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Revegetation of Nabarlek minesite

Seasonal comparison of groundcover vegetation on the minesite and adjacent natural reference areas (September 2003 & May 2004)

P Bayliss, K Pfitzner & S Bellairs

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Left: natural riparian forest with native grass and sedge understorey; Right: dense patch of 2 m tall perennial Mission grass and passionfruit vine on the minesite (Evaporation Pond 2) May 2004 (late wet season)

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Summary

1 A project was commenced by ***eriss*** in mid-2003 at Nabarlek minesite to quantitatively assess revegetation performance since 1995, and to develop survey methodologies applicable to the future rehabilitation of Ranger uranium mine.

2 Canopy cover and ground cover vegetation were characterised on sample transects located on rehabilitated areas of the minesite and on adjacent natural reference sites, and compared. Vegetation on transects was sampled also in two consecutive seasons; one in the late dry (September) of 2003 and another in the late wet (April) of 2004. Whilst the late dry season survey provided necessary ground cover information at a time of environmental stress, the late wet season survey provided more robust characterisation of species composition.

3 This Internal Report summarises the late wet season results for ground cover only and compares them to the ground cover in the dry season. Canopy cover (shrubs & trees) was not sampled in the wet season. The combined results are then used to determine whether or not the preliminary assessment of revegetation performance by Bayliss *et al.* (2004), based on the dry season survey, would suffice.

4 A total of 121 ground cover species were recorded during the wet season survey compared to 85 in the dry season. Of these 34 (28%) were grasses, 73 herbs (60%) and 14 (12%) sedges. There were 11 (32%) weed grasses and 17 (23%) weed herbs. An additional 23 grass species, 30 herb species and 10 sedge species were identified in the wet season compared to the dry season. In the wet season, weeds comprised 48% of all species on the minesite.

5 Twice as many native grass species were found on reference sites than mine sites in both seasons, and more native grasses were found in the wet season at both locations. Whilst no grass weed species were found on reference sites in the dry season, a trace amount of annual Mission grass (*Pennisetum pedicellatum*) was found in the Riparian site (end of Transect 1) in the wet season. About three times more native herb and weed herb species were found in the wet season compared to the dry season on reference sites and, in contrast, there were no seasonal differences on the minesite. Overall, five times more weed herb species were found on mine sites compared to reference sites. Despite more sedge species being recorded in the wet season, there was no significant difference on transects between seasons. However, there were three times more (native) sedge species on reference sites compared to mine sites in both seasons.

6 There were significant differences in ground cover between seasons (wet vs dry), locations (reference site vs mine sites), and plant class (grasses, herbs & sedges), with grasses>>herbs>>sedges. However, mine sites had about twice as much ground cover of grasses in the dry season than reference sites, although both had similar grass cover in the wet season. Mine sites had about five times more herb cover in the dry season than reference sites, and about twice that for the wet season. There were similar covers of sedges in both locations and seasons. The cover of all grasses on the minesite was similar between seasons and, in contrast, increased by 25% on reference sites in the wet season.

7 Reference sites remain largely free of grass weeds that typify the minesite. The cover of native grasses on reference sites was about five times that of mine sites in both seasons, and the cover of native grasses approximately doubled in the wet season in both locations. The cover of weed grasses was similar between seasons on the minesite. Whilst only a

trace amount of weed herb cover was found on reference sites in the dry season (<1%), this had increased to 4% in the wet season. In the dry season there was about twice the cover of native herbs on reference sites than mine sites and, in contrast, about seven times in the wet season.

8 Similar dominance ratios for biomass were found as for percentage ground cover (i.e. grasses>>herbs>>sedges). In the dry season there was about twice the amount of grass biomass on mine sites compared to reference sites and, in contrast, similar amounts of grass biomass in the wet season. In the dry season there was about 14 times more herb biomass on mine sites compared to reference sites, and 2.5 times in the wet season. In both seasons there was about twice the amount of sedge biomass on reference sites compared to mine sites, with the greatest contribution coming from the Riparian site. Mine sites had similar grass biomass between seasons and, in contrast, reference sites had 2.4 times more grass biomass in the wet season than the dry season. Mine sites had 2.9 times more herb biomass in the wet season than the dry season and, in contrast, that for reference sites 16 times more. Both mines sites and reference sites had 3.3 times more sedge biomass in the wet season than the dry season.

9 No grass weeds were found in the dry season on reference sites, and a trace amount was found in the wet season (<0.001 $t.ha^{-1}$). On reference sites there was 2.4 times more native grass biomass in the wet season than the dry season (6.2 cf 2.6 $t.ha^{-1}$). In contrast, mine sites had 4.7 times more native grass biomass in the wet season than the dry season (1.4 cf 0.3 $t.ha^{-1}$). Mine sites had similar amounts of weed grass biomass in both seasons (5.2 & 4.8 $t.ha^{-1}$ for wet & dry season respectively). Across both seasons there was 5.5 times more native grass biomass on reference sites compared to mine sites and, in contrast, 318 times more weed grass biomass on mine sites compared to reference sites.

10 As for the dry season, no woody seedlings were found in any of the 50 x $1m^2$ transects on the minesite in the wet season, suggesting that very little recruitment of woody canopy species is taking place. The dry season results were, therefore, not an artefact of seasonal sampling bias. Results of both seasonal surveys suggest that woody plant density on the minesite is unlikely to increase in the short term, and may decrease as a result of losses due to fire.

11 The wet season results reported here strongly support the preliminary assessment by Bayliss *et al.* (2004), based on dry season soil and plant data, that revegetation at Nabarlek has been largely unsuccessful in relation to the original goal of “blending in with the surrounding woodland”, despite the elapse of nine years. Significant management intervention, therefore, is required in order to achieve self-sustaining vegetation communities analogous to reference sites, in the medium term.

Revegetation of Nabarlek minesite: Seasonal comparison of groundcover vegetation on the minesite and adjacent natural reference areas (September 2003 & May 2004)

P Bayliss, K Pfitzner & S Bellairs

1 Introduction

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, and decommissioned between 1994-95. Rehabilitation earthworks commenced in mid-1995 and revegetation via seeding in late 1995. 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.

In 2003 the Alligator Rivers Region Technical Committee (ARRTC) identified the following three key research issues with respect to the revegetation component of rehabilitation in the region that need to be addressed: (i) what are the criteria for assessing revegetation success?; (ii) what are the indicators of success and how do we monitor them?; and (iii) what can we learn from Nabarlek? Hence, a vegetation assessment project was commenced by ***eriss*** in mid-2003 with the following two aims (Bayliss *et al.* 2004): (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. The basic survey design incorporates characterisation of vegetation canopy and ground covers on the rehabilitated areas of the minesite in comparison to adjacent natural reference sites, and in two consecutive seasons, one in the late dry (September) of 2003 and another in the late wet (April) of 2004. The latter survey was to encompass seasonal variation in ground cover attributes that characterise vegetation. The results of the first dry season survey, and a preliminary assessment of revegetation, are reported by Bayliss *et al.* (2004).

