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Nabarlek revegetation project – presentations to ARRTC and Nabarlek MTC

P Bayliss, K Pfitzner & S Bellairs

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Nabarlek revegetation project – presentations to ARRTC and Nabarlek MTC

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Contents

Background

This report combines all key presentation outputs associated with the Nabarlek revegetation project, encompassing ARRTC Key Knowledge Need 4.1

Section 1 is a Discussion Paper presented to the 13th ARRTC meeting, 15–17th March 2003, by P. Bayliss & K. Pfitzner (2003): 'Revegetation of Nabarlek minesite: Preliminary characterisation of vegetation on the minesite and surrounding landscape'.

Section 2 is a Discussion Paper presented to the 14th ARRTC meeting, 13–15th September 2004, by P. Bayliss & K. Pfitzner (2004): 'Revegetation research on Nabarlek and Ranger mine sites'.

Section 3 is a combination of two Power Point presentations given at the Nabarlek MTC on 18th March 2003:

- Nabarlek revegetation assessment using remote sensing (K. Pfitzner);
- Preliminary characterisation of vegetation on Nabarlek minesite and adjacent natural landscapes (P. Bayliss, K. Pfitzner & S. Bellairs).

Paper prepared by

Peter Bayliss and Kirrilly Pfitzner

for the 13th Meeting of the Alligator Rivers Region Technical Committee (ARRTC)

15-17 March 2004

Revegetation of Nabarlek minesite

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

For the 13th Meeting of ARRTC (15-16th March 2004)

ARRTC Key Knowledge Need:

Develop revegetation monitoring techniques at Nabarlek minesite using remote sensing and ground-based surveys to assess revegetation success.

1.0 Background

One of the Key Knowledge Needs identified by ARRTC under the ***eriss*** Rehabilitation theme is to develop revegetation monitoring techniques at Nabarlek minesite using remote sensing and ground-based surveys to assess revegetation success. Hence, a project was commenced in August 2003 with the following two aims:

(i) to develop ground and remote sensing monitoring and assessment methods for revegetation that can be applied to Ranger uranium mine; and

(ii) to provide a quantitative assessment of the success of revegetation, based on a comprehensive characterisation of soils and plants across the minesite in comparison to adjacent reference sites.

An Internal Report is being prepared in collaboration with revegetation expert Dr Sean Bellairs (Charles Darwin University). The report, available as a draft, outlines progress to date and summarises the results of a ground-based vegetation survey conducted in the late dry season of 2003 (Bayliss, Bellairs, Pfitzner & Vink 2004: Preliminary characterisation of vegetation on Nabarlek minesite and on adjacent natural landscapes in September 2003). A comprehensive characterisation of minesite vegetation condition in relation to adjacent reference sites, and an accompanying assessment of revegetation success, will be made with additional wet season data. Additionally, analysis of complementary high resolution remote sensing captures of Nabarlek in both seasons will commence this year and will provide a "whole of landscape assessment". Furthermore, the results of two CDU postgraduate studies examining soil-plant relationships are yet to be submitted, and will be included in any comprehensive assessment. Outlined below are the Executive summary and Results summary of the report, and three key 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 one photo-point monitoring study (Welch & Gibson 2002). The assessment of revegetation success by Adams and Hose (1999) is contentious because it was carried out two years after revegetation commenced and, nevertheless, cannot be verified. 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 quantitative assessment of the success of revegetation at Nabarlek based on a comprehensive characterisation of soils and vegetation across the mine site 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 minesite vegetation condition in relation to reference sites, and an accompanying assessment of revegetation success, will be made with additional wet season data. Additionally, analysis of complementary high resolution remote sensing captures of Nabarlek in both seasons will commence this year and provide a "whole of landscape assessment". Furthermore, the results of two CDU postgraduate studies examining soil-plant relationships are yet to be submitted, and will be included in future comprehensive revegetation 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 sites sampled with respect to the original objective of blending in with the surrounding landscape. This was also the consensus view expressed by the Nabarlek Rehabilitation Workshop in 2000, five years after revegetation.
7. It is recommended that key research into soil-plant relationships at Nabarlek be implemented, especially in relation to: soil constraints to plant growth and survival; soil seed bank of weeds; ecological interactions between weeds, fire and native plant succession; and further assessment of Landscape Function Analysis as a complementary tool for monitoring rehabilitation success.
8. Management options for the least successful mine site area (Evaporation Pond 2; 35% of rehabilitated area) should now be considered a real possibility by the Nabarlek MTC and

ARRTC. Practical, pragmatic and defensible options should be explored in partnership with Nabarlek Traditional Land Owners and other key stakeholders, and incorporate continued quantitative monitoring and assessments of revegetation success and, critical new research knowledge.

9. On site management could be implemented in the form of increased government and industry support and advice for the current Demed revegetation, fire and weed management programs.

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 50m-transects were located randomly in each strata and orientated along an upslope-down slope gradient. Transects were subdivided into 0.1ha subsamples (10m x 10m plots) to estimate canopy and ground cover attributes. Canopy cover (trees & shrubs) was characterised using: species diversity; density and height of trees and shrubs; projected percentage foliage cover; and dbh of trees. Ground cover was characterised using: 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 1.0m^2 quadrats were sampled along the length of transects to estimate seedling density 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 on the September 2003 survey, including 10 *Eucalyptus* and *Corymbia* spp, 2 *Melaleuca* spp, 1 *Pandanus* sp and 11 *Acacia* spp. Canopy vegetation on Reference 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 and 19 herbs (44.2%) are classified as weeds. There were no weed sedges recorded. Overall, ground cover comprised 40% weed species. No weed grasses were found on reference sites.
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. 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 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 (*Bracharia 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.

7. Eucalyptus woodland and riparian 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 Paragrass and Rhodes Feather Top grass with similar biomasses (0.5 $t.ha^{-1}$).

8. There was a negative correlation between the number of native ground cover species and the number of weed species across all sites; the more weed species the less native species were found. Additionally, there was 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 Mine site by successful succession of vegetation from shrubland-grassland to woodland.

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 $\pm$ 23 seedlings/transect; Woodland: 13 $\pm$ 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, indeed, may well decrease as a result of woody plant 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). Despite these differences, high salinity levels in the evaporation pond areas may be the major issue because it is well above the level which impacts on plant growth.

12. A multivariate statistical model (Fig. 1a) was developed 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. 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 (see Fig. 3). All Mine sites lie along a successional trajectory, in terms of soil and vegetation development, towards the natural Reference sites (Fig. 1b).

13. The primary contributions to the vegetation characterisation axis in the above model are canopy cover (+) , tree and shrub density (+) and ground cover of weeds (-) (Fig. 2a-c). The primary contributions to the soil characterisation axis are nutrient (-) and salt (-) levels reflected in EC values (Fig. 2d).

14. 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. Although the other half of Mine sites sampled are 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 &, hence, high fire risk). These sites may be trapped in a vortex of self perpetuating failure; the worse it gets the worse it gets. To break free and cross the threshold to self-sustaining vegetation communities analogous to Reference sites would 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.

15. Most of the variance in the vegetation axis used in the above model is explained by either tree density or total canopy cover (R^2 ~ 80% for both; Fig. 2a&b)). 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 mine site was sampled.

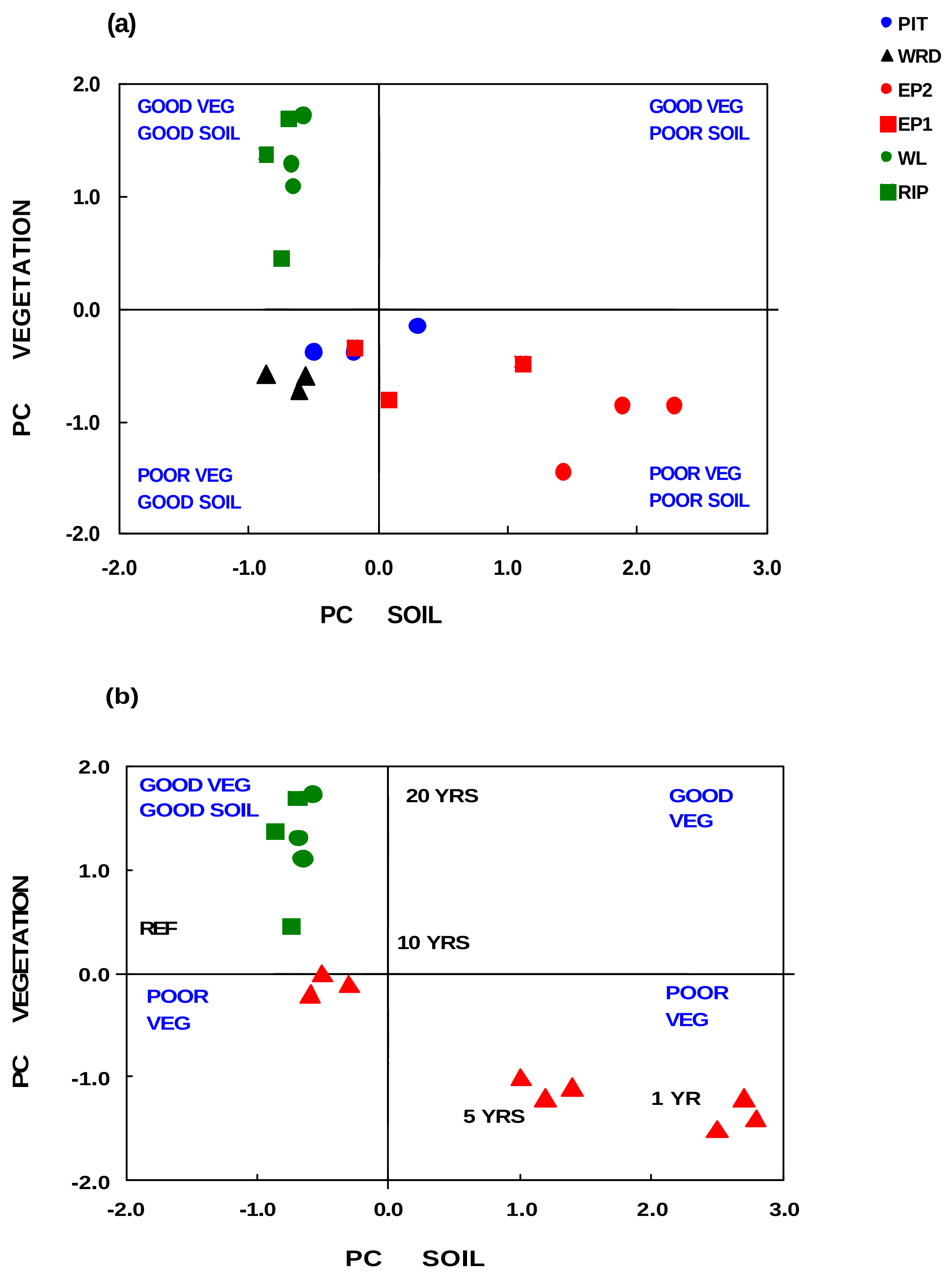

Figure 1a & b. (a) Ordination (Factor Analysis) of plant-soil relationships across all transects/site. The Vegetation PC axis is the 1st Principle component after varimax rotation, and similarly for the Soil PC. REF is Reference sites. Tree density is zero at a PC Veg = -1.0. Nabarlek, September 2003. (b) Hypothetical model showing possible succession trajectory of rehabilitated mine sites towards analogue conditions after 1, 5, 10 & 20 years, and associated soil-plant characteristics. Sites would progress at different rates because of inherent variability in site-specific conditions.

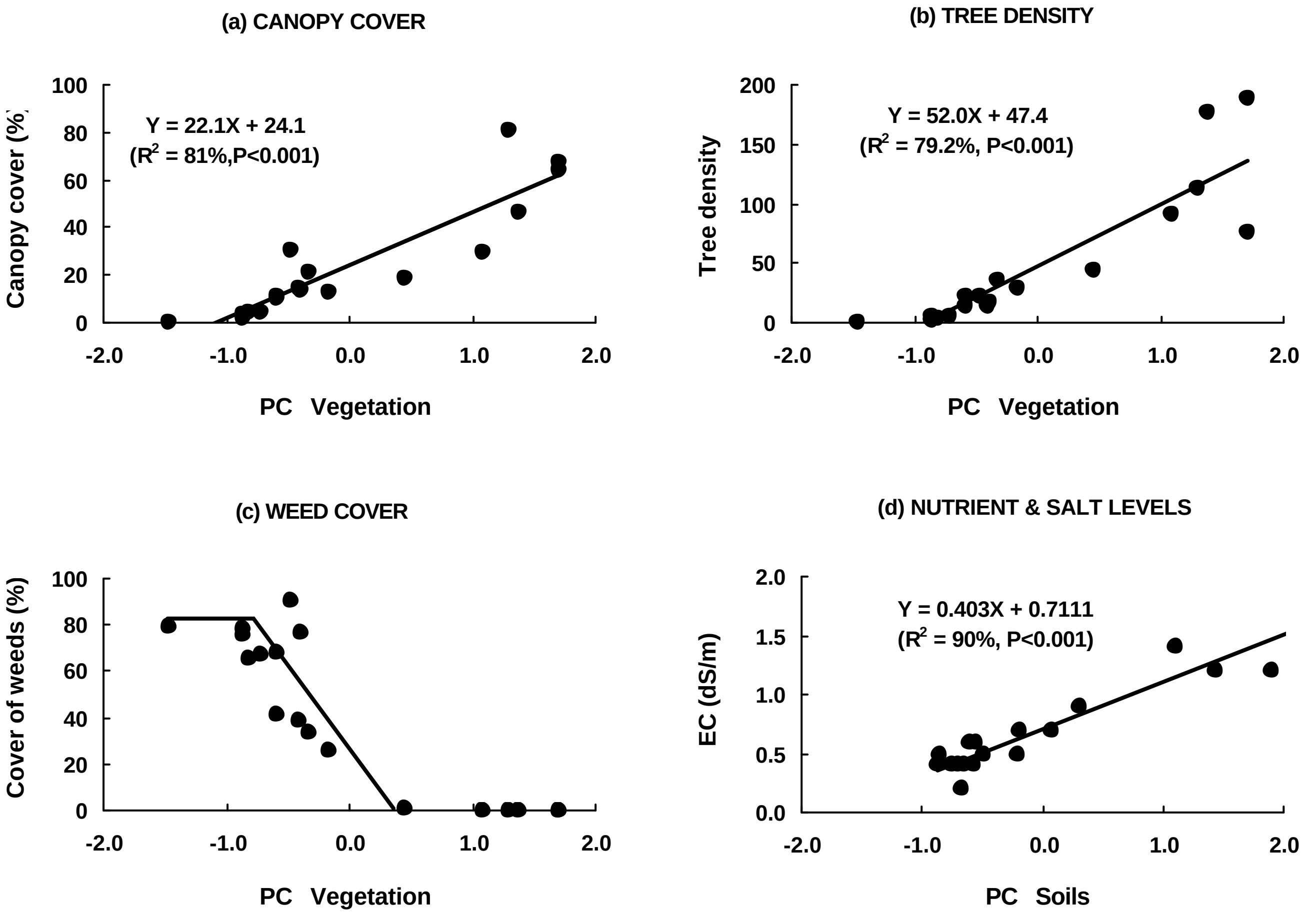

Figure 2 a-d Regression relationships between the Vegetation PC axis and (a) canopy cover (mean % cover/plot/transect), (b) tree density (mean numbers/plot/transect) and (c) weed cover (mean % cover/plot/transect), and between the Soil PC axis and (d) nutrient and salt levels reflected in EC values (dS/m, mean/transect from three subsamples). Nabarlek, September 2003.

