Part 2: Ranger – Rehabilitation

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Reliability assessment of Siberia model outputs

KG Evans & GR Willgoose[1]

Introduction

Several research projects have been completed addressing the application of the Siberia landform evolution model (LEM) to mine site rehabilitated landform design. These projects include derivation of site input parameters (Evans et al 1998, Willgoose & Riley 1998), validation of the model (Hancock et al 2000, 2002), assessment of temporal trends in landform development (Moliere et al 2002) and development of a GIS front-end (Boggs et al 2001).

During the assessment of impacts of uranium mining on Kakadu National Park by the Independent Scientific Panel (ISP), the error bounds/uncertainties in model simulations were questioned. This project was established with Professor G Willgoose, the author of Siberia, to address these questions.

This reliability assessment project comprised four stages: 1) Project design and input errors for quantitative reliability assessment (QRA); 2) Characterisation of errors; 3) Modification of Siberia and associated software; and 4) Risk assessment modelling.

Progress to date

Stages 1 and 2 are complete and reported in the Project Design Document (PDD) (Willgoose 2005).

Stage 1 defined the following model input errors:

- **Uncertain temporal trends:** These are processes, which evolve systematically through time e.g. the grading of an erosion surface to a stable armour.
- **Random temporal events:** These are events that occur randomly with time e.g. rainfall, fire.
- **Uncertain spatial trends, patterns and organisation:** These are properties that vary in space systematically e.g. variation in spoil characteristics due to random dumping.
- **Random spatial effects:** Properties that have spatial variation such as waste rock dump settlement.
- **Model fitting uncertainty:** This is the scatter of data around a best fit in a scatter plot. This scatter generally arises from two sources: (a) model error i.e. the inability to simulate the observed physics, (b) observation error i.e. the inability to correctly measure the observed physics.

The possible sources of error to be considered in LEM predictions are:

- **Climate:** (a) reliability of longterm rainfall record and is representativeness of the actual longterm averages and extremes; (b) the possible effect of extreme events; and (c) the effect of rainfall on vegetation cover and erosion.

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- **Hydrology:** (a) effect of surface roughness on runoff-routing; (b) infiltration properties; and (c) spatial correlation of rainfall on the area-scaling effect.
- **Sediment transport:** (a) temporal and spatial variability of material fluvial erodibility and discharge and slope dependence of fluvial sediment transport; and (b) the effect of ignoring creep/rainsplash diffusion transport.
- **Vegetation:** (a) linkage of vegetation density to climate variability; (b) fire effects; (c) spatial variation of vegetation density.
- **Waste rock dump:** The effects of waste rock dump settlement and tailings consolidation on drainage patterns and incision.
- **Siberia algorithms:** The ways in which Siberia approximates the physics of the system: (a) grid elevation discretisation and algorithms for drainage analysis; and (b) grid discretisation resolution, orientation and origin.

Stage 2 is the characterisation of errors and the PDD (Willgoose 2005) outlines methodologies for characterisation of errors. This will not involve additional data collection beyond what has been completed or currently in progress by ***eriss***.

Stages 3 and 4 involves Monte-Carlo simulations and risk assessment. Further project development is currently underway.

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Assessing the geomorphic stability of the currently proposed final landform at the Ranger mine using landform evolution modelling

JBC Lowry & KG Evans

Introduction

The environmental requirements for mine closure at the Ranger Mine in the Northern Territory specify that the mine landscape must be rehabilitated such that the final landform and composition of the plant communities are compatible with those of the surrounding areas of Kakadu National Park.

A draft landform design was created based on the 2001 life of mine plan, and evaluated using the SIBERIA landform evolution model and ArcView GIS software packages which had been integrated through an interface known as ArcEvolve (Boggs 2003). Siberia uses a series of hydrology and erosion parameters to model long-term changes in elevation with time from the average effect of mass transport processes, such as tectonic uplift, fluvial erosion, creep, rainsplash and landsliding. The input parameters are applied to a series of 'regions' which represent different surface conditions over the landform being modelled. For the purposes of evaluation, surface conditions representing best and worst case scenarios were modelled. Using the hydrological parameters for natural surface conditions and rock / batter surface conditions, it is possible to simulate different scenarios for the evolution of the proposed landform for periods of up to 1000 years.

The evaluation highlighted areas of the draft landform that needed to be redesigned to match analogue specifications and to reduce gully erosion.

Progress to date

Using the methodology described in Lowry et al (2004), the draft landform was modelled for a period of 1000 years, with hydrology parameters held constant for the entire landform and erosion parameters varied for each region of the landform representing different surface treatments. Through the GIS interface, it was possible to identify areas of potential erosion/deposition by subtracting the 1000-year modelled surface from the current surface (figure 1).

The version 3 landform supplied by EWLS has been evaluated by Siberia using the ArcEvolve Siberia interface. The results of the modelling identified areas on the draft landform which needed to be redesigned, in order to minimise erosion from the landform. As indicated by the box in figure 1, a gully with a maximum depth of up to 14 metres was predicted to form on the left side of Pit 3 over a period of 1000 years, with the size and extent of the gully varying for the different scenarios.

Whilst recognising limitations with the modelling process, such as the inability to incorporate the different hydrology characteristics associated with different surface conditions on the landform within the model, the current process is able to perform distributed erosion modelling. This has enabled 'best case' and 'worst case' scenarios to be modelled with confidence within a range of erosion and deposition parameters.

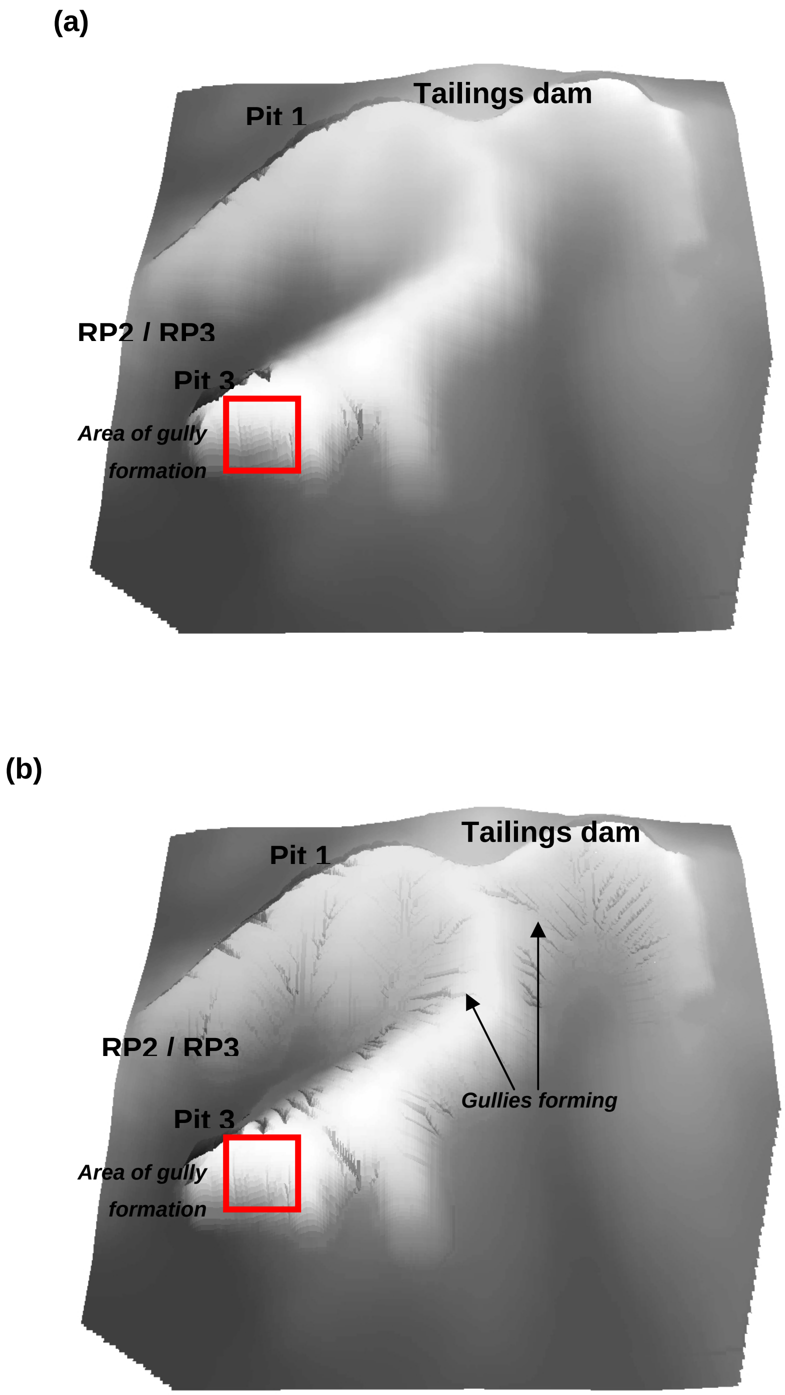

Figure 1 Areas of potential erosion / deposition (illustrated by gullies forming on slopes) on v3 landform using parameters for (a) 'best case' scenario; and (b) 'worst case' scenario

Simulated surface denudation rates (table 1) were calculated using ArcEvolve, and found to compare favourably with regional denudation rates of 0.04 mm/y for natural undisturbed surfaces (Cull et al 1992).