This Internal Report summarises the late wet season results for ground cover and then compares them to the dry season results. The combined results are then used to determine whether or not the preliminary assessment of revegetation performance by Bayliss *et al.* (2004), based on the initial dry season survey, would suffice.

2 Methods

2.1 Repeat sampling

The overall survey design and methods used to measure ground cover vegetation attributes are detailed by Bayliss *et al.* (2004), and summarised below. The post-mining environment at Nabarlek is highly variable, particularly features such as vegetation canopy and ground covers. Hence, 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:

1 Evaporation Pond 1 (EP1)

2 Evaporation Pond 2 (EP2)

3 Waste Rock Dump (WRD)

4 Mine Pit (PIT)

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 listed below represent the two extremes in topography and soil type found within the surrounding landscapes .

1 Eucalyptus dominated woodland (WL)

2 Riparian forest (RIP)

Three transects 50m in length were located in each site on aerial photographs (i.e. 3 replicates per 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. Transects were further stratified into subsamples to rapidly estimate canopy cover and ground cover attributes. There were three 10m x 10m (0.01ha) plots positioned at the start, middle and end of each transect, totalling 0.03 ha per transect or 0.36 ha across the minesite. Hence, only 0.51% of the total rehabilitated area was sampled across the variable minesite. For ease of sampling, each 0.01ha plot was divided into two 5m x 10m or 0.005 ha subplots, and data recorded in each and subsequently pooled.

Transects lines were permanently marked with five star pickets spaced 10m apart in September 2003, and the corners of 0.01 ha transect plots were permanently marked with yellow plastic cattle tags inserted into steel tent pegs in May 2004 (see Plate 1a).

The following ground cover attributes were re-measured in each 0.01ha plot along transects:

1 Number of species in each major vegetation class (grasses, herbs, sedges);

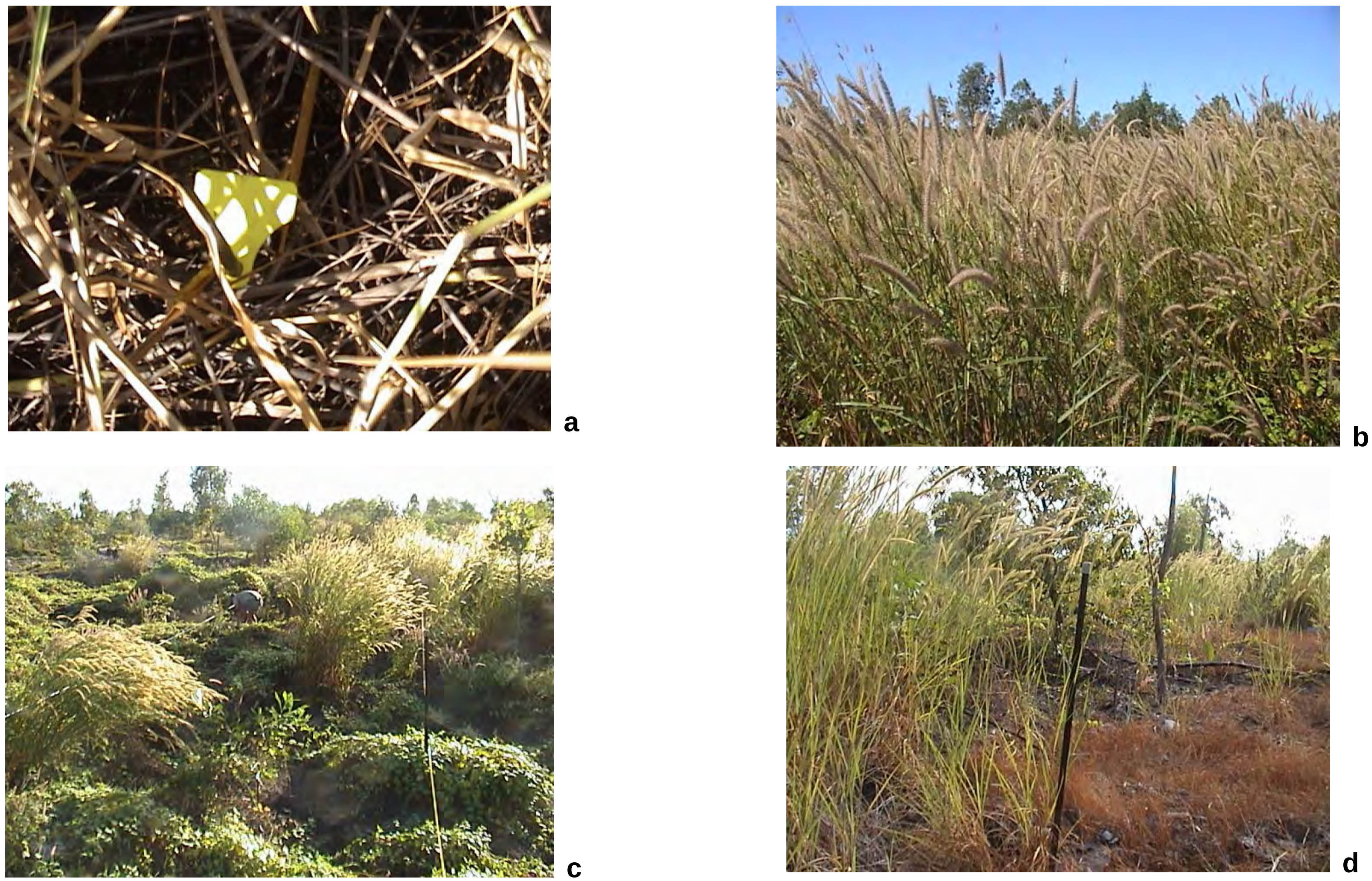
2 Projected percentage foliage cover of each species and their mean height (m); and

3 Projected percentage cover of litter and bare ground.

The visual calibration method used by Bayliss *et al.* (2004) to convert mean height and percentage cover estimates of plants/subplot to estimates of standing ground cover biomass (Oven Dry Weights, t.ha-1) is used here.

Using the same methods used in the dry season survey, 50m x 1m quadrats were positioned down the length of each transect line on the minesite only and searched for woody seedlings. The density of woody seedlings is used as an index of canopy cover recruitment.

Soils were not re-sampled in the wet season survey to determine seasonal variation in soil attributes. However, an additional sample (3 subsamples/transect) were collected in September 2004 to estimate total organic carbon and total nitrogen and, hence, C:N ratios.