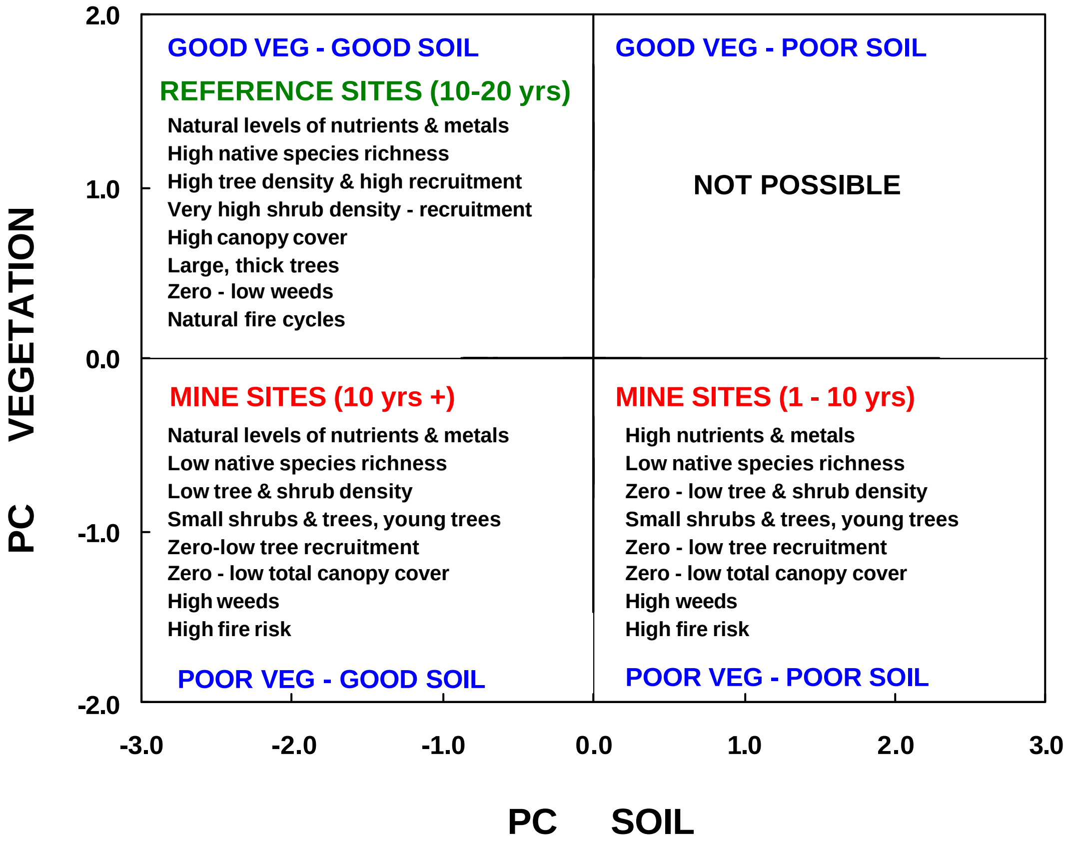

Figure 3 Vegetation and soil characteristics associated with the Principle Components model (Fig. 2b), showing the succession trajectory pathway of rehabilitated mine sites towards analogue conditions after 1, 5, 10 & 20 years.

Paper prepared by

Peter Bayliss and Kirrilly Pfitzner

for the 14th Meeting of the Alligator Rivers Region Technical Committee (ARRTC)

13-15 September 2004

Revegetation research for Nabarlek and Ranger minesites

Progress report: September 2004

For the 14th Meeting of ARRTC (13-15th September 2004)

ARRTC Key Knowledge Need:

Develop revegetation monitoring techniques at Nabarlek minesite using remote sensing and ground-based surveys to assess revegetation success, and for application to the future rehabilitation of Ranger uranium mine.

Dense patch of 2m tall perennial Mission grass and passionfruit vine on the minesite (Evaporation Pond 2), May 2004 (late wet season).

Background

ARRTC has assessed Key Knowledge Needs for research and monitoring in the Alligator Rivers Region and, in doing so, has accepted the following assumptions about uranium mining operations in the region (Johnston & Milnes draft 2004):

- Mining of uranium at Ranger is expected to cease in about 2008. This will be followed by milling until about 2011 and final rehabilitation expected to be completed by about 2016.
- Nabarlek is decommissioned but has not reached a status where the NT Government will agree to issue a Revegetation Certificate to the mine operator. Assessment of the success of rehabilitation at Nabarlek is ongoing and is being used as an analogue for rehabilitation at Ranger.
- Jabiluka will remain in a care and maintenance condition for some years, at least until mining ceases at Ranger.
- It is unlikely that any proposal will be brought forward for mining at Koongarra in the foreseeable future.

The following ARRTC Key Knowledge Needs (KKN) identifies all revegetation research for Ranger and Nabarlek, which will be facilitated through the ***eriss*** Rehabilitation Theme in collaboration with EWLS.

1.0 Ranger

1. Landform design

- Development and agreement of closure criteria from the landform perspective

2. Ecosystem establishment

- Development and agreement of closure criteria from ecosystem establishment perspective
- Characterisation of terrestrial and aquatic ecosystem types at analogue sites
- Establishment and sustainability of ecosystems on mine landform

5. Monitoring

- Monitoring of the rehabilitated landform

5.0 Nabarelek

1. Success of revegetation

- *Revegetation assessment*: The principal ongoing issue at Nabarlek is revegetation. Assessment of the adequacy of revegetation at the site is needed and, following its completion, management options should be developed and submitted to the minesite technical committee for its consideration.
- *Development of revegetation monitoring method:* A methodology and monitoring regime for the assessment of revegetation success at Nabarlek needs to be developed and implemented. The outcomes of current research discussed below is highly relevant to Ranger.

This report reviews progress to date of the KKN revegetation research at Nabarlek minesite, and outlines steps taken in collaboration with EWLS to initiate revegetation research for Ranger.

Progress summary

Nabarlek

1. As recommended by ARRTC, a project was commenced in mid-2003 at the decommissioned Nabarlek mine site to:
    i. develop ground and remote sensing monitoring and assessment methods for revegetation that can be applied to Ranger uranium mine; and
    ii. provide a quantitative assessment of the success of revegetation, based on a comprehensive characterisation of soils and plants across the minesite in comparison to adjacent reference sites.

2. The results of the first quantitative ground survey of vegetation on Nabarlek minesite and surrounds, conducted during the late dry season of 2003, are detailed in a draft Internal Report presented at the 13th ARRTC meeting and summarised in a discussion paper by Bayliss and Pfitzner (2004). The work was conducted in collaboration with Dr Sean Bellairs from Charles Darwin University (CDU) and two of his postgraduate students.

3. Preliminary results showed that revegetation was largely unsuccessful in terms of the original goal of "blending in with the surrounding savanna woodland". Vegetation on the minesite was characterised by extensive cover of grassy weeds, acacia shrubland nearing the end of their successional life and a very low density of trees. No woody seedlings were found in any of the transect plots, suggesting that woody plants were unlikely to increase in the short term and may decrease as a result of losses due to fire.

4. The report is still a draft with publication awaiting final analysis of the vegetation ground survey conducted during the late wet season of 2004. Preliminary analysis of wet season data, however, confirm all conclusions presented in the draft Internal Report. No woody seedlings were found once again in transect plots and, not surprisingly, grassy weeds continue to dominate the minesite. The major seasonal differences were: more native ground cover species were found or identified in the wet season on reference sites, particularly grasses; the standing biomass of ground cover plants on the minestite was significantly higher in the wet season than in the dry season; and the annual and perennial species of Mission Grass were easily separated in the wet season.

5. A more comprehensive characterisation of minesite vegetation condition in relation to reference sites, and a final assessment of revegetation success, will be made using additional wet season data, analysis and interpretation of complementary high resolution QuickBird satellite images of Nabarlek captured over the whole landscape in both seasons, and the results of two postgraduate studies that examined soil-plant relationships.

6. With respect to the remote sensing component of this study, interrogation of multispectral QuickBird data captured in both seasons with intensive ground-based data is well advanced, with a focus on discriminating native and weed ground covers. The results will be reported in a separate ***eriss*** Internal Report by December 2004. In addition, DeBeers Hyperspectral Mapper data at 4m spatial resolution were acquired in May 2004. The discrimination power and accuracy of the hyperspectral and multispectral data will be compared in 2005.

7. With respect to the MSc study, Stefanie Vink has submitted her thesis to the University of Gröningen, Netherlands (see Attachment 1: The revegetation of Nabarlek uranium mine). The aims of her project were to assess differences between the vegetation composition and soil properties of mine sites and reference sites, and to determine whether or not waterlogging limited establishment of some dominant rehabilitation species. With respect to the Honours study, Judy Manning has completed all field work and laboratory experiments, and plans to submit in October 2004. The aim of her study is to determine whether or not key ecological processes, such as soil microbial activity and nutrient cycling, are sufficient to maintain a functional vegetation community. Both postgraduate studies will be published as ***eriss*** Internal Reports.

8. An Honours study at CDU will commence in January 2005 to examine remote sensing methods used to monitor and assess regional and minesite fire risks at Nabarlek and Ranger, through estimation of fuel loads of dominant vegetation communities and the time since last burnt. Methods developed by the NT Bush Fires Council using current and historical Landsat™ captures will be employed. The study will be co-supervised by ***eriss*** staff, Sean Bellairs (CDU) and Andrew Edwards (NT Bush Fires Council).

9. Additionally, an extensive fire occurred on the 21st June 2004 at Nabarlek minesite over the Pit and Waste Rock Dump areas, and less extensively on the Evaporation Ponds area. A QuickBird capture has been obtained to map the fire scar on the minesite, and a survey is currently underway to map fire scars on ground transect plots. The ground transects will be re-surveyed in the late wet season of 2005 to assess the influence of dry season fires on the composition and abundance of native and weed ground cover species, and the regrowth of woody seedlings.

10. The draft Internal Report 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 the Traditional Land Owners. These management options could then be considered by the Nabarlek MTC and may incorporate also continued monitoring and assessments of revegetation success by ***eriss*** in collaboration with Demed Land Management Rangers.

11. One option for on site management of the new revegetation plan is that it be implemented through the Mining Management Plan. We suggest 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:

    i. 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;

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

    iii. estimation of the costs and time frames of all management options, in particular strategies for replanting and the sustainable management of all significant weeds.

Ranger

1. A major milestone was reached when EWLS submitted their Revegetation Strategy for the final landform at Ranger Mine at the 13th ARRTC meeting in March 2004 (Reddell & Meek 2004). Discussions with Ingrid and Paul on opportunities to collaborate on revegetation research at Ranger commenced soon after. However, Ingrid has recently resigned from EWLS and so no follow-up meetings have occurred. Nevertheless, arrangements have been made with Paul in October to commence detailed discussions on research priorities, areas of collaboration, time frames and resourcing. These

discussions will likely run in parallel with institute-wide meetings between EWLS and ***eriss*** to discuss future collaboration on KKNs.

2. Discussions on collaborative research will commence also with EWLS staff with respect to selection of analogue sites, the development of revegetation closure criteria and choice of indicators for monitoring revegetation success. The recent experience gained by ***eriss*** in monitoring and assessing revegetation success at Nabarlek will be highly relevant to these research needs.