Table 1 Predicted denudation rates on the Ranger landform

Landform	'Best case' denudation rate (mm/yr)	'Worst case' denudation rate (mm/yr)
1000-year modelled with natural hydrology parameter	0.02	0.06

A draft report has been jointly prepared by EWLS and SSD describing the results of the modelling of the initial landform. In addition, the results of the modelling have been jointly presented by EWLS and SSD in a paper at the NARGIS (North Australian Remote Sensing and GIS) conference in Darwin (4–7 July 2005).

For the 2005–06 work program, the project will evaluate the final landform design proposed by EWLS. It will also ascertain whether current problems in incorporating hydrological parameters into Siberia are a result of a problem within the GIS interface or the Siberia program itself.

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Radio- and lead isotopes in sediments of the Alligator Rivers Region

A Bollhöfer & A Frostick[1]

Introduction

The aims of this project are to develop an innovative, sensitive and cost-effective methodology to assess and monitor impacts of past, present and future uranium mining activities in the Alligator Rivers Region. A combination of stable lead isotopes, trace metals and radionuclide techniques is used and concentrations are measured in both surface scrapes and sediment cores, to determine the sediment deposition history and extent of erosion and pollution in potentially mining influenced catchments. A pilot study conducted in the Ngarradj catchment (Bollhöfer & Martin 2003) outlines the general approach. The project is funded through the Australian Research Council (ARC) Linkage-Projects scheme and is conducted in collaboration with Charles Darwin University (CDU).

Ranger studies indicate that lead isotope ratios are an ideal source tracer to identify uranium rich solids. Lead isotope ratios are highly radiogenic as shown in a study of airborne dust originating from Ranger (Bollhöfer et al 2005) and measurements of particulates in tailings dam water (Gulson et al 1996). Coupled with the measurement of radionuclide and heavy metal concentrations, past and present erosion and subsequent deposition of contaminants originating from mining activities or unstable landforms may be identified and quantified. Koongarra and the Nourlangie Creek catchment may act as a natural analogue in this regard.

Method

The following 4 catchments will be investigated.

- Rehabilitated Nabarlek mine and the Cooper Creek catchment
- Ranger mine and the Magela and Gulungul Creek catchments
- Jabiluka and the Ngarradj catchment
- Koongarra and the Nourlangie Creek catchment.

Surface scrape and sediment core samples are collected during the early dry season. Core samples are then sliced into 1–2 cm samples and prepared for measurement via ICP-MS for heavy metals and lead isotope ratios (Munksgaard et al 2003). Samples will then be combined for gamma analyses at ***eriss*** for U and Th-series elements, following standard procedures (Marten 1992). Cs-137 will also be measured in an attempt to obtain a chronology for the sediment cores.

[1] Charles Darwin University, Darwin NT.

Results

Soil scrapes and sediments from and adjacent to the Nabarlek mine site were collected in 2004 and 2005. Soil scrapes indicate that radiogenic material is deposited along major drainage lines, which may originate from the radiological anomalous area (RAA), or unit-7, just south of the former pit (figure 1). A former erosion assessment using the Revised Universal Soil Loss Eqaution (RUSLE) estimated that this area produces 74% of the total ^{238}U flux (and 84% of the total ^{226}Ra flux) to the Cooper Creek system, despite it having a relatively small surface area (Hancock et al 2006).

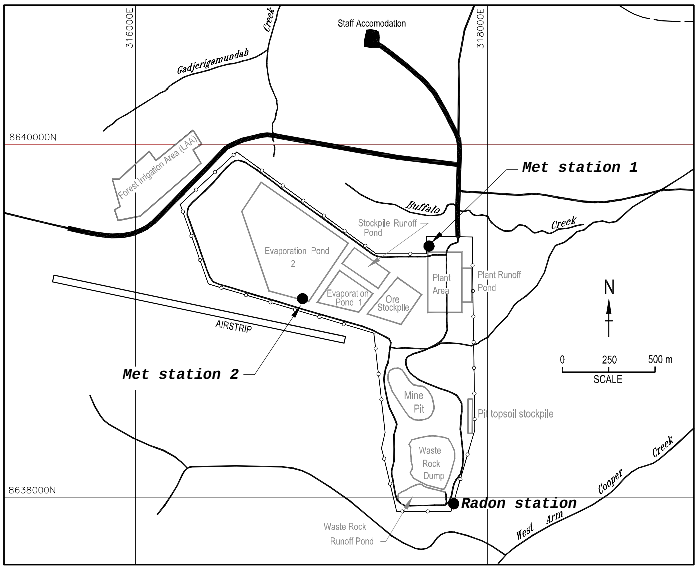

Figure 1 The rehabilitated Nabarlek mine and major features on site

Figure 2 shows lead isotope data measured in the samples from Nabarlek, together with data from a recent study of lead isotopic signatures in dust around Ranger uranium mine (Bollhöfer et al 2005) and results from samples taken in creek beds of the Ngarradj catchment (Bollhöfer & Martin 2003). Scrape samples taken from the Radiological Anomalous Area (RAA) exhibit even more radiogenic lead isotope ratios than those measured in Ranger uranium mineralised material, with higher $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{207}Pb$ ratios. Consequently, the samples collected at Nabarlek clearly follow a trend with a different endmember as the one observed in Ranger studies.

To determine the extent of erosion and deposition at Nabarlek, six sediment cores in backflow deposition zones along Cooper Creek, upstream and downstream of the mine site, have been collected in June 2005 and a further three cores from Kadjirrikamarnda Creek. Lead isotope results of Cooper Creek Core 9 downstream of Nabarlek but upstream of the Kadjirrikamarnda Creek confluence, are shown in figure 2 as well. The core samples follow a trend similar to the trend observed in Ngarradj sediments, exhibiting a mixture of relatively thorium rich sands at the bottom of the core with natural clays and organics at the top, and seem to be relatively unaffected by radiogenic lead.

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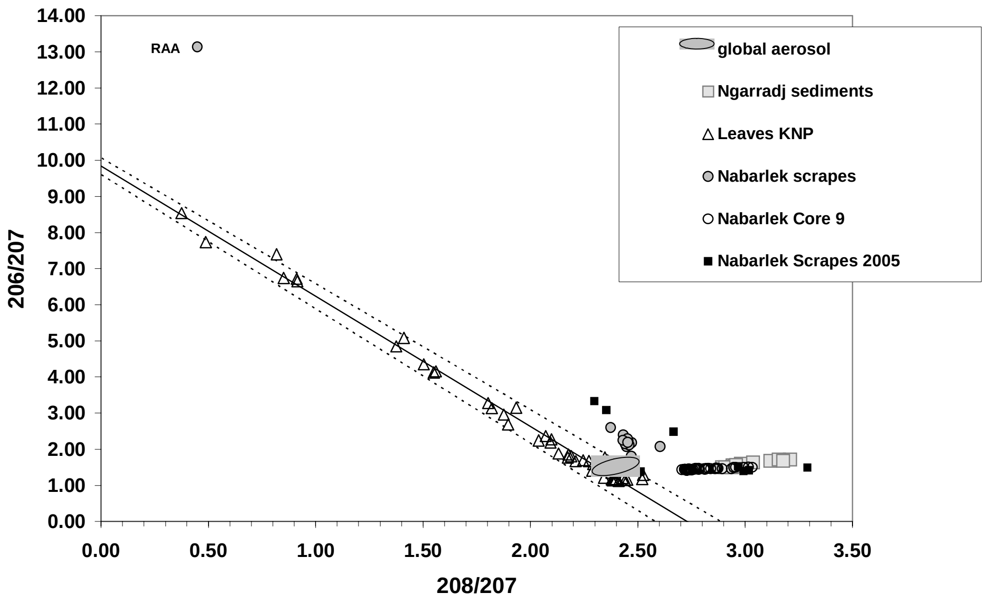

Figure 2 Three isotope plot of sediment samples taken at Nabarlek and Ngarradj and dust samples in the Ranger region

Radon exhalation at and around Ranger uranium mine

C Lawrence[1], R Akber[2], P Martin[3] & A Bollhöfer

Introduction

Airborne dispersion of radon and the subsequent inhalation of radon progeny is the major pathway of exposure of the public to natural sources of ionising radiation. UNSCEAR (2000) reported that radon isotopes contribute to more than 50% of the natural source of radiation exposure and measurements have shown that a dose of approximately 0.7 milliSievert (mSv) per annum is received in Jabiru due to the inhalation of radon progeny. However, it is necessary to distinguish natural and Ranger derived radon. Estimates for the mine-origin radon exposure range from less than 0.01 (Martin 2000) to more than 0.2 mSv per year (Kvasnicka 1990) at Jabiru.