Plates 1 a-d (a) Corner markers of transect plots: yellow plastic cattle tag inserted into a metal tent peg. Wet season vegetation flush on the minesite: (b) dense sward of annual Mission grass (Mine Pit); (c) clumps of annual and perennial Mission grass, and passionfruit vine (Waste Rock Dump); and (d) tall stand of perennial Mission grass and short cover of *Schizachyrium fragile* grass (Mine Pit). May 2004.

2.2 Fire response

On the 21st June 2004 an extensive fire occurred on the minesite over the Pit and Waste Rock Dump areas, and less extensively on the Evaporation Ponds area. A Quickbird satellite image was acquired and will be used to map the fire scar across the entire minesite. Additionally, fire scars were mapped in detail on ground transect plots in September 2004. The ground transect plots will be re-surveyed in the mid-wet season of 2005 to assess the influence of dry season burning on the composition and abundance of native and weed ground cover species, and the regrowth of woody seedlings. Such information may be important to manage extensive weeds across the minesite.

2.3 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 observed weighted means of ground cover of plants (%); biomass of ground cover ($t.ha^{-1}$ in contrast to $kg.ha^{-1}$ as reported for the dry season); 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). Input data were mean values for three 0.01ha plots/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). Figures, however, use untransformed observed weighted means. For the response variables listed above, the following *a priori* hypothesis testing contrasts were made between combined reference and combined mine sites, ground cover type (grasses, herbs, sedges; weeds vs natives). The Statistica™ software package (Statsoft 2003) was used to derive all statistical tests.

3 Results

3.1 Ground cover (grasses, herbs and sedges)

3.1.1 Species composition

A total of 121 ground cover species were recorded during the wet season survey (see Appendix 1) compared to 85 in the dry season. Of these 34 (28%) were grasses, 73 herbs (60%) and 14 (12%) sedges. There were 11 (32%) weed grasses and 17 (23%) weed herbs.

An additional 23 grass species, 30 herb species and 10 sedge species were identified in the wet season compared to the dry season. No weed sedges were recorded in both seasons. Across all sites the ground cover in the wet season comprised 23% weed species with most recorded on the minesite, in contrast to 40% recorded for the dry season. The apparent seasonal decrease in the proportion of weed species simply reflects the large increase in number of new annual native species recorded in the wet season. Nevertheless, on the minesite in the wet season, weeds comprised 48% of plant species which contrasts to results from previous surveys (30%, Brennan & Bach 1994 for the WRD area before rehabilitation; 37% in 1996 and 1997, Adams & Hose 1999).

Dry season data, however, include many grasses identified to genus level only. In contrast, wet season data contain a low number of unidentified plants to species level and, hence, more accurately reflect species composition both on and off the minesite.

There were significant interactions between factors Season (wet & dry), Location (reference sites vs mine sites) and Plant Class (native & weed grasses & herbs) (Table 1): twice as many native grass species were found on reference sites than on mine sites in both seasons, and more native grasses were found in the wet season (Fig. 1a) on and off the minesite. Whilst no grass weed species were found on reference sites in the dry season, one small clump (~ 1% cover) of annual Mission grass was found in the Riparian site (end of transect 1) in the wet season.

Table 1 3-ANOVA summary of mean number of species per transect by factors Season (dry vs wet), Location (reference vs mine sites) and Plant Class (weed vs native, herbs vs grasses)

Factor	df	F	P
Season	1	53.6	P<0.001
Location	1	24.7	P<0.001
Plant Class	3	33.4	P<0.001
Season*Location	1	23.9	P<0.001
Season*Plant Class	3	8.3	P<0.001
Location*Plant Class	3	61.1	P<0.001
Season*Location*Plant Class	3	17.9	P<0.001
Error	128		

About three times more native herbs and weed herb species were found in the wet season compared to the dry season on reference sites and, in contrast, there were no seasonal differences on the minesite (Fig. 1b). Overall, there was five times more weed herbs found on mine sites compared to reference sites.

Despite more sedge species being recorded on transects in the wet season, there was no significant difference between seasons (Fig. 1c). However, there were three times more (native) sedge species on reference sites compared to mine sites in both seasons ($F_{1/32}$ = 11.22, P=0.002).

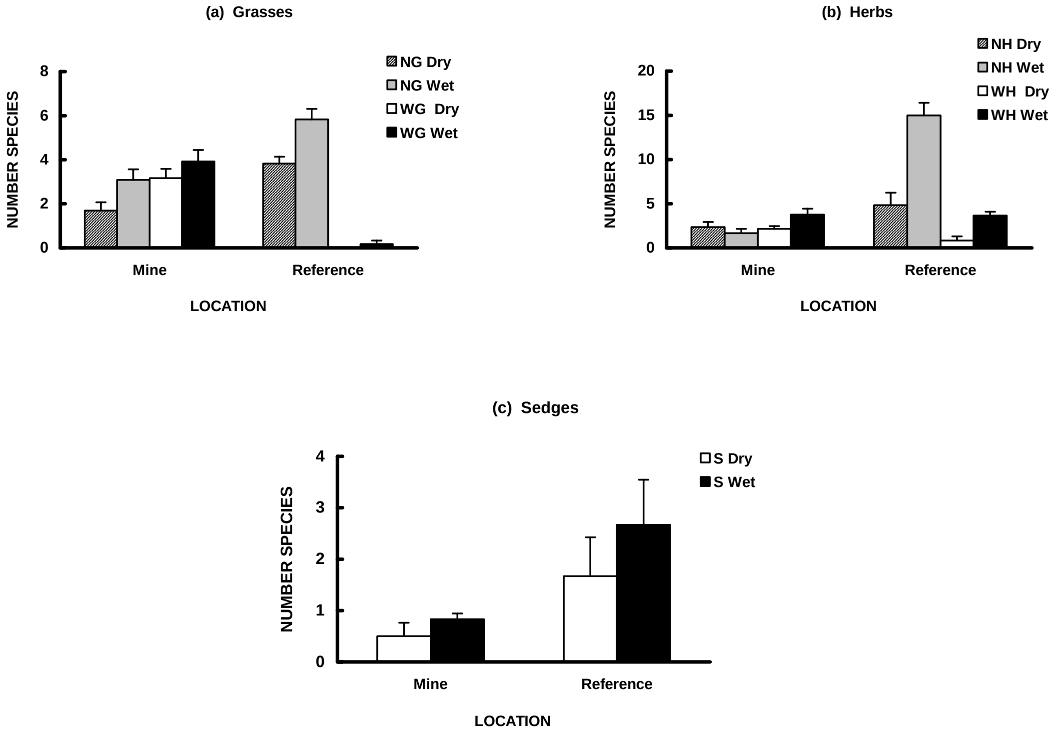


Figure 1 a-c Comparison between mean number of (a) native grass (NG) and weed grass (WG) species, and weed herb (WH) and native herb (NH) species, between seasons (dry & wet) and location (reference sites vs mine sites). (c) Comparison of mean number of sedge species between seasons (dry & wet) and location (reference sites vs mine sites). Mean biomass of ground cover plants in 3 x 0.01ha plots/transect were first derived, averaged across the 3 transects/site and then averaged for reference sites and mine sites. Vertical lines are standard errors.