3. Regardless, collaborative research has commenced in the remote sensing area. Kirrilly Pfitzner (***eriss***), Michael Welch and Philippe Puig (EWLS) recently investigated the utility of a QuickBird high resolution satellite capture to map weeds for monitoring purposes on the Ranger lease. ***Eriss'*** analytical contribution to this project has now finished and results were inconclusive because of poor rectification of the QB capture and lack of design when collecting field-based measurements for the analysis of remotely sensed data. That is, field data were often collected over heterogenous covers encompassing smaller areas than the minimum mapping unit of the remotely sensed data. Additionally, no ground knowledge of native ground covers were supplied to assess separabilities, and poor rectification of the QB capture led to poor correspondence with ground-based control data. The remote sensing study at Nabarlek may be more informative with respect to the efficacy of using multispectral QB captures to detect the extent of weeds on the Ranger lease. Nevertheless, QB data is unlikely to be suitable for monitoring small isolated outbreaks of weeds on sites such as Ranger. It may therefore be more cost-effective to use traditional approaches for such purposes. DeBeers Hyperspectral Mapper data at 4m spatial resolution were acquired by ***eriss*** in May 2004 and will be assessed for mapping vegetation communities on the Ranger lease and surrounds in 2005. Due to limits in spatial resolution with QB, it is unlikely that small weed infestations will be identifiable.

3. A meeting was held in June this year with Carl Grant (ARRTC member), Sean Bellairs (CDU), Max Finlayson and Peter Bayliss (***eriss***) to discuss ARRTC KKNs with respect to revegetation research at Ranger and Nabarlek. General discussions were held on KKN research priorities that relate to revegetation and likely areas of collaboration that required detailed discussion and agreement with EWLS. The meeting concluded that: (i) a one-day workshop should be held with EWLS, ***eriss*** and their external collaborators to map out research priorities, areas of expertise and collaboration, and time frames and details of potential collaborative projects; and (ii) Sean Bellairs and his postgraduate students can offer ***eriss*** and EWLS opportunities to tap into local revegetation expertise and facilities at CDU that we may not have, particularly with respect to seed biology, soil-plant relationships and of choice of establishment species. Meeting outcomes were raised with Ingrid Meek and Paul Reddell (EWLS). Sean was offered a retainer to provide ***eriss*** with expert advice when needed, and to support Honours students undertake relevant research at Nabarlek and potentially Ranger. Specific examples are provided below.

4. The following reviews will be undertaken this Financial Year to complement the comprehensive review of revegetation research needs at Ranger undertaken by EWLS (Reddell & Meek 2004): (i) soil seed biology in the tropics with special reference to revegetation at Ranger (by Bellairs); (ii) the application of landscape ecology to ecosystem establishment and monitoring programs at Ranger (by Bayliss, & see Bell e*t al.* 1997); and (iii) methods to incorporate Indigenous cultural values into rehabilitation success criteria and the rehabilitation process generally (by Bayliss & a nominated expert consultant, see point 7 below).

5. Dr Bellairs has identified for consideration the following research issues within his area of expertise that may be required for successful revegetation:

i. identification of key species for establishment of a stable and functional vegetation community on the rehabilitated site (e.g. Ingrid's work at EWLS);

ii. determining sources of seed for sufficient representative species of the ground, mid and canopy strata, and of sufficient representative species of different functional groups;

iii. determining how to manage that seed with regard to collection, maintaining viability, storage and treatment;

iv. assessing dormancy and developing treatment and sowing protocols that overcome dormancy and maximise germination;

v. overcoming seed biology issues for any key species that are problem species;

vi. developing protocols that allow the desired suite of species to be established without dominance by competitive species or weeds;

vii. developing surface treatments that assist in reliably and economically achieve establishment success.

viii. development of the established community such that nutrient cycling is well developed, the desired suite of species are maintained in the community, the community is resilient to fire and recruitment occurs.

6. Ranger stakeholders may wish to consider financially supporting PhD studies at CDU through ARC Linkage grant applications that progressively address some of the issues outlined in point 5 above, where there is agreement that it is a priority and can't be undertaken in-house. The recently established Territory Innovation Fund (TIF) provides an opportunity for CDU and industry partners to access NTG cash contributions towards ARC grant applications. For the CDU PhD proposal outlined in Attachment 2, cash contributions of $10,000 p.a. each from SSD (via OSS) and ERA for three years may secure $20,000 of matching funds each from the TIF and the ARC, a total of $120,000 (note that the ARC contribution may be more). The deadline for expressions of interest for the first TIF round is due on the 10th September and will be missed, however, there will be future rounds. Nevertheless, an ARC Linkage application can still be submitted in November but would require DBIRD to directly provide $10,000 p.a. in matching industry funds for three years.

7. A major goal of rehabilitation at Ranger is to incorporate Indigenous cultural values into closure criteria and other facets of the rehabilitation process. A partnership approach from beginning to end could be adopted by all Ranger stakeholders in order to achieve this goal, with leadership provided by the NLC. ***Eriss*** could help facilitate necessary values-related research where required; for example, support for a Masters of Tropical Science project at CDU to review methods of community engagement in rehabilitation processes. Stakeholder collaboration with scientists who have the right mix of social and biophysical research skills, and community experience, may lead also to greater participation by Indigenous communities in the rehabilitation process. Dr Sue Jackson from CSIRO Sustainable Ecosystems (TERC) has substantial expertise in Indigenous cultural values of water, and is suitably qualified and interested in providing such advice to the NLC and ***eriss*** (Jackson 2004, see Attachment 3 by Jackson *et al*. 2004).

References

Bayliss P, Bellairs S, Pfitzner K & Vink S (2004 draft). Preliminary characterisation of vegetation on Nabarlek minesite and on adjacent natural landscapes in September 2003.

Bayliss P & Pfitzner K (2004). Revegetation of Nabarlek minesite: Preliminary characterisation of vegetation on the minesite and on adjacent natural landscapes in September 2003. Discussion paper submitted to the 13th ARRTC meeting, March 2004.

Bell SS, Fonseca MS & Motten LB (1997). Linking Restoration Ecology and Landscape Ecology. *Restoration Ecology*, **5 (4),** 318-323.

Jackson S (2004). Preliminary report on Aboriginal perspectives on land-use and water management in the Daly River region, Northern Territory. A report to the Northern Land Council. CSIRO Sustainable Ecosystems, May 2004.

Jackson S, Storrs M & Morrison J (2004). Aboriginal perspectives on river research and management in northern Australia.

Johnston A & Milnes AR (2004). Review of mine-related research in the Alligator Rivers Region 1978-2003. Draft Report to ARRTC.

Reddell P & Meek IK (2004). Revegetation strategy for the final landform at Ranger Mine: approach & current status. Discussion paper prepared by EWLS for the 13th ARRTC meeting, March 2004.

Vink, S (2004 submitted). The revegetation of the Nabarlek uranium mine. MSc Thesis submitted to the University of Gröningen, Netherlands.

The Revegetation of the Nabarlek Uranium Mine

Stefanie Vink






This project took place in the period July to November 2003 at the Charles Darwin University in collaboration with the Research Institute of the Supervising Scientist, Darwin, Australia as part of the authors Master of Science degree at the University of Groningen, The Netherlands.

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SUMMARY

The Nabarlek mine was in operation from 1979 until 1988. Rehabilitation was started in 1994 and was completed a year later with the objective of establishing a woodland community that was as similar to the surrounding areas as possible. Eight years later the main issue still outstanding at the former Nabarlek mine site is the establishment of an appropriate vegetation cover. Initially the vegetation seemed to be developing satisfactorily but in recent years the results of revegetation has turned out to be variable and subject of much debate. As a result it was decided that a long-term project looking at the rehabilitation success of the mine site was necessary, starting with a vegetation survey, conducted in August of 2003. Also, as some areas on the mine site have a tendency to flood in the wet season, the waterlogging tolerance of three species occurring in the Nabarlek area were tested in a shade house experiment.

The aim of the vegetation survey was to find out how the rehabilitation was progressing and more specifically, the degree of similarity between reference sites and rehabilitation areas on the former mine at this point in time. The vegetation survey was carried out in the mid-late dry season when most of the annual species (mainly grasses) have died and the remaining plants become more visible. Six sites on the mine lease were chosen; two native sites (woodland and riparian) and four mine site areas (two evaporation ponds, mine pit and waste rock dump). Each site consists of three 50-m transects, divided into 1 m^2 plots, and the presence of all herb and grass species in each plot was noted. For every tree/shrub the abundance (the number of individuals per species) per 1 m^2 plot was recorded, all tree/shrub species were subdivided into four classes; 0-10 cm, 0.1 – 1 m and > 1 m height and trees/shrubs re-sprout.

The species richness was determined per transect for the total, grass, herb, tree/shrub and exotic species and for the trees/shrubs the abundance per transect was calculated. The native sites showed a much larger total and tree species richness than the former mine sites, while the exotic species richness was higher on the former mine than on the native sites. The abundance of trees and shrubs on the former mine sites was also considerably lower than on the native sites. On the native site the majority of trees and shrubs were within the 0 to 1m height region, whereas on the former mine sites the largest proportion was of a height greater than 1 m, in fact there were no trees smaller than 10 cm. There was very little overlap in species between the native sites and the mine sites, within the native sites or the mine sites. Univariate analysis revealed significant differences for all different richness and abundance, however post-hoc tests showed only differences between native and mine sites for grass, exotic and total richness. Using the amount of occurrences of the species per plot per transect the Shannon diversity index (H') and Simpson's index (D) were calculated. In general the two diversity indices showed similar results. ANOVAs of the indices showed a significant difference between the native riparian site and the other sites, especially the second evaporation pond. Principal component analysis (PCA) was used to determine species grouping patterns with respect to the total, grass, herb, exotic and tree frequency data. The total and grass frequency PCA revealed three groups; mine sites, native woodland together with one riparian site transect and the remaining two transects from the riparian site. The herb species PCA showed only two groups; the native riparian sites and the mine sites, with the native woodland sites very close to the origin. The tree frequency revealed a gradual separation of the native woodland from the native riparian sites while the mine site subplots very close to the origin. The only PCA that did not show any clear direction in separation was that of the exotics frequency. Hierarchical cluster analysis was used between the transects in order to identify relatively homogeneous groups of cases based on the presence/absence data of all species. Two major clusters and two individually separated sites were found. One cluster contained the native woodland sites and, although not as closely linked, the first transect of the native riparian site. The other two transects on the riparian site are separated from all the other transects and therefore do not form any distinct groups. The other major group contains all of the sites on the former mine. Soil samples taken along each transect revealed elevated levels of P, K, Fe, Mn and Cu on the evaporation ponds. Texture, colour, pH, nitrate and carbon levels were within normal range and very similar for all transects

The main aim for the waterlogging experiment was to determine whether different water levels influenced the growth and mortality of three *Eucalyptus* species and whether this was site and/or species specific.
Pots, containing either soil from the evaporation pond or the reference sites, were planted either with seedlings of *Eucalyptus tetrodonta, Eucalyptus miniata* or *Eucalyptus polysciada* and were subjected to one of three water level treatments: free draining (control), water level at approximately 7 cm (low) or at 1 cm (high) below the soil surface. Both soils were very similar in terms of pH, colour, texture, mineral and metal contents, the exeption being higher levels of sulphate and copper and a larger percentage of clay, silt and stones and a lower percentage sand in the evaporation pond soil.

Seedling mortality was high for *E. miniata,* predominantly on the evaporation pond soil (13.9%) and in the high water treatment (11.1%). *E. tetrodonta* seedlings mortality was low at 1.7% while none of the *E. polysciada* seedlings died. In the control treatment all species showed an increase in seedling height but in both high and low water treatments only the *E. polysciada* seedlings showed an increase. ANOVA of the average shoot height revealed highly significant differences between species and water treatment but not for soil type nor was there any interaction between the variables. There was a significant difference in the shoot and root dry weight between species and in shoot dry weight between water treatments but not between soil types. In general the shoot and root dry weights decreased with increasing water levels for *E. tetrodonta* and *E. miniata*. For *E. tetrodonta* this trend occurred on both soils, for *E miniata* only the root dry weight decreased on the evaporation pond soil but this was not statistically significant. The *E. polysciada* seedlings did not exhibit any clear inhibition either by water treatment or by soil type, ANOVAs for both root and shoot dry weight per plant showed no significant differences. *E. tetrodonta* exhibited an increasing root:shoot ratio with increasing water levels on the reference soil and the *E. polysciada* seedlings did the same but only on the evaporation pond soil. *E. tetrodonta* also showed a large difference between the control and the waterlogging conditions, interestingly the low water level was the highest. All the *E. miniata* seedlings showed very similar root:shoot ratios as did the *E. polysciada* seedlings on the reference soils.

This vegetation survey revealed that there are still large differences between native sites and areas on the former mine sites. Therefore, the Nabarlek mine site does not fit the rehabilitation criterion of a vegetation that is similar to the surroundings at the present time. The former mine sites are very different to the surrounding native sites in terms of species richness, tree and shrub abundance and the diversity indices. The lack of recruitment of trees on the mine sites and the presence of weeds, often in large amounts, on all the mine sites is a major problem as is the fact that the species found on the mine sites were very different to those found in the native sites. The areas that were most dissimilar in vegetation composition and appear to have functional characteristics that are most likely to hinder rehabilitation success are the evaporation pond areas. The waterlogging experiment has shown that the periodic flooding of this area can be a hindrance to the establishment of at least *E. tetrodonta* and *E. miniata*.

Recommendations for future research into the revegetation include:

- Repeating and expanding the waterlogging experiment
- Examining competition between exotic and native species
- Analysing the nature and occurrence of mycorrhizas, especially on the evaporation pond
- Exploring the possibilities of introducing a fire regime onto the mine site
- Carry out planting experiments of native juvenile trees onto the mine site

CONTENTS

ATTACHMENT 2

Seed biology of significant species associated with rehabilitation of the Ranger mine

Draft notes for discussion 17 August 2004 (Sean Bellairs)

The flora of Kakadu National Park is diverse with over 1500 flora species and the flora associated with the sandstone formations is particularly diverse. The Ranger Uranium Minesite is required to carry out rehabilitation to establish an environment similar to the adjacent areas of Kakadu National Park such that the rehabilitated area could be incorporated into Kakadu National Park. Revegetation will involve establishing local native plant species similar in density and abundance to those existing in adjacent areas of Kakadu National Park, to form a sustainable ecosystem that will not require a maintenance regime significantly different from that appropriate to adjacent areas of the park. The mine landform will be rocky and elevated and it will be necessary to establish a community of local plant species that will be adapted to this landscape.