In order to reliably model radon-222 (^{222}Rn) concentrations in air following rehabilitation it is necessary to know the ^{222}Rn exhalation source term in the Ranger area. This work was carried out in collaboration with Queensland University of Technology to determine the current source term and its temporal variation, and to develop algorithms that describe ^{222}Rn exhalation in terms of key soil characteristics. The information will be used to predict ^{222}Rn exhalation from the site after rehabilitation. The work program consisted of three main parts:

- Measurements of ^{222}Rn exhalation from surfaces at Ranger during the dry season;
- Measurements of ^{222}Rn exhalation at various sites over a seasonal cycle;
- Measurements of ^{222}Rn exhalation at various sites over several diurnal cycles.

Methods

A total of 654 readings of ^{222}Rn flux density were obtained in dry season conditions. Of these 298 were obtained from pit 3, pit 1, ore stockpile grade 2, ore stockpile grade 7, waste rock dump, overburden, laterite stockpile and irrigated and non-irrigated sections of the Magela land application area.

^{222}Rn flux densities were measured using two methods: activated charcoal canisters and scintillation emanometers. After retrieval, charcoal canisters were stored for an ingrowth period of at least four hours to allow for the establishment of equilibrium between ^{222}Rn and its progeny. The activity of ^{222}Rn adsorbed on the charcoal was then determined by counting on a portable gamma spectrometer with a 3” x 3” NaI(Tl) crystal housed in a lead castle.

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[1] Formerly SSD ; now ERA Ranger Mine, Jabiru NT.

[2] Queensland University of Technology, Brisbane Qld.

[3] Formerly SSD; now Agency’s Laboratories Seibersdorf, IAEA, A-1400, Vienna, Austria.

Results

^{222}Rn flux densities were highest for the ore stockpiles with fluxes from the laterite stockpile being three orders of magnitude larger than from environmental areas, which are typically 70 milliBecquerels per m^2 per second ($mBq \cdot m^{-2} \cdot s^{-1}$). ^{222}Rn flux densities from the waste rock dumps and the pits are 1–2 orders of magnitude higher, whereas those from the irrigated land application area were only slightly higher than the environmental areas at 112 $mBq \cdot m^{-2} \cdot s^{-1}$.

Radon exhalation from soils is influenced by a variety of factors, such as soil moisture, soil porosity and soil radium-226 (^{226}Ra) content. As measurements were conducted over the dry season, we were able to investigate the dependency of the ^{222}Rn flux density on soil ^{226}Ra content and soil porosity. Figure 1 shows the ^{222}Rn flux density plotted versus the soil ^{226}Ra content for various geomorphic groups: barren (disturbed) areas where compaction has taken place as a result of human influence, vegetated woodland and rehabilitated sites with relatively porous vegetated soils, non-compacted fine grains such as the laterite push zone or overburden zones, and non-compacted boulders. Compaction of the ground and reduction of soil porosity decrease radon exhalation whereas vegetation with established root structures leads to higher exhalation fluxes.

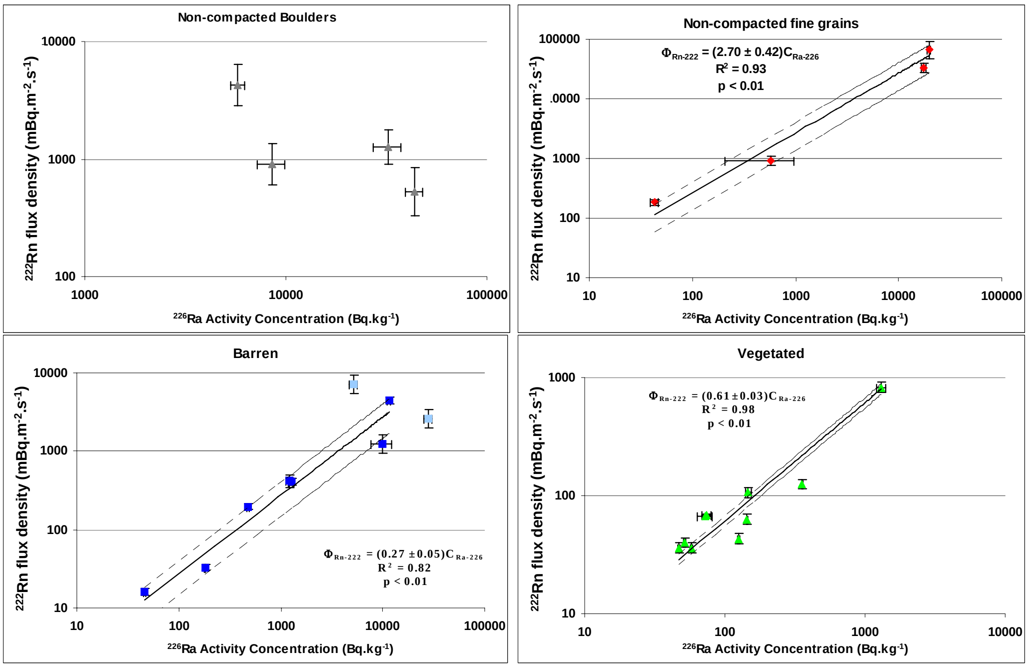

Figure 1 ^{222}Rn flux density plotted versus the soil ^{226}Ra content for various sites

Seasonal measurements of radon exhalation

^{222}Rn flux density measurements were performed over the course of one year at eight sites in the region. Previous studies have indicated that there are large variations in flux between wet and dry season in northern Australia. The influence of soil moisture is the most likely reason for this. Soil moisture profiles (0–1 m) were determined in conjunction with every set of flux measurements at some seasonal sites. The soil moisture data showed large temporal variations throughout the wet season which explains the large variations of ^{222}Rn flux densities during the wet.

Figure 2 shows the annual variation of ^{222}Rn flux densities at four of the eight investigated sites, and the cumulative rainfall during the time. Generally, radon exhalation in the wet season was largely reduced as soil moisture retarded radon exhalation. However, localised variations were also observed. For instance, some of the sampling sites such as the Mudginberri radon station, Jabiru East or Mirray exhibited a peak in radon exhalation during charcoal cup exposure in January, which is likely to be due to evaporation of soil water and the release of trapped radon after a short but intense rain event.

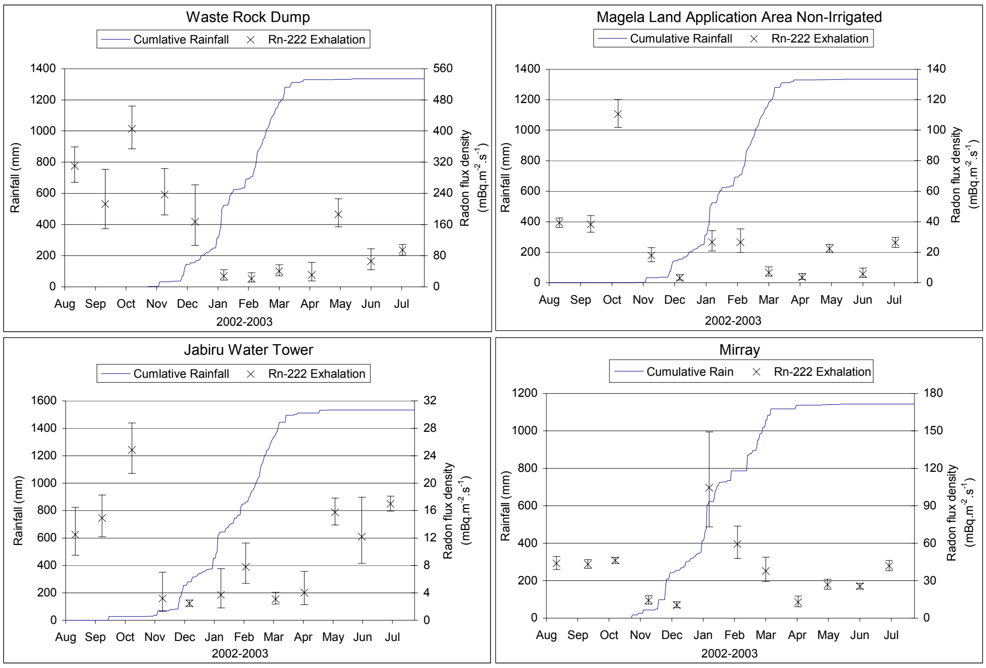

Figure 2 Annual variation of ^{222}Rn flux density and cumulative rainfall plotted versus the date

Diurnal measurements of radon exhalation

The aim of this part of the study was to establish whether there was a correlation between radon exhalation, time of day and meteorological parameters such as atmospheric pressure, site and soil temperature. Diurnal measurements were performed at five of the seasonal sites. To investigate whether diurnal radon flux density variations were dependent upon the soil moisture content, measurements were performed during the wet season and during the dry. The results indicate that there is little or no diurnal variation of ^{222}Rn flux density and that a correlation with soil temperature and atmospheric pressure, if any, is masked by random variations of radon exhalation and measurement uncertainty.