3.1.2 Percentage ground cover

There were significant differences in ground cover between factors Season, Location, and Plant Class (grasses, herbs & sedges), with grasses>>herbs>>sedges. However, there was a significant interaction between Location and Plant Class, and Season and Location (Table 2; Fig. 2a-c). The first interaction results from the mine sites having about twice as much ground cover of grasses in the dry season than reference sites, although both locations had similar grass covers in the wet season. Mine sites had about five times more herb cover in the dry season than reference sites, and only about twice the herb cover in the wet season. There were similar covers of sedges in both locations and seasons. The second interaction was because the cover of all grasses on the minesite was similar between seasons (an observed 10% decrease in the wet season) and, in contrast, increased significantly by 25% on reference sites in the wet season.

Table 2 3-ANOVA summary of mean percentage cover per transect (arcsine transformed by factors Season (dry & wet), Location (reference & mine sites) and Plant Class (grasses, herbs & sedges)

Factor	Df	F	P
Season	1	16.4	P<0.001
Location	1	6.0	0.016
Plant Class	2	105.9	P<0.001
Season*Location	1	5.9	0.017
Season*Plant Class	2	1.7	NS
Location*Plant Group	2	5.3	0.007
Season*Location*Plant Class	2	2.5	NS
Error	96		

NS = not significant

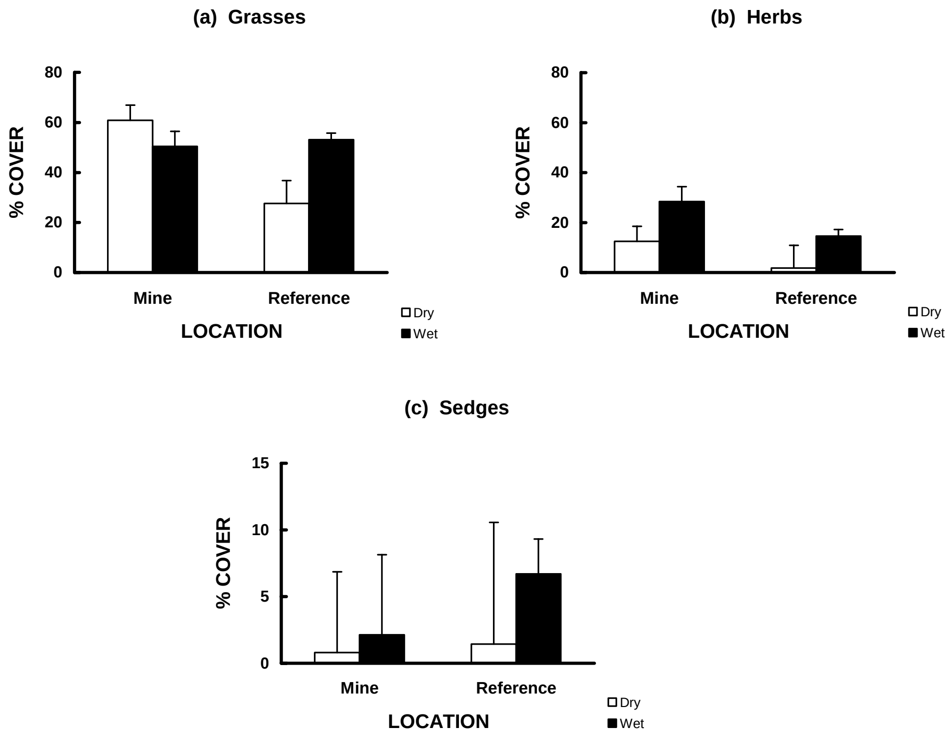


Figure 2 a-c Comparison between mean percentage cover of (a) grasses, (b) herbs and (c) sedges between seasons (dry & wet) and locations (reference sites vs mine sites). Note that the sedge cover axis is scaled 0-15%. Mean biomass of ground cover plants in 3 x 0.01ha plots/transect were first derived, averaged across the 3 transects/site and then averaged for reference sites and mine sites. Vertical lines are standard errors.

Table 3 3-ANOVA summary of mean percentage cover per transect (arcsine transformed) by factors Season (dry vs wet), Location (reference vs mine sites) and Plant Class (native grasses & herbs vs weed grasses & herbs)

		GRASSES		HERBS	
Factor	**df**	**F**	**P**	**F**	**P**
Season	1	0.8	NS	14.60	<0.001
Location	1	7.0	0.010	5.67	0.020
Plant Class	1	3.0	NS	3.13	NS
Season*Location	1	2.9	NS	1.28	NS
Season*Plant Class	1	8.2	0.006	1.60	NS
Location*Plant Group	1	94.1	<0.001	29.85	<0.001
Season*Location*Plant Class	1	0.1	NS	6.87	0.011
Error	64				

NS = not significant

There were significant differences in mean ground cover (%) between factors Season, Location and Plant Class (native & weed grasses & herbs), however there were also significantly strong interactions between Location and Plant Class, and all three factors (see Table 3 for grasses & herbs). Across Season and Location, the cover of grasses was about 2-3 times that of herbs.

Whilst no grass weeds were found on reference sites in the dry season, one small clump (<0.1% mean cover) of annual Mission grass (*Pennisetum pedicellatum*, Plate 1b) was found on the Riparian site (end of transect 1) in the wet season. Hence, reference sites remain largely free of grassy weeds that typify the minesite (Fig. 3a).