These rehabilitation goals require the establishment of a diverse range of native species that would need to perform all the ecological functions required to achieve a sustainable community. Overstorey and ground cover species will both be important to achieve stability. Further, a diverse range of both groups of species will be required to so that functional community responses are maintained in spite of fluctuating environmental conditions.

To establish this range of species it is necessary to develop propagation protocols and for most species this requires collection of seeds and efficient seed germination. For commercial crop and pasture species this is not an issue; seeds are readily available and germinate when moistened. Seed collection of viable seeds of native species and germination of those seeds is not as simple. Protocols for seed collection need to be developed so that the seed is of optimum viability following collection and storage. Many seeds have developed blocking mechanisms that only allow germination following certain environmental stimuli. Treatments need to be developed to overcome these dormancy mechanisms if the seeds are to be used for revegetation.

Establishment of a diverse flora following mining can be achieved, it has been demonstrated at several sites in Australia, but it requires research effort and planning. We can however take advantage of over 30 years of research into establishment of native species on minesites and adapt it for the Kakadu species. Some preliminary studies by Eriss have investigated germination requirements for some key species. Work by EWLS has identified an appropriate analogue community and measured the abundance of species within that community. Research at other mine sites has indicated that seed biology issues will include variable seed viability; variable seed production; only a proportion of species readily germinating; development of treatments to stimulate germination and storage of seeds to build up a seed supply for revegetation.

It is proposed to develop a propagation protocol for rehabilitation target species. To achieve this aim individual objectives would be:

- Determine the seed production phenology of key understorey and ground cover species.

- Determine when the seeds are of optimum viability.
- Determine which species will germinate readily and which have dormancy mechanisms.
- Determine the nature of those dormancy mechanisms and how to overcome them.
- Determine the conditions that optimise storage of the seeds.

A project of this scale would be highly suitable for a PhD student, although some support would be required for seed collection and other field activities. It would also be assisted by honours students and by second year undergraduate student activities. The PhD project will identify many issues for further investigation. Some of these will then be investigated by the PhD student, however the PhD project will also identify problems that can be studied in detail by BSc(Hons) students.

ATTACHMENT 3

Aboriginal perspectives on river research and management in northern Australia

S. Jackson[1], M. Storrs [2] and J. Morrison [3].

Abstract

Aboriginal people in northern Australia hold distinct cultural perspectives on water, relating to identity and attachment to place, environmental knowledge, resource security, and the exercise of custodial responsibilities to manage inter-related parts of customary estates. Despite being major landowners and representing a large proportion of regional communities, Indigenous people have historically been marginalised from water resource decisions. As water resources come under increasing development pressure and are subject to greater research and management activity, it is vital that provision is made for Indigenous values and participation in water management. This paper highlights the cultural significance of rivers and water in selected northern regions, and provides a preliminary outline of research and management priorities as determined by key north Australian Aboriginal land management organizations. Priorities include developing the capacity for collaborative wetland management, conservation of traditional ecological knowledge, riparian resource inventories and threat assessments, as well as improved Aboriginal participation in catchment management and water policy.

Additional keywords : traditional environmental knowledge, Aboriginal land management, cultural values.

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Introduction

Aboriginal cultural values of water and rivers are markedly different from those of mainstream Australia, and water researchers and managers alike have very limited understanding of them. Given the importance of Aboriginal interests in the regional economies of northern Australia, it is imperative that we increase our knowledge of Aboriginal interests in riparian environments, and improve Aboriginal engagement in aquatic science and management.

The Aboriginal population comprises a significant and growing proportion of the total population of northern Australian regions, and riverine resources are a vital part of the Aboriginal customary economy. For instance, in the Kimberley region the Aboriginal population is approximately one half of the total. Moreover, Aboriginal communities are substantial landholders, with a growing land base coming under their control. In the Northern Territory, approximately 80% of the coastline and 50% of the total land mass is held under Aboriginal title. Under Commonwealth legislation (*Native Title Act 1993* and the *Aboriginal Land Rights Act (Northern Territory) 1976*), a range of wetland landscape types can be claimed, including the beds and banks of rivers, the inter-tidal zone, bays and gulfs, and islands. Native title rights encompass rights to the use of natural resources in accordance with tradition. Therefore, Aboriginal rights to hunt, fish, and gather living natural resources, such as crocodiles and turtles, may arise in association with a native title claim to particular lands and waters, or by virtue of customary practice independent from any association with native title claims to land (Meyers 1995; see also Morrison et al 2004). Clearly there will be implications for living resources management by the Commonwealth and States/Territories as they examine to what degree native title rights may affect the right of the Crown to manage the allocation, development and conservation of those resources (Meyers 1995). In coming years native title claims, customary resource rights and negotiated agreements may contribute to strengthening Indigenous control of land, water and biological resources across the country.

North Australian catchments are therefore socially complex. They are characterised by a distinct spatial pattern where most Aboriginal people are located in relatively small settlements, invariably remote, while the vast majority of the non-Aboriginal population resides in larger urban centres or cities. In any given catchment there may be numerous Aboriginal groups with rights and interests in particular river locales. The impact of a particular water management activity or policy might be felt on downstream groups, or on neighbouring groups outside the catchment, depending on the systems of regional social organisation and the rules for using and managing resources. Langton affirms the importance of taking account of the social impacts of water use decisions on ‘all the groups who draw from water sources their identity and traditional relational patterns’ (2002: 53). The Daly, a large catchment in the Northern Territory for example, encompasses the estates of at least eleven distinct groups. The Kimberley’s Fitzroy Valley, an area of some 95,000 square kilometres, is home to at least thirty Aboriginal communities and crosses seven ethno-linguistic areas with a consequent complex array of cultural and political affiliations (Toussaint et al 2001).

Cultural understandings of water

It cannot be assumed that there is a universal way of conceptualising nature, one which is beyond the influence of cultural processes and social histories. The complexity and diversity of Aboriginal perspectives warrants specialised attention sensitive to the different ways in which human societies come to understand and value the natural world and construct institutions to manage human-nature interactions.

In a seminal paper on the significance of freshwater to Australian Indigenous cultures, Langton draws attention to the different ways in which societies attribute meaning to water (2002). Cultural differences apply equally to the perception of water resources as much as any other, and they affect the way that institutions such as Western and customary legal systems allocate rights and responsibilities to land and resources. In part, the greater significance of land over water in the Western environmental consciousness explains why Indigenous relationships to land, rather than water, have tended to be more readily recognised and documented. Western law has treated water as a fluid element and, as a consequence, rights to water have been poorly defined. Whilst land, which is more or less fixed, is more readily traded and valued. Langton observes that water's

> *fluidity has resulted in a web of legal difficulties with respect to the formalisation and recognition of water rights in Western law. This theoretical space between the indigenous recognition and the Western legislation of water rights has created a need for a broader understanding of indigenous rights to waters and water sources (2002: 44).*

According to a national discussion paper on onshore Indigenous water rights that was prepared to stimulate debate in Indigenous communities:

> *Aboriginal peoples have never drawn a distinction between the land and the waters that flow over, rest upon or flow beneath it. The land and waters are equal components of 'country', all that require care and nurturing, and for which there are ongoing responsibilities (Lingiari Foundation 2002: 6).*

Most accounts of Aboriginal attachment to rivers and water bodies are found in the anthropological literature (Langton 2002: 46). The literature devoted specifically to the cultural values of rivers and water in a water resource management context is limited and biased towards the Kimberley. A recent report by anthropologists Toussaint, Sullivan, Yu & Mularty (2001) provides a useful preliminary assessment of indigenous cultural values of the Fitzroy valley in the West Kimberley, as does Barber and Rumley's study of the cultural values of the Lower Ord, East Kimberley (2003). The Kimberley bias is likely to be a result of the interest expressed by the State water agency for cultural interpretations to assist the development of water resource allocation plans (Toussaint et al 2001). Although other northern jurisdictions have significant Aboriginal populations, with large land-holdings, water resource agencies do not appear to have had the same level of interest in determining the cultural significance of water prior to the development of water resource management plans. In the Northern Territory, three recent hydrological studies of water resources on lands held under Aboriginal title point to a growing awareness of the need to address this knowledge gap.

The significance of water to Aboriginal people

Water plays a central role in Aboriginal cultures and societies: 'their lives and various religious, legal, social and economic beliefs and practices' (Barber and Rumley 2003: 3). All studies reviewed here observe that Aboriginal groups conceptualise water sources and rivers, as with the land, as having derived from the Dreaming, the time when the world attained its present shape (Barber and Rumley 2003; Langton 2002; Toussaint et al 2001; Natural Resources and Mines 2001; Yu 2000). They emphasise the importance of mythic beings as significant to the origin and maintenance of all water sources.

Cultural institutions governing peoples' systems of rights and interests were also created by the Dreamings. Rights and responsibilities in relation to places under Aboriginal law arise from what Langton refers to as 'wide mytho-geographical bodies of knowledge' (2002:

45). Knowledge of the environment, the natural features and vitally, its spiritual dimensions, is a prerequisite to exercising rights to land, including water bodies.

Water's vitality is underscored in the cultural studies from north Australia. It is described as an element that lives or embodies a life force. Yu describes how water is understood as a living entity in Kimberley Aboriginal cultures:

> *'Living water' is an Aboriginal English expression that requires translation as it refers both to the physical properties of water sources and their cultural significance. Living water sources …. are permanent water sources …. characterised as kunangkul – everlasting – and are a defining element of an individual's country (2000: 20)*

Aboriginal environmental knowledge is conscious of cycles and seasons and the interactions between the metaphysical and human realms. For instance, rainmaking rituals are critical to maintaining water supplies in many Aboriginal traditional societies, regenerating the country and ensuring the health of the ecosystem, including people (Toussaint et al 2001: 58). In Wardaman mythology from the Fitzmaurice region of the Northern Territory, the Rainbow Serpent is a widespread travelling creature that:

> *came inland when the sea rose and caused the land to flood. He is connected to the Lightning – he spits out from his forked tongue and the lightning replies – flashing (Drew 2001: 74). The electric storms bring the first rain and the frogs emerge from the ground announcing the wet season (ibid).*

Cultural affiliations to water are expressed in a many different ways: through social etiquette, place-based knowledge, narratives, beliefs and daily practices (Toussaint et al 2001: 39). Barber and Rumley explain that each place along the Ord River, for example, is viewed as distinctive because of the combination of historic interactions, cultural and environmental elements (2003: 18). An affiliation with a dominant environmental feature, such as a river, may play a key role in the formation of group identity. For example, it is common to hear particular groups identify either as 'desert mob' or 'river people' (Toussaint et al 2001). On a finer scale there is an intensely localised identification with water sources, especially springs in Arnhem Land and waterholes in more arid regions (Langton 2002).

For one group, whose country is found between the Fish and Moyle rivers west of the Daly river in the Northern Territory, their very name refers to the riparian world where language relates people to place. *Ngan'gikurunggurr'* means Deep Water Sounds (Ungunmerr 2003: vii). It is described as the language of the swamp people who live in the lower reaches of the Moil River.

Mythological accounts of poor water management serve as ecological parables; pointing to a strong awareness of the need to cautiously manage and share water resources within Aboriginal cultures. In Kimberley language groups there are numerous mythological accounts related to water production and management (Toussaint et al 2001). Benigna Ngulfundi of the Daly River region explains how rules are interpreted from the antics of ancestral beings:

> *We have been told different stories about what happened when Dreamtime animals stole water. Sometimes it was just to make mischief but 'payback' for selfishness could also be a motive. The water was always recovered and the animals who stole it seemed to be sorry for the trouble they caused (2003: 13).*

Riparian management issues

Environmental degradation of water bodies and riparian landscapes from pastoralism, tourism and other European land uses is a source of consternation to Aboriginal people in north Australia, as are the impacts of water resource developments (see Lewis 2002; Toussaint et al 2001; Marshall 1988; Cooke 1999). Recent Kimberley research identified the regulation of rivers, especially impoundment for dams, as a threat to a valued cultural principle: the unimpeded flow of a river body (Toussaint et al 2001: 65).

Aboriginal people encounter and seek to address the pervasive threats to riparian health within areas under their control and beyond: sedimentation from erosion, weed infestations (usually pasture grasses), deteriorating water quality, feral animal impacts, saltwater intrusion and other degrading processes.

According to an elder from the Malak Malak people for example, the NT's biggest river, the Daly, is no longer 'small and pretty' with a deep channel, but wider and shallower (Biddy Lindsay pers comm). Biddy Lindsay explains:

> *we were born in the bush, we know what we're talking about. Me, I come from paperbark, not from tin house. The river himself, I'm telling you from looking at it, not measuring it, I've seen from television, from NSW, him dry. That river himself (Daly), he was pretty and now he's wider and shallower (pers com 21 October 2003, Darwin).*

In the Daly, as in many other regions, weeds have displaced the native grasses that lined the riverbanks and made particular places more attractive for sitting, socialising and fishing. The riverbanks are said to be 'running away' as they erode (B. Lindsay pers com 21 October 2003). Similar observations are made of the Fitzroy River by Aboriginal pastoralists, Harry and John Watson (Toussaint et al 2001). Floodwaters in that river now travel much faster 'like an arrow, going straight ahead instead of curving like a snake', according to Harry Watson (ibid). Aboriginal people have also observed structural changes in the estuarine zone of the macro-tidal northern rivers (e.g. Toussaint et al 2001: 67).