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Development of predictive habitat suitability models of vegetation communities associated with the rehabilitated Ranger final landform

C Humphrey, I Hollingsworth[1] & G Fox

Background

Target plant and animal communities must be identified and characterised for a number of sites and ecosystem types following Ranger mine-site rehabilitation, including the final, post-mine landform. Monitoring of target communities will then be required at these sites to assess the extent to which rehabilitation is being successfully sustained and achieved.

For vegetation communities, Hollingsworth et al (2003) identified natural analogue areas similar in size, underlying geology and conformation to a draft Ranger final landform design and representing the local range of habitats and ecosystem diversity in the lowland, Koolpinyah land surface. Hollingsworth and Meek (2003) made a detailed survey of plant communities in one of these analogue areas, the Georgetown area to develop criteria for ecosystem reconstruction.

The Georgetown analogue area is adjacent to and south-east of the Ranger mine (figure 1B). The authors related six ecosystem types identified from multivariate classification methods to key geomorphic features (parent material, slope, effective soil depth etc). Such relationships are essential in identifying sustainable and achievable 'landscape' analogues (or target habitats) for the final, post-mine landform at Ranger (Reddell & Meek 2004).

In a critique of the analogue work of Hollingsworth et al (2003), Dr Carl Grant, independent member of ARRTC, recommended: (i) that the study be expanded beyond the current narrow geographic extent to the broader environment of Kakadu National Park; and (ii) that the vegetation classification incorporates species abundance data (hence, aligned better to the broader rehabilitation objectives set for Ranger for which plant density must be considered) (ARRTC request 3H from the 13th meeting March 2004, redo vegetation classification to consider species abundance.) Reddell and Meek (2004) also noted that this initial EWLS work may need to be extended by way of additional surveys, to 'refine some of the target vegetation types once the design features of the final landform are finalised (eg for drainage lines, or for potentially waterlogged areas such as the former tailings dam floor)'.

In this current project, vegetation survey data previously obtained by ***eriss*** across a broad geographical range and broad landform types throughout the ARR (Brennan 2005) have been combined with the EWLS Georgetown analogue data, in accordance with the above recommendations. The aim of the project is to (i) use this extended analysis to re-classify and characterise plant communities; and (ii) from plant community-environment relationships, derive predictive models based upon physical and chemical input variables. The derived, target plant communities may then be considered as the basis of revegetation and post-rehabilitation monitoring programs.

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[1] Earth, Water, Life Sciences, Darwin NT

The objectives of Brennan's (2005) study, data for which were gathered in the early 1990s, were also based upon Ranger final landform-analogue analysis. The objectives of his study were twofold:

1 To obtain quantitative data from undisturbed native plant communities in areas adjacent to the Ranger uranium mine site that may be considered useful as models for future revegetation strategies and standards.

2 Acknowledging that sites from 1. may not necessarily be useful analogues of the final landform (considering substrate, aspect etc), to describe undisturbed native vegetation on a range of sites elsewhere in the ARR where the topography and/or substrates were perceived to be more similar to conditions expected to prevail on the Ranger waste rock dump. 'Comparison of vegetation communities on these sites with those adjacent to the WRD could indicate the degree to which adjacent vegetation might be useful as a model for revegetating the Ranger WRD' (Brennan 2005).

This progress report:

- provides summary results of some multivariate analyses, including classification and plant association analysis, performed on combined eriss and EWLS plant community datasets; and
- considers some key issues to be considered in progressing this plant analogue study further.

More complete reporting of results of this study are provided in Humphrey et al (2006), including additional methods descriptions and multivariate analyses, and tabulation of the full plant datasets.

Multivariate analyses

Methods

Survey sites

Quantitative plant community data were gathered by Brennan (2005) over the period 1991 to 1993, from 20 potential analogue sites (figure 1):

- 10 well-drained lowland sites, on low, broad ridges adjacent to Ranger, and on the weathered Koolpinyah surface (amongst the 'Ranger sites' in figure 1A and designated 'R' in figure 1B);
- five sites on weathered hills composed of Cahill formation schists: four at Tin Camp Creek and 1 at Fisher (figure 1A); and
- five sites on sandstone (four sites) and quartzite (one site Mt Cahill) hills (figure 1A).

Similar quantitative plant community data were gathered by Hollingsworth and Meek (2003) from 18 sites in the Georgetown analogue area, adjacent to and south-east of the Ranger mine – figure 1B. These sites are located on the weathered Koolpinyah surface, though unlike comparable sites of Brennan's (2005), site selection was deliberately broad, encompassing rocky outcrops, slopes and crests, stream alluvium and poorly-drained flats.

Data analysis

'Trees and shrubs' data for the 38 collective sites of EWLS and ***eriss*** described above were combined (species density per hectare). (Herb data are available from both sources but have not yet been examined.) Brennan (2005) and Hollingsworth and Meek (2003) classified 'trees and shrubs' as >1.5 m and >2 m respectively. This size class difference is regarded here as sufficiently small that it would not lead to any significant artefacts in data pooling. Other consequences of pooling of the two datasets are described in Humphrey et al (2006). Two data transformations were applied to data analysis: log (x+1) and presence-absence.

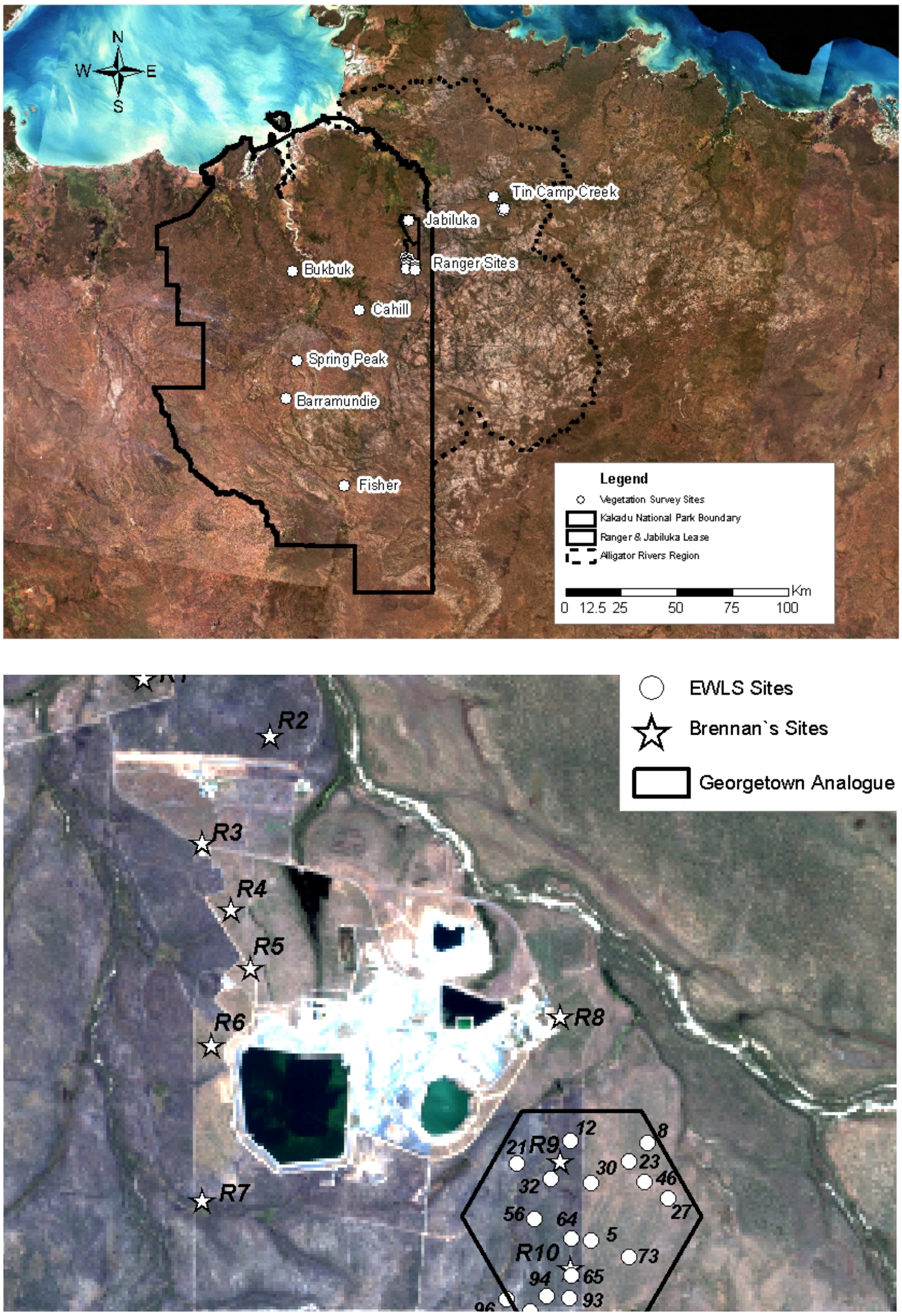

Figure 1 Maps of plant analogue sites surveyed by Brennan (2005) (A and B) and EWLS (Hollingsworth et al 2003) (B)

Plant community data were analysed using multivariate procedures from the PRIMER (v5) software package (Clarke & Gorley 2001). Three levels of analysis were applied:

1 Describing pattern amongst the assemblage data using cluster (classification) and ordination techniques. The basis of these analyses was Bray-Curtis dissimilarity matrices. The clustering technique used a hierarchical agglomerative method where samples of

similar assemblages are grouped and the groups themselves form clusters at lower levels of dissimilarity. A group average linkage was used to derive the resultant dendrogram. The ordination method used was Multi-Dimensionsal Scaling (MDS) (Clarke & Warwick 2001). Ordinations were depicted as two-dimensional plots based on the site by site dissimilarity matrices.