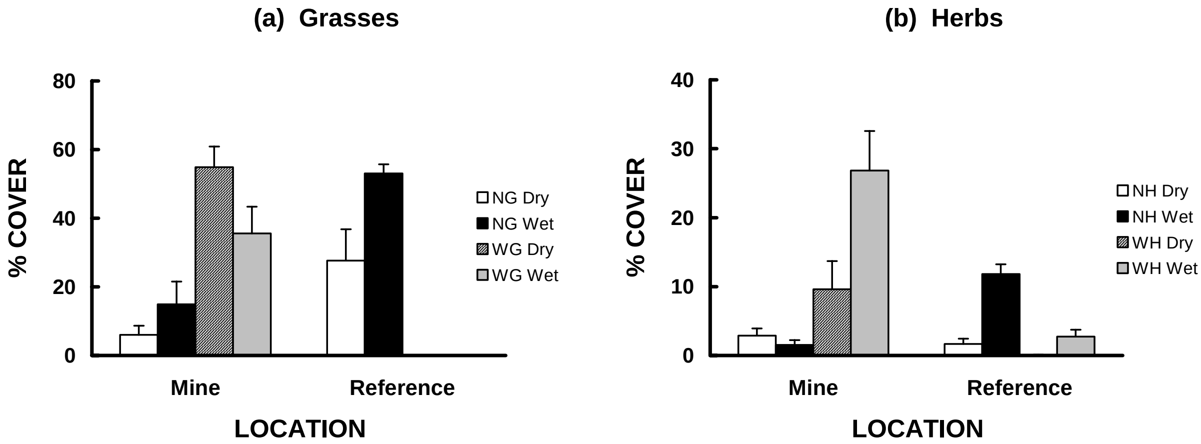


Figure 3 a & b Comparison between mean ground cover (arcsine transformed) of (a) native and weed grasses, and (b) native and weed herbs between seasons (dry and wet) and locations (reference sites vs mine sites). Mean biomass of ground cover plants in 3 x 0.01ha plots/transect were first derived, averaged across the 3 transects/site and then averaged for reference sites and mine sites. Vertical lines are standard errors.

The cover of native grasses on reference sites was about five time that of mine sites in both seasons, and the cover of native grasses approximately doubled in the wet season in both locations. The cover of weed grasses was not significantly different between seasons on the minesite, although the observed mean decreased by about 20% (see above & Fig. 3a). Both annual (Plate 1b) and perennial (Plates 1c & d) species of Mission grass were easily differentiated in the wet season and combined for analysis, hence the slight decrease in grass cover on the minesite was not due to confusion between these two species in the dry season. Additionally, because tall dry grasses were more easily identified to species in the wet season, it appears that sorghum (*Sorghum plumosum*) was mistaken for Mission grass in the dry season on two transects in the PIT site. Regardless, even adding the sorghum cover to Mission grass cover still produced a decrease of 15% grass cover across the minesite in the wet season. This decrease may be real as much of the extensive cover of dry standing annual Mission grass encountered during the dry season had fallen over and was classified as litter in the wet season. It may be replaced fully in the early dry season period.

Whilst only a trace amount of weed herb cover was estimated on reference sites in the dry season (<1%), this had increased to 4% in the wet season (Fig. 3b). In the dry season there was about twice the amount of native herb cover on reference sites than mine sites and, in contrast, there was about seven times the amount in the wet season (Fig. 3).

3.1.3 Biomass

There was no significant differences in overall ground cover biomass between Location (reference sites vs mine sites), but significant differences between Season (wet vs dry) and Plant Class (grasses, herbs & sedges) (Table 4). Similar dominance ratios for biomass were found as for percentage ground cover (i.e. grasses>>herbs>>sedges). However, there was a significant and complex interaction between Season and Plant Class (Table 2; Fig. 4a-c). In the dry season there was about twice the amount of grass biomass on mine sites compared to reference sites and, in contrast, similar amounts of grass biomass in the wet season. In the dry season there was about 14 times more herb biomass on mine sites compared to reference sites, and reduced to 2.5 times in the wet season. In both seasons there was about half the amount of sedge biomass on mine sites compared to reference sites, the greatest contribution coming from the Riparian sites. The mine sites had similar grass biomass between seasons and, in contrast, reference sites had 2.4 times more grass biomass in the wet season compared to the dry season. Mine sites had about 3 times more herb biomass in the wet season compared to the dry season. In contrast, reference sites had 16 times more herb biomass in the wet season compared to the dry season. Both mines sites and reference sites had 3.3 times more sedge biomass in the wet season compared to the dry season.

As in the dry season, grasses contributed most to ground cover biomass in the wet season. However, many more annual native grasses were present in the wet season. The following ANOVA compares differences in grass biomass between factors Season (dry vs wet), Location (reference sites vs mine sites) and Plant Class (native vs weed).

There were no significant differences in grass biomass across Season, Location and Plant Class, however, there was a was a significant interaction between Season and Plant Class

Table 4 3-ANOVA summary of mean biomass per transect ($t.ha^{-1}$) by factors Season (dry vs wet), Location (reference vs mine sites) and Plant Class (grasses, herbs & sedges)

Factor	df	F	P
Season	1	7.0	0.009
Location	1	3.0	NS
Plant Class	2	98.8	<0.001
Season*Location	1	2.1	NS
Season*Plant Class	2	3.7	0.027
Location*Plant Class	2	1.7	NS
Season*Location*Plant Class	2	2.5	NS
Error	96		