In the Ord River area, traditional owners have witnessed major environmental changes and associated social impacts. Land and sites were flooded by dams and altered as irrigated agriculture was introduced. Where the environment was generally predictable and ordered the post-dam environments are disordered and vegetation types are out-of-place as new environments are created. Barber and Rumley report on the altered vegetation dynamics as described by traditional owners:

The vegetation is, however, a composite of species previously found in other environmental niches… In this post-Argyle Dam environment, species which were once found in riparian zones and around springs and in jungle pockets, are now established together in large complex communities along the banks of the river. In this new environment, these indigenous species are also interspersed with introduced species such as caltrophe (2003: 22).

Caring for Country: Aboriginal Community-Based Initiatives

A community-based groundswell of activity is being seen on Aboriginal lands across northern Australia. As a result, Indigenous lead agencies developed the North Australian Indigenous Land & Sea Management Alliance (NAILSMA) to coordinate and address issues common to all three jurisdictions. Engagement of Indigenous people in the water reform debate is an emerging issue identified by NAILSMA. The relevant management programs of an agency participating in NAILSMA, the Northern Land Council, will be highlighted here. The Northern Land Council is the statutory body established under the

Aboriginal Land Rights Act (Northern Territory) 1976 to protect the land-based interests of Aboriginal people in the northern half of the NT

The Northern Land Council's land management activities are carried out by its Caring for Country Unit. The unit's operating principle is that 'the land needs its people' (Storrs et al 2003). It works collaboratively with a range of Aboriginal and non-Aboriginal agencies to build local capacity to institute effective management of land and sea resources through the development of formal land and sea management programs. A key feature of the Caring for Country initiative has been the brokerage of partnerships with NT and Commonwealth research, training and management agencies as well as non-government organisations. The Caring for Country's Unit fosters and applies two kinds of knowledge: Western Science-based knowledge and indigenous traditional knowledge. Science-based knowledge is critical in dealing with issues such as invasive weeds for which there is no traditional experience.

Aboriginal people have managed their water bodies and riparian areas for millennia. They rely heavily on these nationally and internationally significant wetlands for food, for cultural values and, increasingly, for economic independence. The need for external advice or assistance has arisen chiefly from recent changes driven by European settlement and other land management practices. In 1996 the Top End Indigenous People's Wetland Program was established to assist Aboriginal people with wetland management planning. Total catchment management is central to the Program's implementation (Thurtell et al 1999).

The process of wetland management planning started at the grass roots level using an issues-based approach (Storrs et al 2001). The major issue was invasion of riverine floodplains by the devastating weed *Mimosa pigra* (mimosa). This organic 'ground-up' process takes a significant amount of time given the risk of disenfranchising Aboriginal landowners. Over time, and with community consensus, local issue-based plans can be incorporated into more holistic total catchment and regional management regimes. An incremental approach to capacity-building, particularly provision of training and financial resources for equipment such as boats, is needed if Aboriginal land owners are to assist in river management on and off their land base. Capacity-building programs, such as the NLC's, builds on existing Indigenous governance, and develops new skills that are directly relevant to planning and management.

Processes that systematically identify and assess existing and potential threats are also required for Aboriginal lands. Allied with this requirement is the need for fundamental mapping and inventory work to build the knowledge base for monitoring environmental health of rivers and wetlands. For example, Aboriginal people have expressed a desire for freshwater fish surveys of the Fitzroy River (M Horstman pers com 2002). A further benefit arises from the opportunities field-based research provides for custodians to demonstrate knowledge and maintain attachment to significant landscapes.

The great interest in conservation oriented land management activity has not precluded the consideration of income generating options. Various groups are seeking either sustainable utilisation regimes for existing industries, such as grazing, fishing, hunting, and tourism, or emerging opportunities such as tradeable water rights or 'fee for service' conservation initiatives.

Water policy and collaborative catchment management

Concern over the efficiency of water use and the environmental impacts of water resource management prompted the profound reforms undertaken by the Council of Australian Governments during the 1990s. A number of analysts have noted the lack of consideration given to the impact of these reforms on Indigenous peoples (Langton 2002; Kay 2002). According to McKay (2002), the key issues for Indigenous Australians are the separation of land and water and the creation of a water market. A further consideration is the need for Aboriginal participation in the developing areas of integrated catchment management, water quality monitoring and water resource planning.

Within contemporary water quality management practice (e.g. National Water Quality Management Strategy) cultural values are now identified as a beneficial use of water bodies. Developing management targets and guidelines to protect such subjective values will be a challenge to water resource managers and community organisations such as catchment groups representing Aboriginal interests. Less well established in the water resource field is the notion of a *cultural flow*, as distinct from an environmental flow, which has emerged from discussions with Indigenous communities in the Murray Darling Basin (Morgan et al 2003).

The need to respect and value indigenous knowledge systems is therefore paramount to the successful inclusion of Indigenous interests in the water management paradigm. Given the tendency for the dominant Western worldview to overwhelm and devalue Indigenous views and knowledge, the challenge lies in building relationships across cultures which value difference whilst encouraging consensus on ultimate research and management goals (Duff et al, 2004).

A popular metaphor used by Yolngu people from north-east Arnhem Land reflects an appreciation of the interdependence of water bodies and illustrates the advantages Aboriginal people perceive from collaborative research and management endeavour. In the Yolngu world-view, relationships between people, totems, country and natural phenomena are divided and ordered into two moieties Dhuwa and Yirritja (Robinson and Munungguritj (2001). *Garma* is described as both a swirling estuarine whirlpool (McGowan 2002:18) and the 'philosophical enterprise' of collaborative endeavour between Indigenous and Western knowledge traditions (Yunupingu 2003: 4). Raymattja Marika-Munungguritj elaborates on the concept that underpins an annual educative cultural festival in north-east Arnhem Land:

> *There is always a dynamic interaction of knowledge traditions. Freshwater from the land, bubbling up in fresh water springs to make waterholes, and salt water from the sea are interacting with each other, with the energy of the tide and the energy of the bubbling spring. When the tide is high the water rises to its full. When the tide goes out the water reduces its capacity…. In this way, the Dhuwa and Yirritja sides of Yolngu life work together. And in this way, balanda (non-Yolngu) and Yolngu traditions can work together. There must be balance: if not, either one will be stronger and harm the other (cited in McGowan 2002: 19).*

Many Aboriginal communities look forward to improved engagement and opportunities for partnerships that serve the public interest. They are also dedicated to conserving their environmental knowledge so as to ensure the continuity of their culture – their preferred lifestyles. This can be achieved through everyday activities – fishing, hunting, collecting bush tucker; through management practice – weed removal, burning, site protection, ceremonies; and through other conservation measures such as documentation of histories and stories about place and country for the education of younger generations. Rapid loss of knowledge alarms and motivates all groups across the north.

Conclusion

Cultural values are an important sphere of human concern, ones that can underpin a 'vibrant public mandate' for conservation policy and sustainable regional development (Jepson and Canney 2003: 271). Effective river science requires multi-disciplinary and trans-disciplinary approaches, as Poff et al argue:

> *social science knowledge about human values, perceptions, behaviours, and institutional culture also need to be integrated into the science that guides river*

> *management. With such integration, science can better inform the decision-making process, despite the complexity of coupled human-natural systems (2003: 302).*

Rivers and riparian habitats are key areas of traditional and contemporary Aboriginal interest. It is imperative therefore that in the quest for sustainable management of northern rivers, the values, ecological knowledge and management aspirations of Indigenous communities are respected and influential in collaborative research and management endeavours. Involvement of communities with a crucial stake in river and wetland management, and especially a culturally distinct landscape perspective, is a central tenet of sustainability for it engenders commitment to developing and achieving shared goals.

References

Barber, K and H. Rumley (2003) *Gunanurang: (Kununurra) Big River, Aboriginal Cultural Values of the Ord River and Wetlands*, A Study and Report Prepared for the Water and Rivers Commission, June 2003.

Cooke, P. (1999) Preface. *In: Wise Use of Wetlands in Northern Australia: Indigenous Use* (eds P. Whitehead, M. Storrs, M. McKaige, R. Kennett and M. Douglas) pp xi-xiii. Centre for Tropical Wetlands Management & Centre for Indigenous Natural and Cultural Resource Management, Charles Darwin University.

Duff, G., Jacklyn, P., Landsberg, J., Ludwig, J., Morrison, J., Walker, D. & Whitehead P. (2004), Managing Pluralism in North Australian Natural and Cultural Resource Management: Reflections on a Decade of Cooperative Activity, Unpublished Paper, Cooperative Research Centre for Tropical Savannas Management, Charles Darwin University, Darwin.

Langton, M. (2002) Freshwater, in Background Briefing Papers: Indigenous Rights to Waters, Lingiari Foundation, February: 43-64.

Lewis, D. (2002) Slower Than The Eye Can See, Environmental Change in Northern Australia's Cattle Lands: A Case Study From the Victoria River District, Northern Territory, Tropical Savannas Co-operative Research Centre, Charles Darwin University, Darwin.

Lingiari Foundation (2002) Onshore Water Rights Discussion Booklet One, February.

Magowan, F. (2002) Ganma: Negotiating Indigenous Water Knowledge in a Global Water Crisis. *Cultural Survival*, **26**, 18-19.

Marshall, P (1988) *Raparapa Kularr Martuwarra*: *Stories From the Fitzroy River Drovers*, Magabala Books, Broome.

McKay, J. (2002) Onshore Water Project: Briefing Paper, in Background Briefing Papers: Indigenous Rights to Waters, Lingiari Foundation, February: 25-42.

Meyers, G.D. (1995) Implementing Native Title in Australia: The Implications for Living Resources Management. *University of Tasmania Law Review* **14**, 1-28.

Morgan, M., L. Strelein and J. Weir (2003) Indigenous Rights Discussion Paper, Living Murray Initiative: In Support of the Indigenous Final Report to the Living Murray Initiative, Draft, August.

Morrison, J.H, Altman, J.C, Whitehead, P.J, & Griffiths, A.D, (2004), Indigenous Values in Tree Retention Booklet, CRC Tropical Savannas Management, Charles Darwin University.

Natural Resources and Mines (2001) Indigenous Report Barron Water Resource Plan, Queensland Department of Natural Resources and Mines.

Robinson, C and N. Munungguritj (2001) Sustainable Balance: A Yolngu Framework for Cross-Cultural Collaborative Management. *In: Working On Country: Contemporary Indigenous Management of Australia's Lands and Coastal Regions,* (eds R.Baker, J. Davies and E.Young) pp 92-104. Oxford University Press, Melbourne.

Storrs M., Yibarbuk D, Whitehead P & C. Finlayson (2001) The Role of Western Science in Contemporary Aboriginal Community Wetland Management in the 'Top End' of Australia. *In: Science and local communities: Strengthening partnerships for effective wetland management*, (eds M. Carbonnell, N. Nathai-Gyan & C. Finlayson) pp. 7-13. Ducks Unlimited Inc., USA.

Storrs M, Cooke P & Josif P (2003). Caring for Country: The rapidly developing formalised structure for Aboriginal natural resource management in the Northern Land Council region of the Northern Territory. In *Proceedings of the National Landcare Conference* 28 April-1 May 2003, Darwin, Australia. Landcare Australia CD. 8pp.

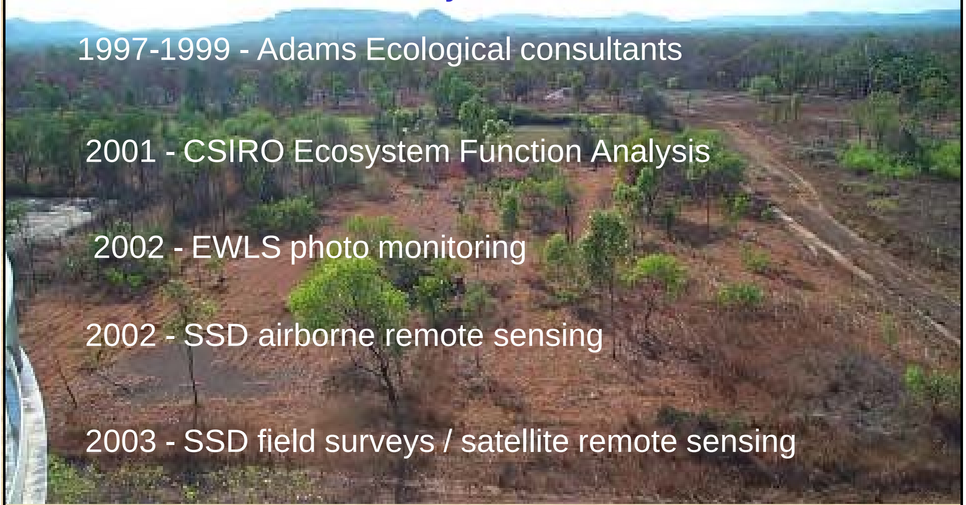
Thurtell, L., CM Finlayson, D. Yirbarbuk and M. Storrs (1999) The Blyth-Liverpool Wetlands, Arnhem Land, Northern Australia: Information for Management Planning, Supervising Scientist Report 146 146, Supervising Scientist, Canberra.

Toussaint, S., P.Sullivan, S. Yu and M. Mularty Jnr, (2001) *Fitzroy Valley Indigenous Cultural Values Study, Report for the Water and Rivers Commission*, Centre for Anthropological Research, University of Western Australia, Perth.