2 For the *a priori* factor, landform type (comprising three groups, Koolpinyah lowlands, schist hills and sandstone hills), Analysis of Similarity (ANOSIM) – effectively an analogue of the univariate ANOVA – was conducted to determine if the group comparisons were significantly different from one another. The ANOSIM test statistic reflects the observed differences *between* groups (landform types) with the differences amongst replicates *within* the groups. The test is based upon rank dissimilarities between samples in the underlying Bray-Curtis dissimilarity matrix.

3 The SIMPER routine was used to examine which plant species were contributing to the differences of landform groups that were found to be different according to the ANOSIM procedure. For visualisation, the numeric value of some key plant species were superimposed onto plant density MDS ordinations, as circles of differing sizes – so-called 'bubble plots'.

Results

Pattern analysis (classification and ordination)

Cluster analysis of plant community data showed similar groupings for both density and presence-absence data (figure 2). At a relatively high level of dissimilarity (~75% for density data and ~65% for presence-absence data), five groups were identified. For density data, the hill sites of Brennan (2005) were dispersed across three of these groups while EWLS sites were dispersed across four of the groups (figure 4).

In ordination space, for both density and presence-absence data, hill sites of Brennan's (2005) were located to one (right-hand) side of Axis 1 of the ordination, while his and the EWLS lowland Koolpinyah sites were generally dispersed across the other (left-hand) side of Axis 1 of the ordination (figure 3).

EWLS sites were well dispersed in ordination space and amongst classification groups. This spread is much greater than Brennan's (2005) equivalent lowland sites, even though the EWLS sites are much more geographically constrained than Brennan's. This indicates the EWLS analogue location has captured a greater variety of landform types, borne out in the study designs of both studies where Brennan's Koolpinyah sites were deliberately confined to low, broad ridges while the comparable EWLS sites were selected from across a range of landforms. Nevertheless, the EWLS sites do not appear to capture well 'hill' flora (figure 3).

In general, the groups identified from cluster analysis do not separate according to the broad *a priori* landform types based upon substrate and topography (figure 4). While axis 1 of the corresponding plant density ordination distinguishes hills and lowland vegetation communities, the two largest cluster groups cut across both ordination axes, each capturing hills and lowland vegetation sites (figure 4). To some extent, the ordinations and classifications may be influenced by plant density and species richness (number) *per se*. Thus Axis 2 of the ordinations appears to be correlated with increasing plant density and species richness (figure 5).

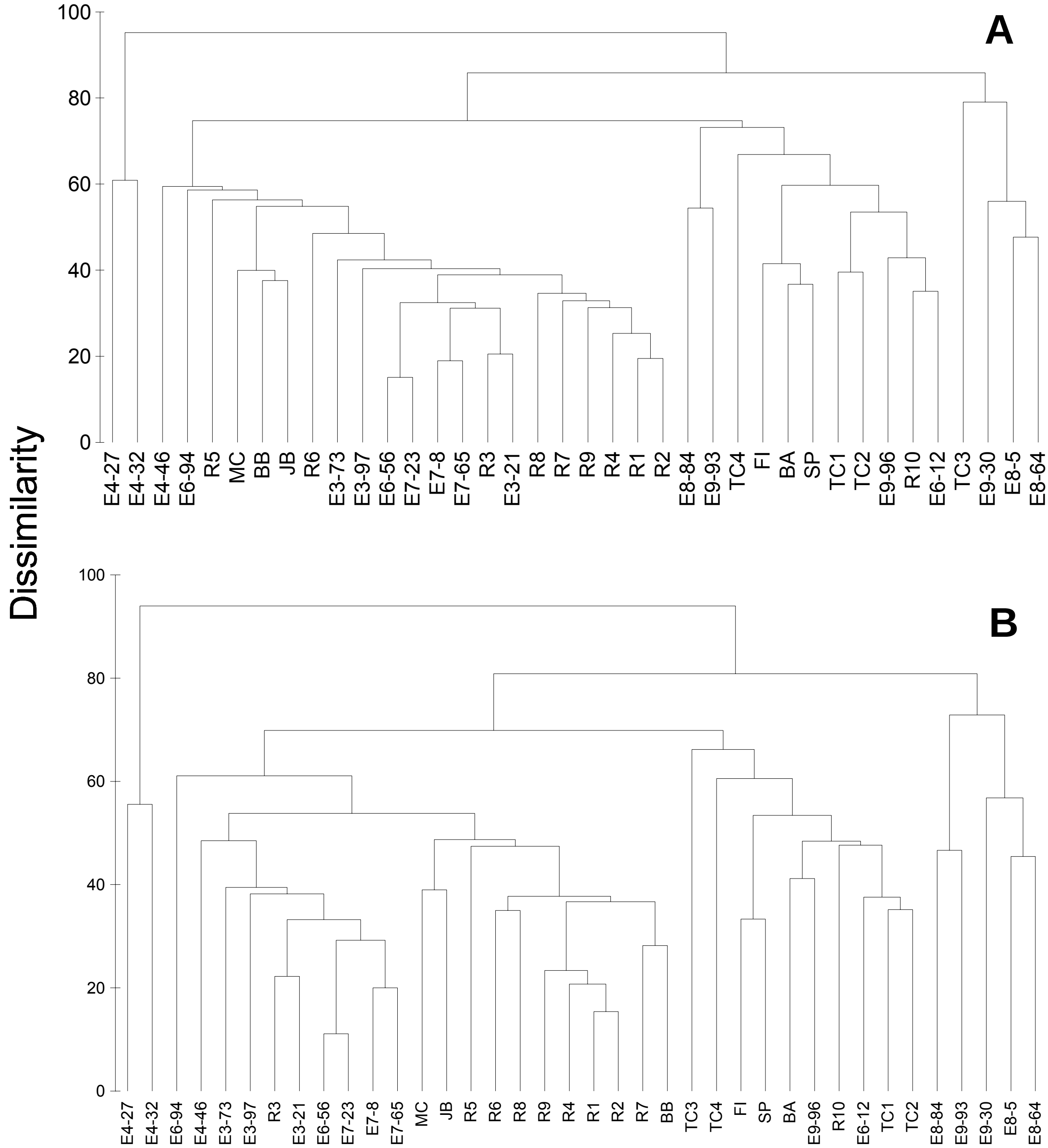

Figure 2 Cluster analysis (group average linkage) of combined ERISS and EWLS 'trees and shrubs' data from different ARR landforms. Data for A are log transformed density/hectare units, data for B are presence-absence.