NS = not significant

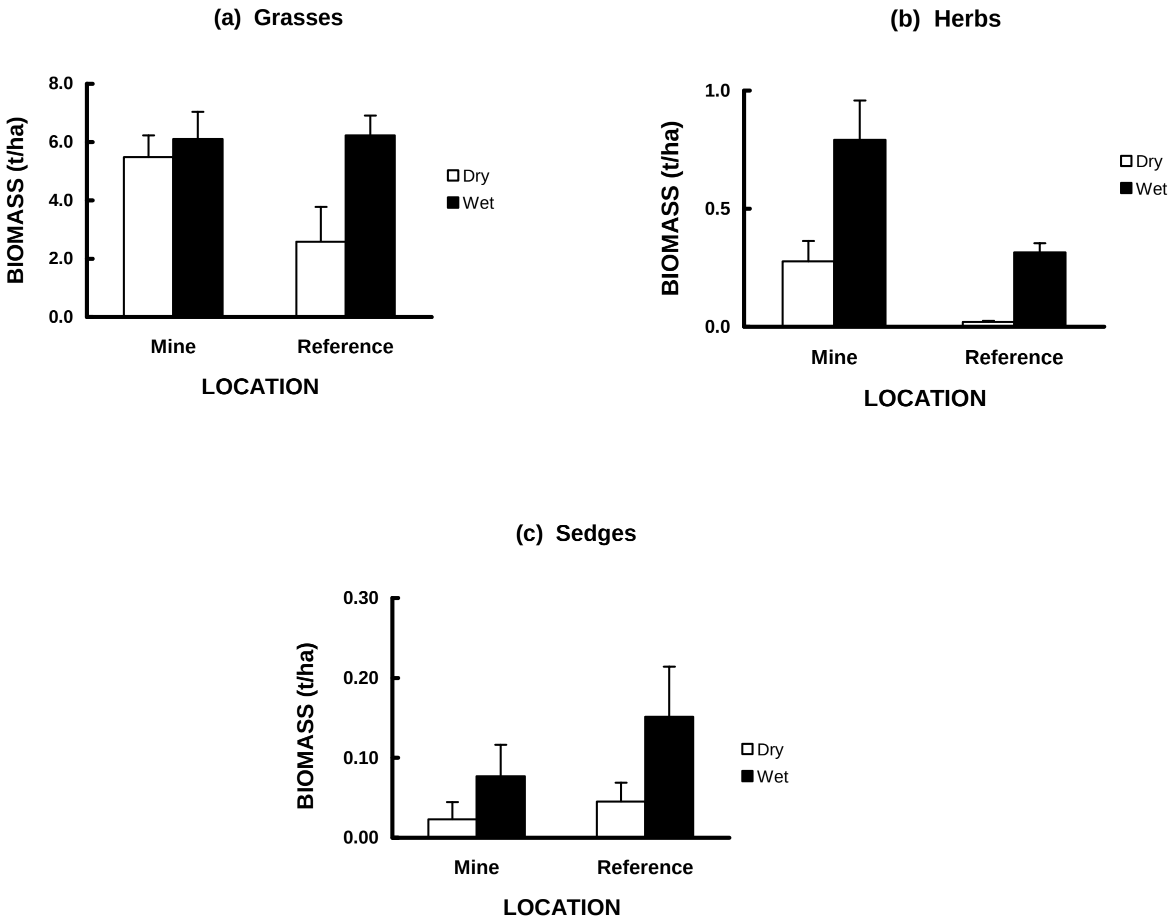


Figure 4 a-d Comparison between mean above ground biomass (ODW, t.ha^{-1}) between seasons (wet vs dry), locations (reference sites vs mine sites) and plant class (grasses, herbs & sedges). See Appendix 9.2 in Bayliss *et al*. (2004) for method of estimating biomass. Mean biomass of ground cover plants in 3 x 0.01ha plots/transect were first derived, averaged across the 3 transects/site and then averaged for reference sites and mine sites. Vertical lines are standard errors.

Table 5 3-ANOVA summary of mean biomass per transect (t.ha^{-1}) by factors Season (dry vs wet), Location (reference vs mine sites) and Plant Class (native & weed grasses).

Factor	df	F	P
Season	1	3.1	NS
Location	1	1.3	NS
Plant Class	1	0.0	NS
Season*Location	1	1.6	NS
Season*Plant Class	1	4.5	0.039
Location*Plant Group	1	50.4	<0.001
Season*Location*Plant Class	1	0.8	NS
Error	64		

NS = not significant

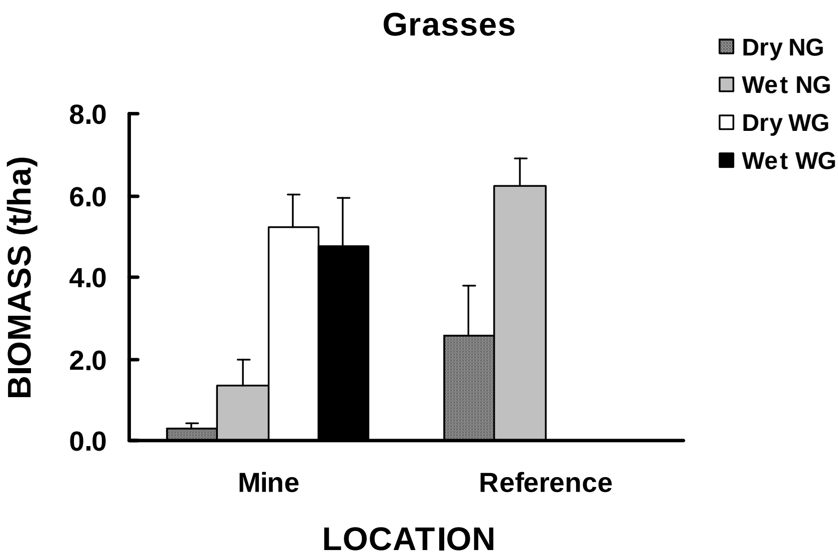


Figure 5 Comparison between mean biomass (ODW, t.ha^{-1}) of grass between seasons (dry vs wet), locations (reference sites vs mine sites) and plant class (native vs weed). The mean biomass of 3 x 0.01ha plots/transect were first derived, averaged across the 3 transects/site, and then averaged for reference sites and mine sites. Vertical lines are standard errors.

No grass weeds were found in the dry season on reference sites but a trace amount was found in the wet season on Transect 1 (~ 0.001 t.ha^{-1}). On reference sites there was 2.4 times more native grass biomass in the wet season than the dry season (6.2 cf 2.6 t.ha^{-1}). In contrast, on mine sites there was 4.7 times more native grass biomass in the wet season compared to the dry season (1.4 cf 0.3 t.ha^{-1}). Mine sites had similar amounts of weed grass biomass in both seasons (5.2 & 4.8 t.ha^{-1} for wet & dry season respectively). Across both seasons there was 5.5 times more native grass biomass on reference sites compared to mine sites and, in contrast, 318 times more weed grass biomass on mine sites compared to reference sites.

3.2 Woody seedling density

No woody seedlings were found on any of the 50 x 1m^2 transects on the minesite in the dry season and similarly for the wet season, suggesting that very little recruitment of woody canopy species is taking place. Therefore the dry season results were not an artefact of seasonal sampling bias.