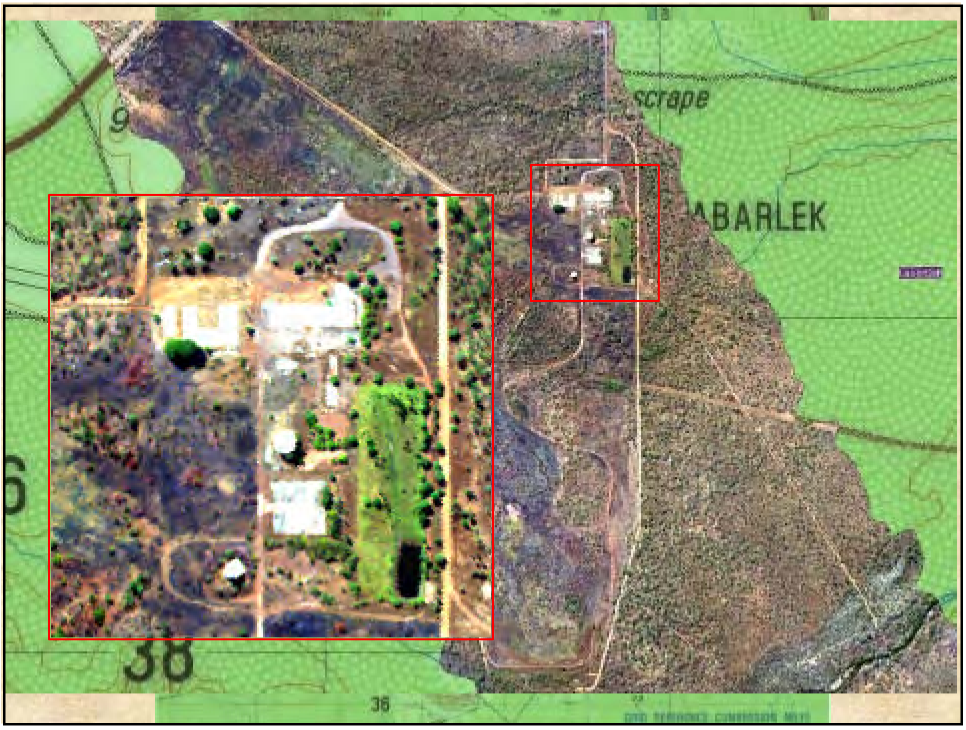
Yu, S. (2000) *Ngapa Kunangkul: Living Water, Report on the Aboriginal Cultural Values of Groundwater in the La Grange Sub-Basin*, Prepared by the Centre for Anthropological Research, University of Western Australia, for the Water and Rivers Commission of Western Australia. Second Edition.

Yunupingu, M. (2003) Bringing Our Pasts into Our Futures, Presentation at the Charles Darwin Symposium (1st), Charles Darwin University, Darwin.

Nabarlek revegetation assessment
Kirrilly Pfitzner



Compact **A**irborne **S**pectrographic **I**mager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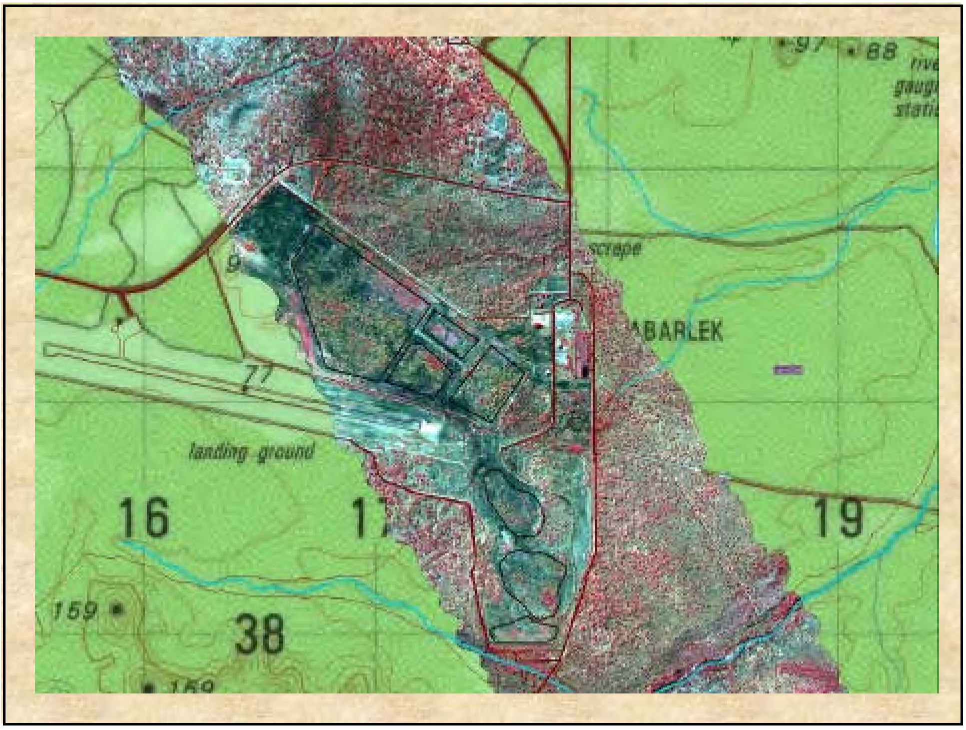
97
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scrape
ABARLEK
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landing ground
16
19
159
38

“Green” “Yellowy” Drying

Acacia leaves | Para grass | Heteropogan

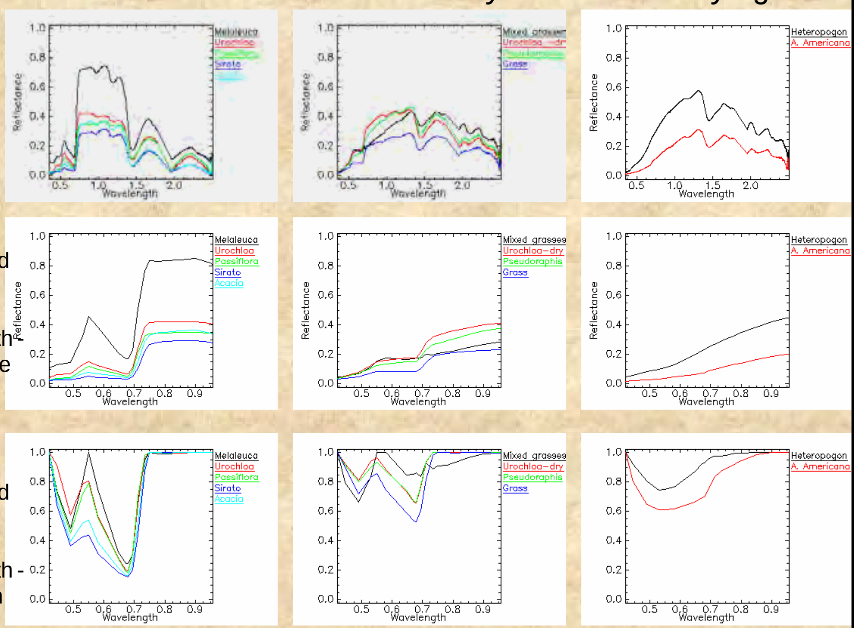
Siratro | Couch grass | *A. americana*

“Green” “Yellowy” Drying

Field spectra VNIR – SWIR

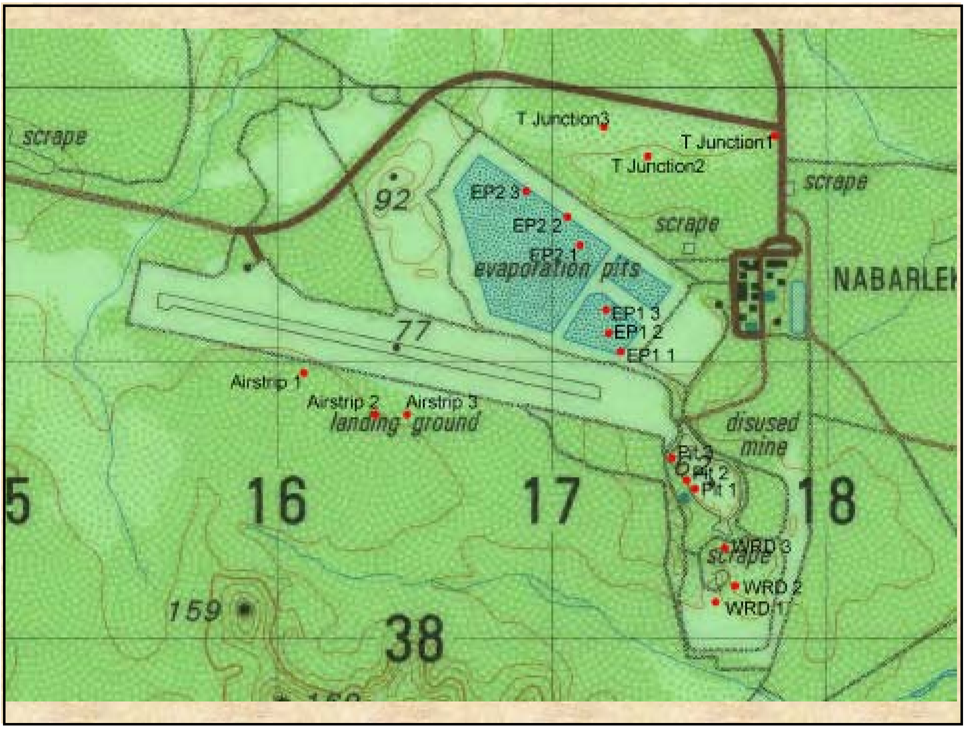
Resampled to CASI wavelength - reflectance

Resampled to CASI wavelength - continuum removed



Quickbird satellite coverage

Airborne gamma survey extent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EP2 3
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77
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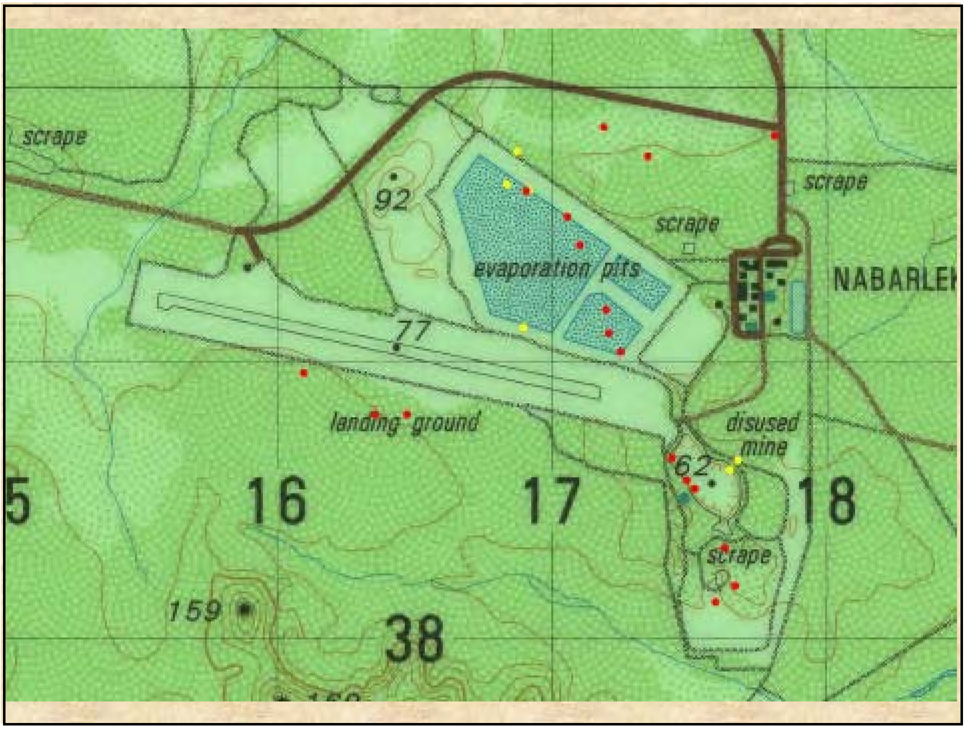
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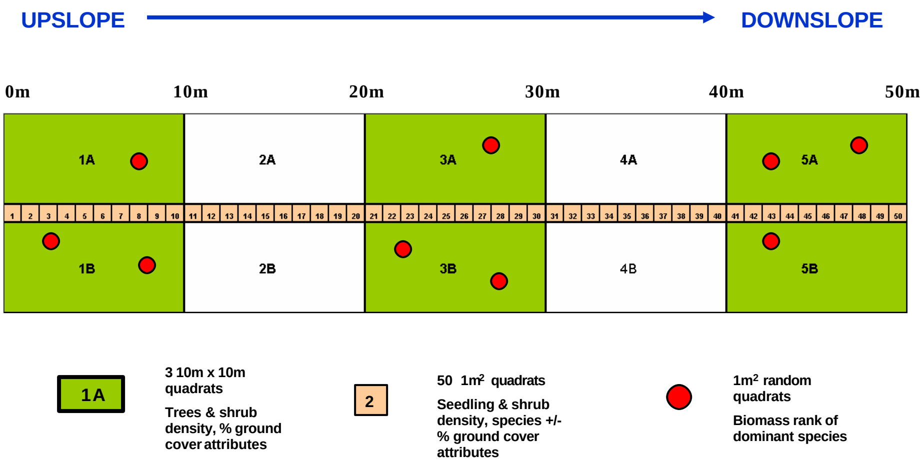
Transect design – Nabarlek Vegetation Surveys



1 m^2 plots along 50 m transect

Seedling recruitment, growth and survival:
- density of each shrub and tree species
-3 height classes: < 10 cm, 10 cm – 1 m and > 1m

Presence/absence of grasses/herbs and sedge species

Basal area of ground cover

% bare ground, litter, sticks, logs, rocks

Biomass and fuel load

9 samples per transect = 27 per site

Dynamics of ground cover

- height and % cover

Species composition by weight

- 3 dominant plant species recorded

- Phenology noted

10 m x 10 m plots

Shrubs and trees

- many dGPS

- height and density of each species (> 10 cm)

