecting revegetation success at Nabarlek". Any other use of this data will be by written agreement between DEH and CDU.

2. The data belonging to CDU will be used by DEH to characterise the vegetation across the Nabarlek mine-site and in two reference (or analogue) areas not subjected to past mining impacts. Specifically, the data will be published as an SSD Internal Report (and/or as a Journal paper) that characterises the vegetation at Nabarlek and surrounds, with special reference to application of vegetation monitoring methods to Ranger Uranium Mine rehabilitation issues, and to a contemporary assessment of revegetation success at Nabarlek.

Additional Conditions:

1. That joint publications arising from the collaborative research are subjected to the DEH internal review process and approval.

2. That, if required by DEH, a suppression period of 6 – 12 months from the date of this agreement be applied to publication of the results from both the MSc and Honours theses, and other collaborative research, to allow time for appropriate stakeholder consultation processes.

Licence Conditions

1 Interpretation

1.1 In these Conditions, unless the contrary intention appears:

"Commercialise" in respect of the Data or a product or service derived from the Data, includes distributing, giving away, selling, letting for hire, or by way of trade, offering or exposing for sale or hire any article embodying the Data or any product or service derived from or incorporating the Data;

"Contributor" means:

I. (in relation to the Commonwealth) an agency of the Commonwealth which is custodian of a particular item of Data on behalf of the Commonwealth; or

II. third party contributors

identified in the Schedule to this Agreement as having provided particular items of Data which are the subject of this Licence Agreement;

"Data" means the data to which access is made available, and which is listed in the Schedule and includes any Enhancements to the Data;

"Enhancement", in relation to the Data, includes any modification, adaptation or redevelopment of the Data, any work derived from the Data, machine readable representations of any of the foregoing and any associated material intended at the time of its creation to be used primarily in conjunction with the Data;

"Intellectual Property" includes all copyright, and all rights in relation to registered and unregistered trademarks (including service marks), registered designs and confidential information (including trade secrets and know-how), and all other rights resulting from intellectual activity in the industrial, scientific, literary or artistic fields;

"Licence" means the licence referred to in Condition 3.

2 Duration

2.1 The Licence commences on the date of the Agreement as set out in the Schedule, and continues unless terminated in accordance with Condition 11.1. Where a defined duration for this Agreement is required this will be specified in the Schedule.

3 Licence Conditions

3.1 The Commonwealth grants to the Licensee, a royalty-free, non-exclusive, non-transferable licence to use, reproduce, make Enhancements to and print the Data, and combine it with other data held by the Licensee.

3.2 The Licensee is limited to use of the Data as specified in this agreement.

3.3 The Licensee shall not Commercialise Data belonging to the other party, or any product or service derived from that Data, without the permission of the owner of the Data.

3.4 The Commonwealth warrants that the grant of the Licence does not infringe the Intellectual Property rights of any person and that it is entitled to grant the licence in relation to the data of third party Contributors.

3.5 Data items identified in the Schedule as having been provided by individual Contributors are subject to the additional conditions (if any) set out in the Schedule. In the event of any conflict between the terms of the Licence Conditions and any additional condition set out in the Schedule, the terms of the Licence Conditions shall take precedence.

4 Intellectual Property Rights Reserved

4.1 All rights not expressly granted to the Licensee under Condition 3 are reserved.

4.2 The Licensee acknowledges that the Data are a special, unique and valuable product in which the copyright and other applicable Intellectual Property rights vest in the Contributors as listed in the Schedule.

4.3 The Contributors of items of Data retain ownership of that Data, whether in its original form or as modified by the Licensee and of the Intellectual Property rights therein.

4.4 Intellectual Property in any Enhancement to the Data vests, upon its creation, in the Contributor named in the Schedule in relation to the relevant item of Data.

5 Custody of the Data

5.1 The Licensee shall maintain the Data in safe custody.

5.2 The Licensee shall not give the data to any other person without the explicit written permission of DEH and after providing evidence that any such other person is aware of these Conditions and uses the Data only in accordance with this Agreement.

6 The Licensee must acknowledge the Contributor

6.1 All information products of whatever nature produced or derived from the shared data must acknowledge DEH and any third party contributors. The Licensee shall ensure that the appropriate acknowledgement and copyright notice is prominently displayed on all copies made of the data or enhanced products produced from the data.

> **"[Base data/Data] reproduced with the permission of the Supervising Scientist. Copyright Commonwealth of Australia (*or third party contributor*)"**

7 Publication

7.1 A copy of all reports produced by the Licensee using the data will be lodged with DEH unless agreed otherwise by DEH.

7.2 The Licensee shall present the information in a thesis lodged at CDU (Judy Manning and Stephanie Vink) and University of Groningen, Netherlands (Stephanie Vink) and provide a copy of the thesis to DEH. All further publications using the data shall be submitted to DEH for comment before being published. Where the Licensee and DEH disagree about any analysis of the information or interpretation placed on the information the Licensee agrees to allow DEH to append to the publication a succinct comment that outlines DEH views on the analysis or interpretation.

8. Precautions

8.1 The Commonwealth cannot guarantee that the data, including any third party data, is free from errors, and does not warrant the quality, performance or suitability of the data for any purpose.

8.2 The Licensee assumes responsibility for selection of the data to achieve any intended results, and for its use.

8.3 The Licensee assumes responsibility for the interpretation of any results obtained from use of the data, and must exercise all appropriate precautions before placing reliance on those results.

9 Retention of Notices

9.1 The Licensee shall not remove, obscure or interfere with any copyright notice, trademark, warning or disclaimer incorporated in the Data.

10 Commercial Exploitation

10.1 The Parties shall not Commercialise the Data or any product or service derived from incorporating the Data except as specified in this agreement without the prior written consent of the relevant Contributor(s).