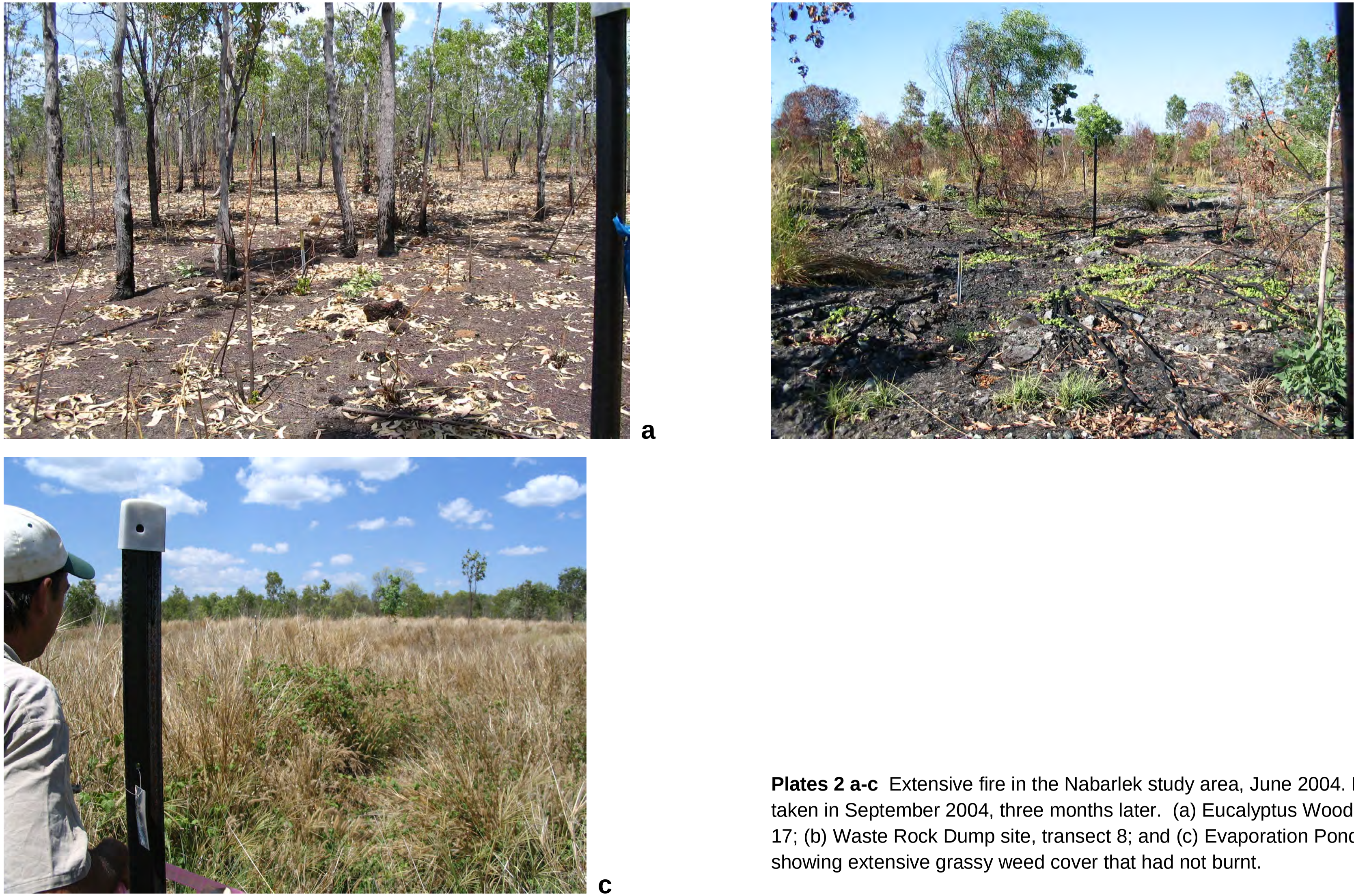
3.3 Fire on the minesite

Appendix 8.3 summarises the proportion (% cover) of each transect subplot that was burnt by the June 2004 fire. The Riparian and Evaporation Pond 2 sites escaped burning.

4 Discussion

4.1 Revegetation assessment

The results reported here contrasts ground cover vegetation attributes on Nabarlek minesite with adjacent natural reference sites in the late 2004 wet season and, strongly support the preliminary assessment by Bayliss *et al.* (2004), based on dry season soil and plant data, that revegetation has been largely unsuccessful in relation to the original goal of “blending in with the surrounding woodland”.



a

b

c

Plates 2 a-c Extensive fire in the Nabarlek study area, June 2004. Photos by G. Fox taken in September 2004, three months later. (a) Eucalyptus Woodland site, transect 17; (b) Waste Rock Dump site, transect 8; and (c) Evaporation Pond 2 site, transect 6, showing extensive grassy weed cover that had not burnt.

Bayliss *et al.* (2004) recommended that management options for a new revegetation plan, particularly for the Evaporation Ponds, should be developed. A necessary first step, however, is that new closure criteria need to be developed by the Nabarlek Minesite Technical Committee (MTC) stakeholders in consultation with Traditional Land Owners. These management options could then be considered by the Nabarlek MTC and may incorporate continuation of the vegetation monitoring and assessment project commenced by ***eriss*** and, ideally, in collaboration with Demed Land Management Rangers. Bayliss and Pfitzner (2004) suggested that one option for on site management of any new pragmatic revegetation plan would be to implement it through the Mining Management Plan. They suggested also that in order to expedite this process, stakeholders on the Nabarlek MTC consider joining forces this Financial Year to employ a community land management coordinator to facilitate:

1 development of closure criteria (or revisiting old closure criteria) for the new revegetation plan that incorporates Indigenous cultural values and reference to time frames necessary to achieve revegetation milestones;

2 provision of research and technical advice in the development of all viable management options proposed to the Nabarlek MTC; and

3 estimation of the costs and time frames of all management options, in particular strategies for replanting, the sustainable management of all significant weeds and close monitoring of the performance of agreed plans.

4.2 Future vegetation monitoring

Vegetation has now been characterised at Nabarlek minesite and on adjacent natural reference sites sufficiently to form the first quantitative base line for future monitoring and assessment purposes. The first dry season survey established the base line for canopy cover attributes, and the dry and wet season surveys combined established the base line for ground cover attributes. Additionally, a base line for soil properties was established in the first dry season survey. The contrast in soil and vegetation characteristics was so great (Bayliss *et al.* 2004, & this report) that we consider the limited sample size (n=12 transects on the minesite, 0.17% of rehabilitated area; n=6 transects on reference sites) to have sufficient power for medium term (5-10 years) monitoring purposes. However, if the contrast in vegetation characteristics between the minesite and reference sites becomes less, then more sample effort may be required to detect differences, and this is particularly important with respect to having more quantitative and explicit revegetation success criteria with defined agreed upon differences in key vegetation attributes.

In order to track vegetation performance, we recommend that wet season ground surveys be undertaken every three years at the most for canopy cover (in the absence of large-scale disturbance to trees & shrubs), and every two years at least for ground cover. However, Bayliss and Pfitzner (2004) recommended that Nabarlek stakeholders develop new pragmatic revegetation closure criteria in consultation with Traditional Owners. Hence, the frequency of monitoring and assessment of revegetation performance at Nabarlek would depend to a large extent on what these criteria are. Nevertheless, each survey would require four people for five days in the field. Plant identification, data analysis and reporting would require two people for two weeks. Standardised data bases for canopy and ground cover data have been established in Excel, and includes VB programs for rapid analysis.

The findings of this report and the previous report by Bayliss et al (2004) indicate that active management of the mine rehabilitation area is likely to be necessary to reduce the weed abundance on the sites and to increase woody plant establishment. If actions are undertaken to reduce weed abundance and to increase woody densities, then at least annual monitoring of the effects of these actions needs to be undertaken to allow adaptive management to occur. The monitoring would be targeted to assess the effect of specific management actions and would not be as extensive as the triennial monitoring activities.