- long and short axis of foliage cover and density estimates (5% intervals)

-1.5m high DBH – growth rates/vigour of trees

- Notes on fire effects and phenology

- DBH of dead trees in future

Ground cover

-species > 1% cover recorded as % cover, trace species noted

- % rocks, logs, sticks, bare ground, litter


2003. 8. 29 16:57


2003. 8. 29 16:48


2003. 8. 28 17:18


2003. 8. 29 10:14


2003. 8. 27 15:38


2003. 8. 29 16:03


2003. 8. 29 11:56


2003. 8. 28 10:51


2003. 8. 29 11:11


2003. 8. 30 09:46


2003. 8. 25 16:01


2003. 8. 24 09:10


NO FIRES
TO BE LIT
FIRE WILL KILL
SMALL PLANTS
GROWING
2003. 8. 30 17:15


2003. 8. 23 14:43

Preliminary characterisation of vegetation on Nabarlek minesite & adjacent natural landscapes

Take Home Message

- Nabarlek is a model of what can go wrong with revegetation at Ranger & how to avoid it

Revegetation objective

- **1993 – QML signed Settlement Deed with NLC:**

  "primary objective of revegetation program is to return mined areas to self-sustaining woodland areas that blend in with surrounding environment"

ARRTC key Knowledge Needs (2002)

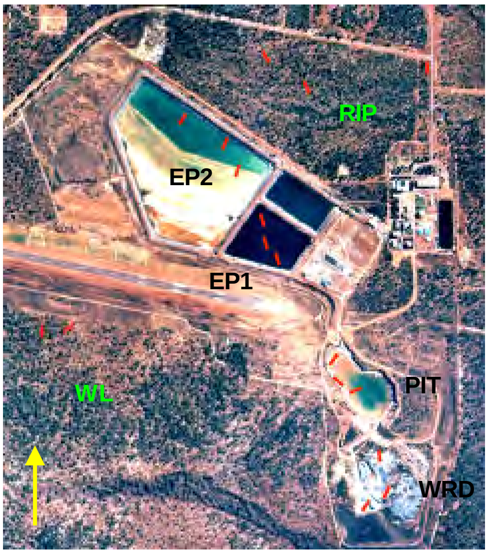
- **New *eriss* focus on rehabilitation issues at Ranger**
- **Key revegetation questions:**
  - What are the criteria for assessing revegetation success?
  - What are the indicators of success?
  - How do we monitor them?
  - What can we learn from Nabarlek?
- **Criteria = functional processes (e.g. nutrient cycling) &/or composition & structure of vegetation**

Project aims at Nabarlek

1. Develop cost-effective ground-based & remote sensing vegetation monitoring & assessment methods that can be applied to Ranger.

2. Provide a quantitative assessment of revegetation at Nabarlek based on characterisation of soil & vegetation attributes.

Location of vegetation transects & the pre-rehabilitated minesite



1982 1:25000 air photo

Reference sites (6 transects)

RIP Riparian woodland
WL Eucalyptus woodland

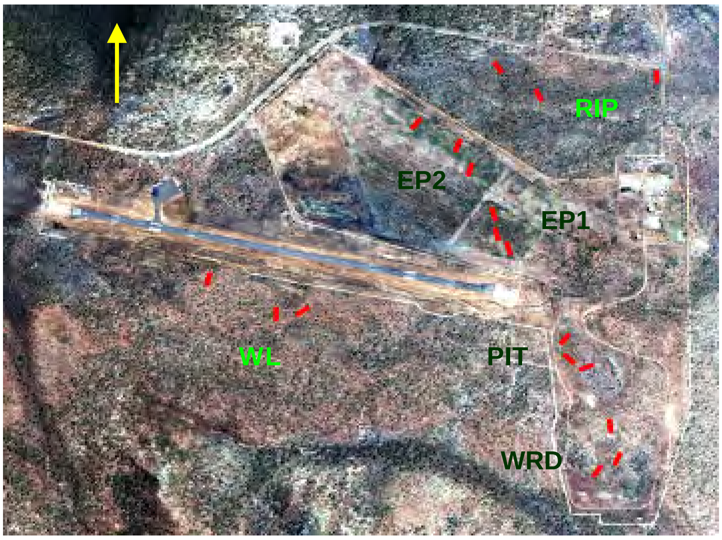
Mine sites (12 transects)

EP1 Evaporation pond 1
EP2 Evaporation pond 2
PIT Mine pit
WRD waste rock dump

Total transects = 18

But only 0.07% minesite sampled

Quickbird satellite image (Sept 2003): location of transects on minesite & adjacent natural reference sites



Reference sites

RIP Riparian woodland
WL Eucalyptus woodland

Mine sites

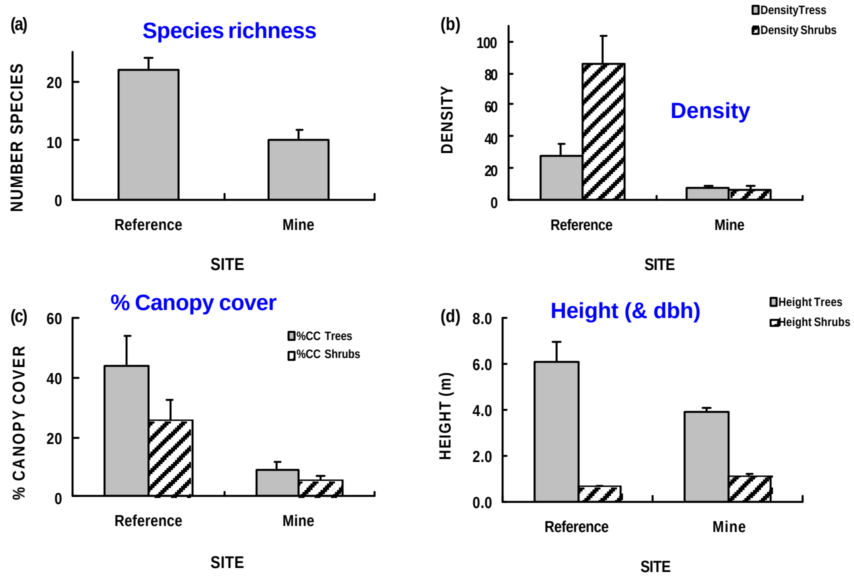
EP1 Evaporation pond 1
EP2 Evaporation pond 2
PIT Mine pit
WRD waste rock dump

CANOPY COVER RESULTS

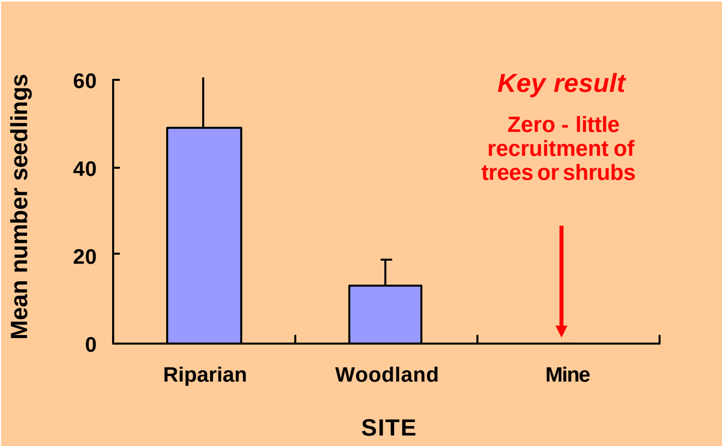
Attributes = mean value / 0.01ha plot / transect

Woody seedling	<= 0.1m
Shrub	> 0.1m & <= 2.0m
Tree	> 2.0m

Comparison of canopy cover characteristics between reference sites & mine sites



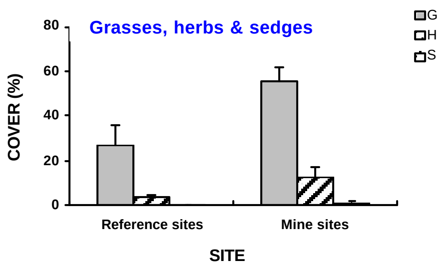
Comparison of mean density of woody seedlings between reference sites & mine sites

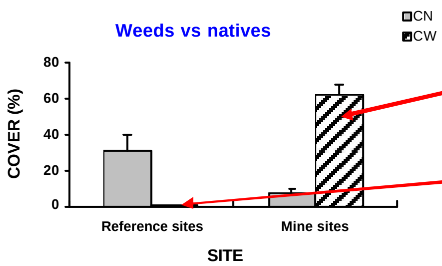


GROUND COVER

Attributes = mean value / 0.01ha plot / transect

Comparison of mean ground cover (%) of plant classes between reference sites & mine sites



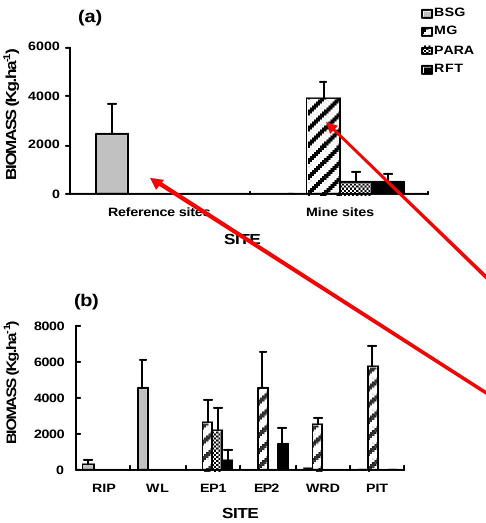


Key results

Minesite dominated by grassy weeds

Herb weeds present but trace amounts (<1% cover)

Comparison of mean biomass of dominant grasses between reference sites & mine sites



BSG = Black spear grass
MG = Mission grass
PARA = Para grass
RFT = Rhodes feather top grass

Key results

High fuel load grass weeds on minesite, mostly Mission grass

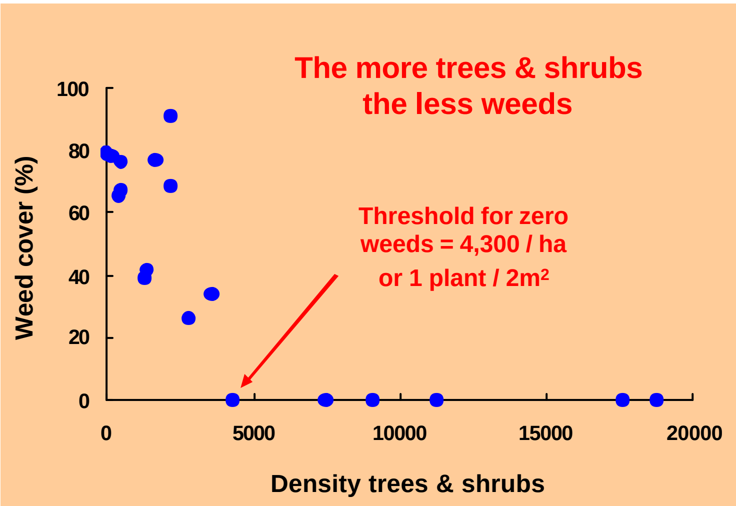
No grassy weeds on adjacent natural reference sites

Native & weed grasses on the minesite

Impact of weeds & fire on successful revegetation

- Weeds
  - increased fuel load & fire risk (eg Mission grass)
  - suppressed establishment of native seedlings & native ground cover species through competition for resources
  - source of infestation to surrounding, natural landscapes
- Fire
  - kills native woody seedlings
  - kills fire sensitive species & promotes fire tolerant species
  - can promote weeds
  - impacts on nutrient cycling via loss of leaf litter

Correlation between % cover weeds & density (nos/ha) of trees & shrubs

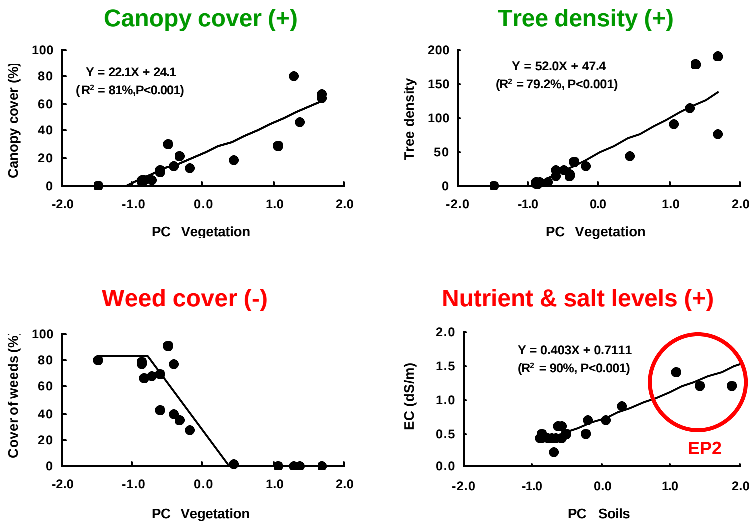


Soil – Plant Relationships

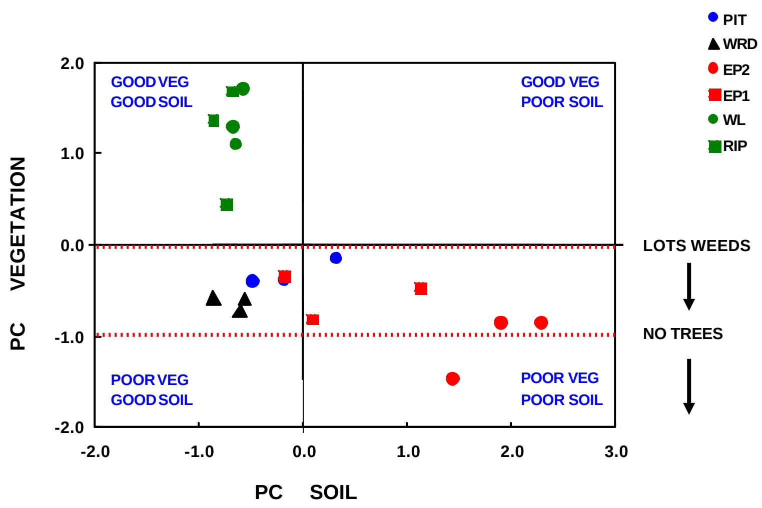
Multivariate statistical model (PCA) used to:

- Reduce complexity of intercorrelated soil-plant data
- Search for structure or patterns across sites with respect to both soil & vegetation successional development
- Search for best set of revegetation success indicator (s)

Relationships between key plant & soil attributes (success indicators) & PC axes

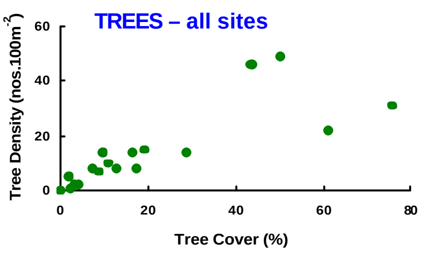


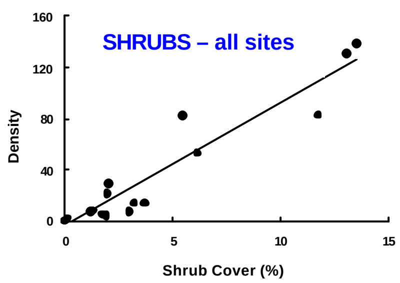
Ordination of plant - soil characteristics across the minesite & reference sites: assessing reveg success

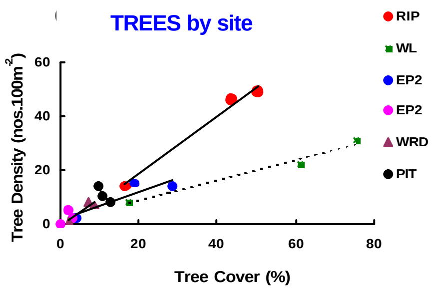


Relationship between tree & shrub density & canopy cover (%)

- Canopy cover or stand density explains 80% of PC vegetation condition axis
- Can we estimate canopy cover & hence canopy density, from RS images?







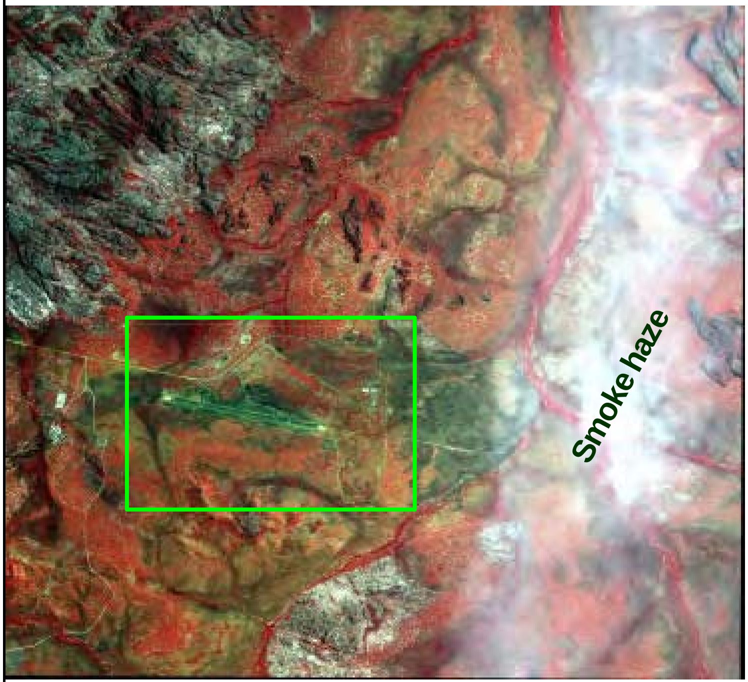
Remote sensing & assessing revegetation

- Ground-based vegetation surveys labour intensive & costly; inherent undersampling problems
- Despite huge effort, only 0.50% of minesite was surveyed
- Quickbird (QB) remote sensing captures timed with ground surveys
- Allows a "whole of landscape" approach to monitoring & assessment of broad canopy & ground cover attributes
- Complements detailed ground surveys

Aim

- Evaluate high resolution QB data for minesite rehabilitation assessment & monitoring
- Specific objectives:
  - differentiate & measure key cover types on minesite & surrounding natural landscapes
  - determine optimal season for QB capture
  - undertake benefit-cost analysis of ground-based & RS methods

Quickbird data

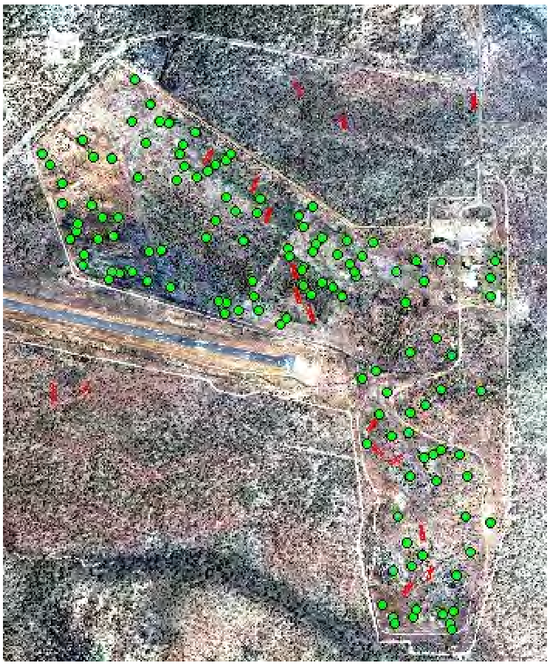


Panchromatic data 0.61m spatial resolution

4 band multispectral imagery (VNIR) 2.44m spatial resolution

Captured 03/09/2003

Quickbird data & ground-truthing



Location of ancilliary data (helicopter & ground, n=137)

Transects

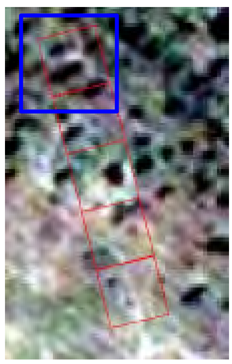
Canopy cover

- Can often see individual trees (at 0.61m spatial resolution, pan-sharpened)
- But often better indicated by shadow c.f. green canopy, especially on minesite as green canopy & green grass spectrally similar
- However, shadows generally related to canopy cover in ground plots
- Offsite eastern area, Eucalyptus woodland extensively burnt – can monitor fire scars at landscape scale
- NDVI indicates greenness & possibly health of canopy

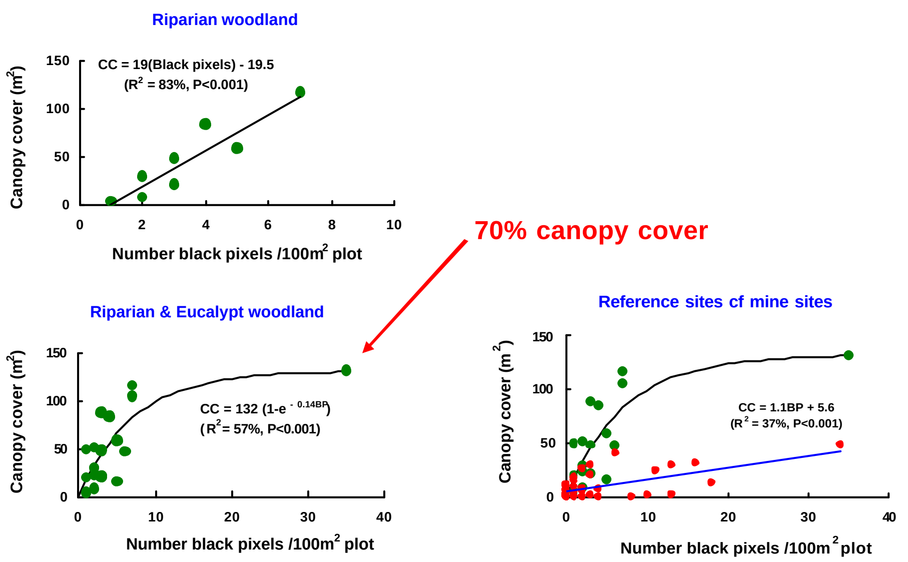
Using shadows to count trees & shrubs?

PIT: transect 10
plot 3

252 x 0.61m pixels
per 10m x 10m plot



Canopy cover & spectral patterns



Ground cover

- Ground cover on minesite dominated by complex spatial & spectral mixes
- Requires knowledge based classification
- However, some broad covers (e.g. weeds of different shades of green may be separable)
- Timing of capture may optimise separation of key ground cover types

RESOLUTION
e.g. SW corner of WRD

B & W

Color

~235 m

Dead herbs (buffalo clover 80%)
Dead grass *B. bladhii* (10%)
Grader grass (10%)

Dead-green *B. bladhii* (100%)

Couch (80%) & herbs *Hyptis* (10%), bleached litter (100%)

Bleached Mission grass (100%)

Paspalum (90%) & couch (5%)

Weeds
Natives

Summary – Remote Sensing

Preliminary evaluation of QB data:

- Huge variability in land cover of rehabilitated landscapes
- Classification of spatially & spectrally complex land surfaces requires knowledge based techniques cf automated algorithms – but need research
- Spectral resolution QB data limiting – hyperspectral data more powerful, but more costly & less available
- In contrast, temporal availability QB an advantage – but need to determine optimal capture time for maximum separability of cover types

Preliminary revegetation assessment

Presence (1) or absence (0) of success, weighted for area of site

CATEGORY	ASSESSMENT CRITERIA	MINE SITES				Expected yr 10	Max score	Actual
		EP1	EP2	PIT	WRD	MINESITE	% success	% score
LANDFORM	Stable substrate, low erosion	1	1	1	1	1	100	100
	Suitable substrate, medium vegetation	0	0	1	1	1	100	28
SOILS	Ability to recycle nutrients ??	0	0	1	1	1	100	28
	Low salt levels & other mine pollutants	0	0	1	1	1	100	28
VEGETATION	Tree density sufficient to self-sustain WL	0	0	0	0	1	100	0
	Woody seedling recuitment high	0	0	0	0	1	100	0
	Weed abundance low	0	0	0	0	1	100	0
RESILIENCE TO DISTURBANCE	Low risk of uncontrolled fire	0	0	0	0	1	100	0
	High resistance to weed invasion	0	0	0	0	1	100	0
ANALOGUE COMPARISON	Ecosystem developing towards analogue	0	0	0	0	1	100	0
	Blends with adjacent Euc woodland	0	0	0	0	1	100	0
	Area of sites (ha)	34.8	7.8	5.5	10.9	Expected yr 10	100	17
	Total area (ha)	59.0				% success =	17	

Ground-based methods - Transects

N

Key Results Ground Survey

- Canopy & ground cover vegetation attributes measured across the minesite & on two adjacent reference sites using ground transects, in the dry (2003) & wet (2004) seasons.
- Indicators of revegetation success examined using multivariate statistics.
- In contrast to reference sites, Nabarlek minesite is characterised by an abundance of grassy weeds, high fire risk, few trees & with little woody recruitment.
- Revegetation has largely been unsuccessful in terms of the original goal of "blending in with surrounding savanna Eucalypt woodland".
- Preliminary analysis of wet season data confirm initial assessment using dry season data.

Future - Nabarlek

- Assist Nabarlek MTC develop new revegetation closure criteria with TOs.
- Assist Nabarlek MTC develop realistic, practical & pragmatic options for a new revegetation plan encompassing sustainable replanting & grassy weed control strategies.
- To expedite the process, we recommend that Nabarlek MTC join forces & employ a community land management coordinator to:
  - help develop closure criteria
  - facilitates research & management advice
  - estimate costs, timelines & milestones for all management options
- Assess vegetation response to extensive fire in June 2004 at start & end of the 2004/05 wet season.
- Commence CDU Hons study Jan 2005 examining remote sensing methods (Landsat) to asses regional & minesite fire risks (& at Ranger), in collaboration with NT Bush Fires Council (DIPE).

Nabarlek: complete outputs 2004/05

- 1 IR seasonal ground surveys & revegetation assessment by October 2004
- 1 IR assessment of QB multispectral remote sensing survey methods
- 1 MSc Thesis University Gröningen-Netherlands (soil nutrients, waterlogging & veg characteristics) – Stefanie Vink
- 1 Hons Thesis CDU submit Oct 2004 (nutrient recycling, soil microbes) – Judy Manning
- 1 journal MS submit Dec 2004 (Bayliss, Pfitzner, Bellairs)

Ranger

- EWLS submitted Revegetation Strategy for final landform at 13th ARRTC meeting.
- Suggest a workshop with EWLS to map out collaborative research strategies for selection of analogue sites, development of revegetation closure criteria & choice of indicators for monitoring revegetation success.
- Initial collaborative project completed with EWLS on assessing multispectral QB satellite data to map & monitor weeds.
- Collaboration with CDU (Sean Bellairs) strengthened – expertise in soil seed biology & establishment species. Seeks stakeholder support for an ARC-Linkage (PhD) grant in soil seed biology.
- To incorporate Indigenous cultural values into rehabilitation success criteria, we suggest a partnership approach with NLC & other Ranger stakeholders, & external experts (e.g. Dr Sue Jackson CSIRO SE – cultural values water).

QuickBird – satellite images

Late dry 2003

Late wet 2004

QuickBird satellite image – late wet 2004