10.2 A Contributor may grant or refuse consent in their absolute discretion and subject to any condition whatsoever, including payment of royalties.

10.3 Any of the Data or any product or service derived from incorporating the Data which is Commercialised in accordance with this clause, must be accompanied by or incorporate an appropriate acknowledgment of the Contributor as the source of the Data in the terms specified in the Schedule.

11 Termination

11.1 If the Licensee breaches any of these Conditions, the Commonwealth may terminate the Agreement immediately by notice in writing to the Licensee.

11.2 The termination of the Agreement under Condition 11.1 shall be without prejudice to the rights of either party accrued under the Agreement prior to termination.

11.3 The Licensee shall cease using DEH Data described at item number 1 in ‘the Data’ for any purpose from the date of termination of the Agreement and shall return the Data and any copies made of it to the Commonwealth within 30 days of the date of termination.

12 Entire Agreement

12.1 The Agreement supersedes all prior agreements and understandings between the parties relating to the Data and Data Products and constitutes the entire agreement between the parties.

13 Variation

13.1 No addition to or modification of any provision of the Agreement shall be binding unless it is made in writing and signed by both parties.

14 Assignment

14.1 The rights granted under the Licence are restricted solely to the Licensee and may not be assigned, transferred or sublicensed without the prior written consent of the Commonwealth.

14.2 The Commonwealth may grant or refuse consent in its absolute discretion and subject to any condition whatsoever.

15 Law

15.1 The Agreement shall be governed by and construed in accordance with the laws of the Australian Capital Territory.

16 Waiver

16.1 No forbearance, delay or indulgence by a party in enforcing the provisions of the Agreement shall prejudice or restrict the rights of that party, nor shall waiver of those rights operate as a waiver of any subsequent breach.

17 Severance

17.1 Any reading down or severance of a particular provision does not affect the remaining provisions of the Agreement.

18 Application

18.1 Where the Licensee is an agency of the Commonwealth of Australia, such that it is not permitted to enter into a binding legal agreement except as the Commonwealth, then the conditions shall be read as merely giving rise to an arrangement between the Department of the Environment and Heritage and the Licensee.

COMMONWEALTH	**LICENSEE**
Signed for and on behalf of Environment and Heritage	Signed for and on behalf of Department of the

9.6.1 MSc project brief (Stefanie Vink)

Ms Stefanie Vink is completing a Masters degree at the University of Groningen (Netherlands). A portion of that degree involves a research project that is expected to take three months. This research project involved an assessment of vegetation at the Nabarlek mine site in the dry season of 2003 and was undertaken under the supervision of Dr Sean Bellairs of Charles Darwin University and Dr Peter Bayliss of ***eriss***.

The Nabarlek mine site contains several quite different rehabilitation areas. These include evaporation pond areas which tend to retain water into the dry season and coarse textured freely draining waste rock and pit areas. Background information gathered prior to this project indicated that the dominant vegetation in the evaporation areas differed to that of the other rehabilitated areas.

The aims of this project were to assess differences in the vegetation composition and to determine if waterlogging was differentially affecting the establishment of some of the dominant rehabilitation species. As the project was of limited scale only preliminary glasshouse investigations could be carried out.

Stefanie Vink was involved in the design and monitoring of the vegetation survey that was carried out in September 2003, especially the vegetation and soil surface monitoring that was carried out in the 50 x 1 m^2 plots at each site. Results of the field survey are presented and discussed in this report. Analysis and writing up of the glasshouse trials is underway at the University of Groningen in the Netherlands. A copy of the thesis will be forwarded to the ***eriss*** library when completed and a summary of the glasshouse work will be provided in the next report.

9.6.2 Hons project (Judy Manning)

Functional sustainability and future successional development of the vegetations are two factors of key importance in assessing the rehabilitation of the Nabarlek mine. For a community to be sustainable it has to achieve satisfactory levels of a range of ecological functional processes. These functional processes include the recycling of nutrients sufficient to maintain the desired vegetation community, resilience of the community to disturbance and the retention of resources in the community. The community is also required to achieve a particular structure and composition to be successful and to maintain those characteristics over time.

Nutrient cycling is a key ecological process for maintaining a functional vegetation community. Vegetation litter needs to be broken down and decomposed so that the nutrients contained within are again available for plant growth, otherwise the vegetation will become nutrient deficient. Soil microbes are a critical component of this process of providing vegetation with a continual supply of nutrients. Soil bacteria and fungi transform nutrients from compounds that are not able to be taken up by plants to simple molecules that can be taken up by plant roots. The soil microbial population and the rate of breakdown of litter can both be measured. Both have been used as indicators of nutrient cycling capability during land rehabilitation in northern Australia.

Fire will be a frequent cause of disturbance at Nabarlek. The soil seed bank and the ability of species to resprout from protected buds provide indicators of the resilience of the community to fire. Differences in the proportion of species or individuals that are killed by fire to the species or individuals that are able to resprout following fire is also an indicator of the response characteristics of the community to fire. Where the soil seed bank is markedly different in composition it indicates differences in the likely future composition of the community. Species that are to become established in the community need to have a source of propagules present in the community. Thus the soil seed bank also provides an indicator of future development of the community.

The aim of this project is to assess functional characteristics of rehabilitated and unmined communities at the Nabarlek mine site and to discuss the implications of the findings to the sustainability of the rehabilitation. Specifically the study will characterise litter breakdown, soil microbial biomass and soil seed bank composition for evaporation pond, waste rock dump and pit rehabilitation areas at the Nabarlek site, along with two adjacent natural vegetation sites that have been minimally disturbed by mining. Ms Manning will also participate in assessing the vegetation composition and density of a range of sites at the end of the wet season.