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7 Appendices

7.1 Plant species found on transects in the late 2004 wet season (May)

GRASSES		HERBS		VINES		SEDGES
Native/Weed	**Genus species**	**Native/Weed**	**Genus species**	**Native/Weed**	**Genus species**	**Genus species**
N	Aristida holathera	N	Allium cernum	N	Ipomea abrupta	Arthrostylis aphylla
N	Aristida ingrata	N	Alysicarpus schomburgkii	N	Ipomea diversifolia	Cyperus iria
N	Bothriochloa bladhii	N	Alternanthera augustifolia	N	Ipomea eriocarpa	Fimbristylis composita
N	Chrysopogon fallax	N	Bergia pusilla	N	Ipomea sp1	Fimbristylis dichotoma
N	Digitaria bicornis	N	Blumea axillaris (probably)	N	Merremia quinata	Fimbristylis furva
N	Digitaria gibbosa	N	Blumea sp1	N	Tephrosia remotiflora	Fimbristylis pauciflora
N	Dimeria ornithopoda	N	Blumea tenella	N	Xenostegia tridentata	Fimbristylis phaeoleuca
N	Eragrostis potamophila	N	Bonamia pannosa	W	Passiflora foetida	Fimbristylis squarrulosa
N	Eragrostis spartinoides	N	Buchnera asperata			Leptocarpus spathaceus
N	Eriachne burkittii	N	Buchnera sp			Rhynchospora longisetis
N	Eriachne major	N	Cartonema parviflorum			Tricostularia undulata
N	Heteropogon contortus	N	Cartonema spicatum			Xyris cheumatophila
N	Heteropogon triticeus	N	Cartonema trigonospermum			Scleria brownii
N	Imperata cylindrica	N	Cyanthillium cinereum			Scleria novae-hollandiae
N	Pseudopogonatherum contortum	N	Euphorbia muelleri			
N	Pseudopogonatherum irritans	N	Euphorbia schizolepis			
N	Pseudoraphis spinescens	N	Euphorbia schultzii			
N	Rottbeollia cochinchinensis	N	Fabacea sp			
N	Schizachyrium fragile	N	Galactia tenuiflora			
N	Sorghum plumosum	N	Gomphrena flaccida			
N	Yakirra nulla	N	Goodenia armstrongiana			
W	Andropogon gayanus	N	Goodenia pilosa			
W	Chloris inflata	N	Goodenia porphyrea			
W	Chloris gayana	N	Haemodorum sp			
W	Chloris virgata	N	Hybanthus enneaspermus			
W	Cynodon dactylon	N	Hydrolea zeylanica			
W	Echinochloa colona	N	Jacquemontia browniana			
W	Melinis repens	N	Ludwigia octovalvis			
W	Paspalum plicatulum	N	Ludwigia perenis			
W	Pennisetum pedicellatum	N	Malachra fasciata			
W	Pennisetum polystachion	N	Marsdenia viridiflora			
W	Setaria sp	N	Minuria macrorhiza			
W	Sporobolus sp	N	Mitrasacme connata			
W	Urochloa maxima	N	Mollugo pentaphylla			
W	Urochloa mutica	N	Murdannia graminea			
		N	Pachynema junceum			
		N	Pachynema sphenandrum			
		N	Phyllanthus eutaxioides			
		N	Physalis minima			
		N	Polycarpaea holtzei			
		N	Polygala longifolia			
		N	Polygala triflora			
		N	Ptilotus corymbosus			
		N	Pycnospora lutescens			
		N	Sauropus ditissoides			
		N	Scoparia dulcis			
		N	Sebastiana chamaelea			
		N	Sowerbaea alliacea			
		N	Spermacoce stenophylla			
		N	Stylidium semipartitim			
		N	Stylidium turbinatum			
		N	Thysanotis banksii			
		N	Utricularia chrysantha			
		W	Aeschynomene americana			
		W	Alysicarpus vaginalis			
		W	Euphorbia heterophylla			
		W	Euphorbia hirta			
		W	Hyptis suaveolens			
		W	Macroptilium atropurpureum			
		W	Macroptilium lathyroides			
		W	Sida acuta			
		W	Sida rhombifolia			
		W	Stylosanthes hamata			
		W	Stylosanthes viscosa			
		W	Tridax procumbens			

7.2 Photo-reference numbers of Transects (taken from zero unless otherwise stated)

Site	Transect	Date	Photo numbers	Notes
RIPARIAN	1	11/05/04	1, 2, 3 & 4	down line & to left, 3 pig rooting, 4 Judy's peg
RIPARIAN	2	11/05/04	5 & 6	6 off to left
RIPARIAN	3	11/05/04	7 & 8	both down line, 9 & 10 car bog
EP2	4	12/05/04	1 & 2	1 down line, 2 to left
EP2	5	12/05/04	3 & 4	3 down line, 4 to left
EP2	6	12/05/04	5 & 6	5 down line, 6 to left
WRD	7	14/05/04	5 & 6	down line & to left from end
WRD	8	14/05/04	3 & 4	down line from end
WRD	9	14/05/04	1 & 2	down line from end
PIT	10	14/05/04	7 & 8	down line & to left
PIT	11	14/05/04	9 & 10	down line & to left
PIT	12	14/05/04	11 & 12	down line & to left
EP1	13	14/05/04	13 & 14	down line & to left
EP1	14	14/05/04	!5, 16 & 17	15 down line, 16 to left, 17 to right
EP1	15	14/05/04	18 & 19	
WOODLAND	16	11/05/04	13 & 14	13 down line, 14 to left
WOODLAND	17	11/05/04	15 & 16	15 down line, 16 to left
WOODLAND	18	11/05/04	11 & 12	11 down line, 12 to left

7.3 Percentage of Transect 0.01 ha^{-1} plots burnt in June 2004 (data collected by G Fox)

Site	Transect	0-10	10-20	20-30	30-40	40-50	Photo numbers
RIPARIAN	1	0	0	0	0	0	15
RIPARIAN	2	0	0	0	0	0	16
RIPARIAN	3	0	0	0	0	0	17
EP2	4	0	0	0	0	0	13 & 14
EP2	5	0	0	0	0	0	12
EP2	6	0	0	0	0	0	11
WRD	7	100	100	100	100	100	3 & 4
WRD	8	100	100	100	100	100	2
WRD	9	100	100	100	100	100	1
PIT	10	100	100	100	100	100	5
PIT	11	5A 100	4A 100	100	100	100	6
		5B 0	4B 0				
PIT	12	1A 30	2A 30	3A 5	4A 0	0	7
		1B 25	2B 25	3B 10	4B 75		
EP1	13	100	100	100	100	100	10
EP1	14	100	100	100	100	100	9
EP1	15	100	100	100	100	100	8
WOODLAND	16	100	100	100	100	100	20
WOODLAND	17	100	100	100	100	100	18 & 19
WOODLAND	18	100	100	100	100	100	21