Key to site codes:
'E' sites = Hollingsworth et al (2003) Georgetown analogue site,
'R' sites = Brennan's (2005) lowland Koolpinyah sites around Ranger
'TC' (Tin Camp Creek) and 'F1' (Fisher) = schist hills
JB, BB, BA, SP = sandstone hills
MC = quartzite hill

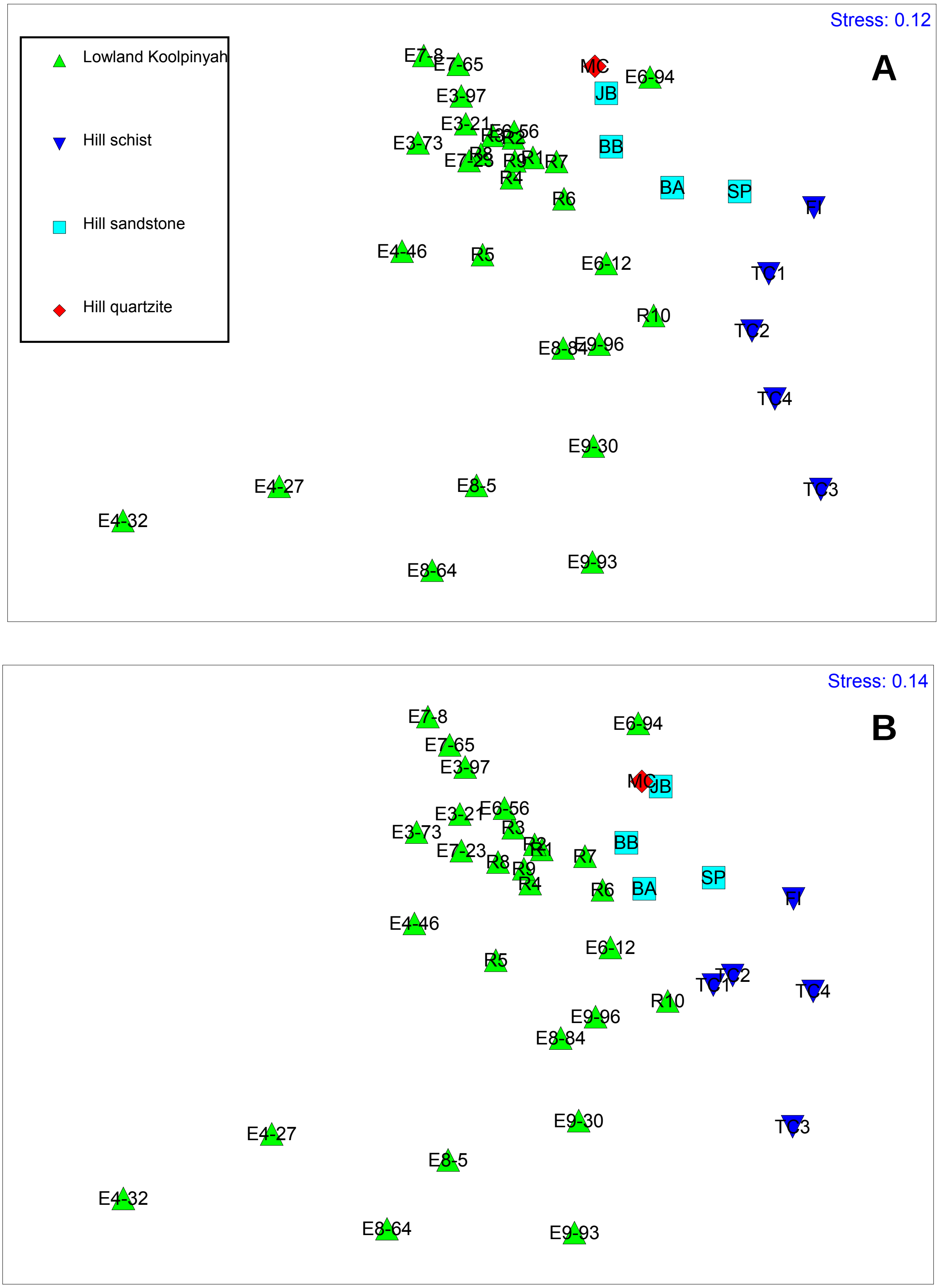

Figure 3 MDS ordination of combined ERISS and EWLS 'trees and shrubs' data from different ARR landforms. Data for A are log transformed density/hectare units, data for B are presence-absence. General key to site codes is provided in figure 2.

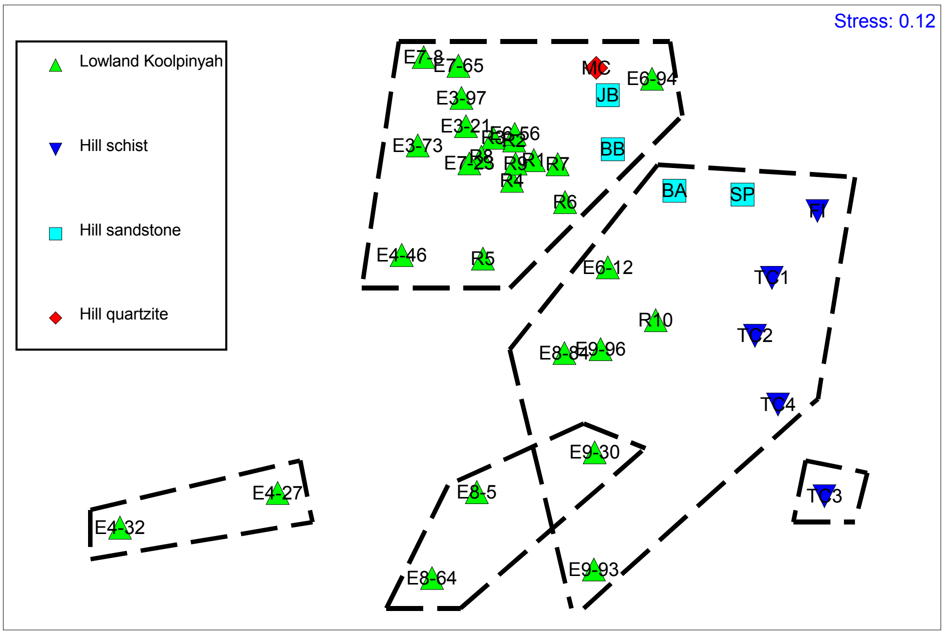

Figure 4 MDS ordination of combined ERISS and EWLS 'trees and shrubs' density data from different ARR landforms, overlain by groupings identified from (plant density-derived) cluster analysis (from figure 2). General key to site codes is provided in figure 2.

Analysis of Similarity (ANOSIM)

Results for ANOSIM, performed on the *a priori* groups sandstone hills, schist hills and Koolpinyah lowlands, are shown in table 1 according to plant density and presence-absence data. Significance levels for the global test are low (~5%) indicating significant group, pairwise differences somewhere amongst the landform comparisons. The important statistic to observe for the pairwise comparisons (table 1) is not so much the significance level (which is sensitive to sample size, in this case sites within a landform), but the pairwise R values. The table caption of table 1 provides some 'rules of thumb' in interpreting R values. For both plant density and presence-absence data, there is significant separation between lowland Koolpinyah and schist hill sites, and between schist hill and sandstone hill sites (table 1).

Table 1 ANOSIM on factor landform type, giving the significance of the test, with degree of separation between groups (R-statistic), where R-statistic >0.75 = groups well separated, R-statistic >0.5 = groups overlapping but clearly different, and R-statistic <0.25 = groups barely separable. A significance level <5% = significant effect/difference.

Groups	R Statistic	Significance level (%)
Species presence-absence data		
Sample statistic (Global R) = 0.196; Significance level of sample statistic: 5.3%		
Lowland Koolpinyah, Hill schist	0.376	1
Lowland Koolpinyah, Hill sandstone	0.014	44.2
Hill schist, Hill sandstone	0.484	1.6
Species density data		
Sample statistic (Global R) = 0.196; Significance level of sample statistic: 5.3%		
Lowland Koolpinyah, Hill schist	0.455	0.5
Lowland Koolpinyah, Hill sandstone	0.082	29.7
Hill schist, Hill sandstone	0.463	1.6

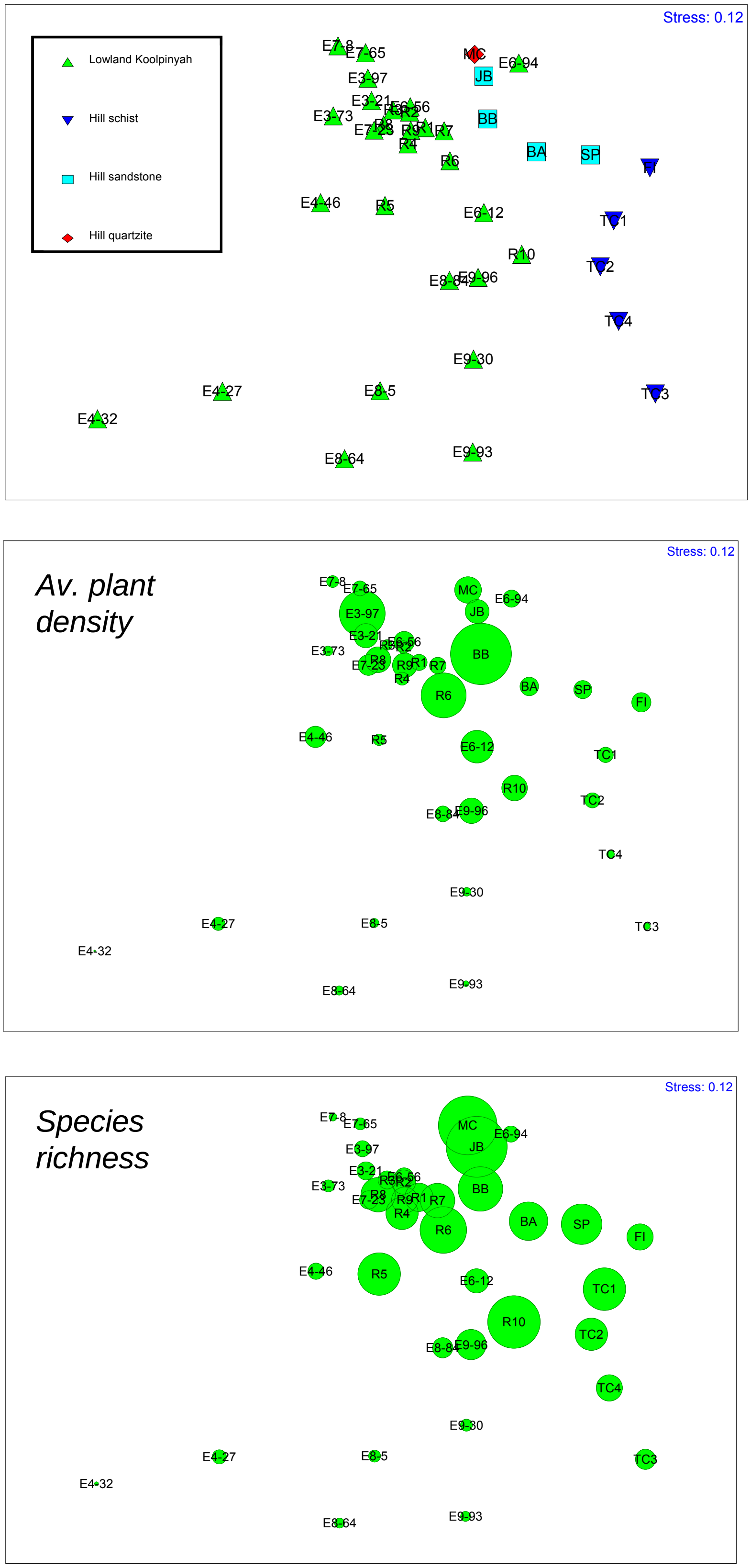

Figure 5 MDS ordination of plant density data, with bubble plots of average plant density and species richness (number)

Taxa contributing to the differences of site groups (SIMPER)

SIMPER analysis examines the plant species best representing and separating different multivariate groupings. SIMPER results are shown in tables 2 and 3 for the two landform comparisons, lowland Koolpinyah versus schist hill sites, and schist hill versus sandstone hill sites respectively. These two comparisons were shown to be significantly different in the ANOSIM analyses for both plant density and presence-absence data. Results are shown for plant density data (only) by way of (i) the average dissimilarity between all pairs of inter-landform samples, (ii) the dominant taxa, in decreasing order of importance, in contributing to the average dissimilarity between the two groups, and (iii) the cumulative percentage of overall dissimilarity contributed by the dominant taxa.

The average inter-landform dissimilarity was highest (= best group discrimination) for the lowland Koolpinyah versus schist hill sites comparison – 83% compared with the schist hill versus sandstone hill sites comparison – 70% (tables 2 and 3). The cumulative percentage of overall dissimilarity contributed by the dominant (say) 10-15 taxa is generally high (~50%) indicating that these taxa are contributing quite significantly to the landform differences. Some 'signature' dominant plants of sandstone versus schist substrates, identified from SIMPER analysis (tables 2 & 3), are plotted as 'bubbles' in figure 6.

Implications and possible future directions of analogue work

Brennan (2005) and other workers in the early 1990s regarded schist hills and associated landform responses (including runoff and infiltration characteristics) and resident biota as potentially suitable analogues for the future rehabilitated Ranger landform. (A reference list is provided in Humphrey et al (2006) of studies conducted by ***eriss*** and consultants at Tin Camp Creek analogue locations near Nabarlek.) In relation to the flora, Kym Brennan (pers comm) suggested the indicative flora of schist hills (tables 2 and 3), often with deciduous elements such as *E. tectifica*, was well suited to the heavy clay soils of these hills which do not allow deep root penetration. Ken Evans (pers comm) also notes the highly-resistant underlying metamorphic bedrock of ARR schist hills.

While the schist-hill-analogue hypothesis is potentially appealing, it also needs to be tested. It is questionable as to whether the Ranger final landform with its coarse rock fragments will present the same physical barrier to root penetration, even though surface armouring and a 'washed-in' layer of fine silt and clay will form (which itself could act as a barrier to root penetration of germinating seeds).

Workers at the Tin Camp Creek analogue sites in the early 1990s were mindful of the need to assess the edaphic features of analogue sites and hence affirm a basis for an analogue in terms of porosity and water movement/drainage, in addition to other soil properties including soil profiles, water availability and chemistry. However, it does not appear that the edaphic factors responsible for plant species composition have been sufficiently well investigated though much of the data required to do this may have already been gathered.

Table 2 SIMPER results for plant species discriminating pairs of analogue lowland Koolpinyah and Schist hill sites, based upon plant density data. Average dissimilarity between all pairs of inter-landform samples = 83%. Other key summary statistics are explained in the text.

Species	Lowland Koolpinyah Av.Abund	Schist Hill Av.Abund	Av. Dissim	Dissim/SD	Contrib'n%	Cumul.%
Acacia mimula	196.52	0.00	5.02	1.42	6.04	6.04
Eucalyptus tectifica	7.77	100.00	4.63	1.92	5.57	11.60
Calytrix achaeta	0.18	71.50	4.09	1.50	4.92	16.52
Eucalyptus tetrodonta	76.96	2.00	3.96	1.60	4.76	21.28
Xanthostemon paradoxus	110.18	10.00	3.90	1.32	4.69	25.97
Corymbia foelscheana	34.11	64.50	3.76	1.27	4.53	30.49
Cochlospermum fraseri	14.73	41.50	3.63	2.06	4.36	34.85
Erythrophleum chlorostachys	13.66	66.50	3.39	1.28	4.07	38.92
Corymbia porrecta	58.57	0.00	3.23	1.06	3.89	42.81
Grevillea decurrens	19.82	25.50	3.03	1.29	3.64	46.45
Eucalyptus pruinosa	0.00	48.00	2.80	0.72	3.36	49.82
Eucalyptus miniata	33.75	1.00	2.69	1.03	3.23	53.05
Hakea arborescens	9.20	12.50	2.52	1.15	3.03	56.08
Terminalia ferdinandiana	27.50	5.00	2.49	1.31	2.99	59.07
Planchonia careya	24.02	0.50	2.37	0.96	2.85	61.92
Buchanania obovata	5.80	13.00	2.34	1.10	2.81	64.73

Table 3 SIMPER results for plant species discriminating pairs of analogue schist hill and sandstone hill sites, based upon plant density data. Average dissimilarity between all pairs of inter-landform samples = 70%. Other key summary statistics are explained in the text.

Species	Schist Hill Av.Abund	Sandstone Hill Av.Abund	Av. Dissim	Dissim/SD	Contrib'n%	Cumul.%
Acacia mimula	0.00	112.50	3.41	2.61	4.86	4.86
Livistona humilis	0.00	48.75	3.21	2.33	4.58	9.44
Xanthostemon paradoxus	10.00	97.50	3.17	1.73	4.53	13.97
Eucalyptus tetrodonta	2.00	120.63	2.77	1.83	3.95	17.92
Corymbia foelscheana	64.50	0.00	2.74	1.39	3.91	21.83
Eucalyptus tectifica	100.00	4.38	2.53	1.68	3.61	25.44
Corymbia dichromophloia	37.00	50.63	2.41	1.01	3.44	28.88
Terminalia ferdinandiana	5.00	57.50	2.32	1.78	3.31	32.18
Erythrophleum chlorostachys	66.50	131.88	2.31	1.17	3.30	35.48
Eucalyptus miniata	1.00	28.75	2.25	1.67	3.20	38.68
Calytrix achaeta	71.50	26.88	2.12	1.40	3.02	41.70
Corymbia chartacea	16.50	94.38	2.10	1.00	2.99	44.69
Eucalyptus pruinosa	48.00	0.00	1.79	0.74	2.55	47.24
Livistona inermis	0.00	215.63	1.78	0.78	2.54	49.78
Croton arnhemicus	0.00	15.00	1.71	1.50	2.44	52.22

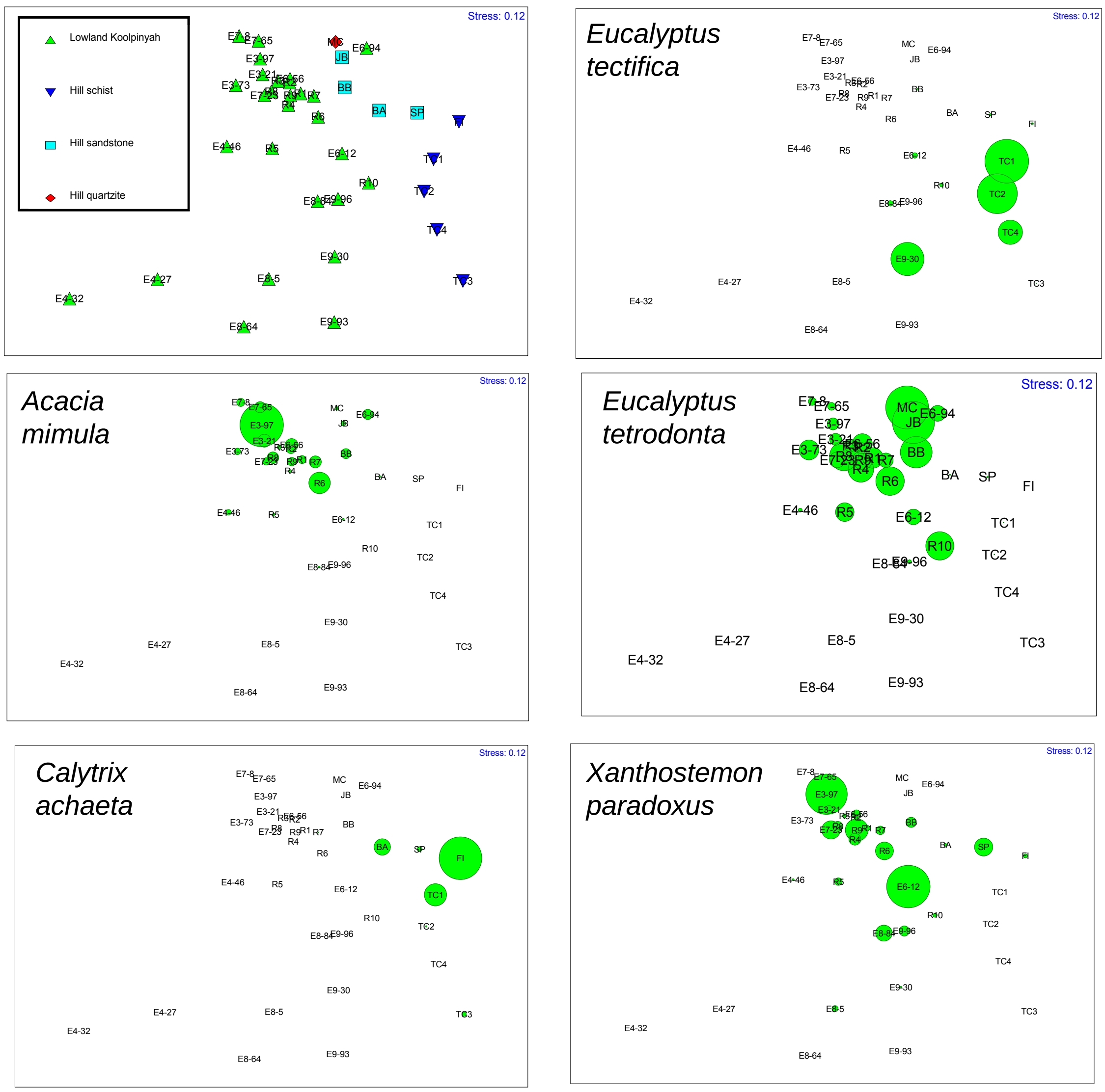

Figure 6 MDS ordination of plant density data, with bubble plots of key species identified by SIMPER as discriminating between schist and sandstone substrates

This objective of the ensuing study is to examine environmental relationships of the vegetation patterns found in the multivariate analyses performed to date. Anticipated components of the project are:

1 Review the ***eriss*** Tin Camp Creek analogue work and collate relevant databases.

2 Plant/edaphic relations:

a Investigate physical soil properties of the analogue sites and tease out physical versus chemical constraints to plant presence and abundance. (Soil chemistry data, at least, are available.)

b Review information available from elsewhere in Australia on this topic.

c Re-survey original analogue sites if necessary, to acquire critical data, particularly on physical features of the soil profile (as these affect water availability).

d Consider plant surveys at mine-disturbed sites along the upper South Alligator River valley. The Scinto 6 site has slopes of rock-fragment overburden that have revegetated naturally. A comparison of this flora to that on adjacent undisturbed slopes may assist in assessing the effects of a fractured rock matrix on vegetation composition and density.

e Model vegetation patterns, conceptually and empirically, as a function of landform properties and soils in analogue sites. This is a step that both ***eriss*** and EWLS wish to take further. The modelling would be used to predict potential ecological outcomes for final landform designs.

f If required, survey additional 'hill' analogue sites: while the current data adequately characterises plant communities of different landforms, more replication may be required to develop statistically robust models of the type described in step e.

For step 2e, one of us (IH) proposes applying terrain analysis to the vegetation patterns determined from this study. The tenet of this investigation is that the geomorphic properties that distribute water and nutrients in the landscape exert control over the distribution of plant communities and ecosystem function. Understanding the way in which water and nutrients are distributed in hill slope environments, similar to the Ranger mine landform, could establish the pattern and form of interaction between biological communities and the landscape at a scale that is appropriate for planning mine rehabilitation at Ranger.

The outputs from the full study will provide a firm basis for:

1 selection of an appropriate distribution of species for initial planting on the constructed Ranger landform, and

2 providing an envelope of possible natural outcomes against which the progress of evolution of the plant assemblage on the Ranger mine landform can be quantitatively assessed with respect to ER 2.2a

Acknowledgments

Thanks to Peter Bayliss, David Jones and Paul Reddell who provided valuable comments on a draft of this paper or on analogue concepts raised in the paper.

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Key aspects of native flora seed biology that support Ranger mine rehabilitation goals

P Bayliss & S Bellairs[1]

Introduction

The aim of this project is to determine seed viability, dormancy, longevity and germination characteristics of native plant species local to the Ranger mine site in order to aid reliable germination and promote establishment of diverse local vegetation on rehabilitated landforms. Kakadu National Park contains a diverse range of native plant species, and ERA is required to rehabilitate the Ranger mine site with a selected range of these species. EWLS/ERA and SSD are collaborating with Charles Darwin University (CDU) and Kakadu Traditional Owners (principally Kakadu Native Plant Suppliers) to investigate the seed biology of local species with potential for use in revegetation. A broad range of species will be investigated so that information is available on which species can be effectively established from seed for later discussions between all stakeholders on choosing species for inclusion in the rehabilitation mix. An Australian Research Council (ARC) Linkage application was submitted in the April 2005 round to fund a PhD project and a post-doctoral position at CDU to research aspects of seed biology relevant to the succcessful revegetation of Ranger. Partners in the application were ERA and EWLS, Department of Business, Industry and Resources Development, Office of Supervising Scientist and Charles Darwin University. Despite an excellent application, substantial cash and in-kind contributions from Industry Partners, and highly favourable reviews at all stages, the bid failed. Although partners decided to re-submit to ARC in the November 2005 round, it was decided also to access the partner cash and in-kind commitments in order to commence work this dry season. Delays to critical research caused by seeking high risk funding options will have negative impacts on revegetation timelines. Hence, a full-time research position based with Dr Sean Bellairs at CDU will be advertised immediately.

Progress

This project is reported in two parts (following papers). The first was prepared by Honours student Kate Sangster and her supervisor Dr Sean Bellairs of Charles Darwin University, and reports on research progress into germination of a selection of native grass species. The second part was prepared by Dr Mark Gardener as a report to EWLS, and summarises progress in establishing a commercial seed collecting enterprise by Kakadu Tradional Owners Peter Christophersen and Sandra McGregor (Kakadu Native Plant Supplies, KNPS), funded by ERA Pty Ltd.

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1 Charles Darwin University, Darwin NT.

Key aspects of native flora seed biology that support Ranger mine rehabilitation goals

Part 1: Seed biology of selected Australian native grass species

K Sangster[1] & S Bellairs[1]

Background

Native grasses are an important part of the savanna landscape in the Top End of Australia. They have a range of crucial ecological roles and provide food and shelter to native fauna. Native grasses can also have an important role in rehabilitating land following mining activities. In general, grasses are used post mining to stabilise the soil, which aids in water retention, controlling erosion and creating a primary habitat for the establishment of other plants. Exotic grasses are often used for land rehabilitation as they are quick to establish from seeds, therefore providing fast vegetation cover. However exotic grasses can become problem weeds and may out compete native species if the rehabilitation aim is to establish a native species community.

Currently plans are underway for the rehabilitation of the Ranger mine site in Kakadu National Park. Native grasses are an important component of the savanna landscape in this region and therefore need to be replaced. It is also necessary to use only native species so that exotic species are not introduced into the National Park area. However, seed biology factors have limited the use of native grasses in other projects. Issues concerning seed viability and seed dormancy can result in low germination making the use of native grasses inefficient and impractical.

The aim of this project is to successfully germinate a selection of native grass species from the Ranger mine site region that have the potential to be of use in rehabilitation. Objectives to achieve this aim are to:

- identify species within the Ranger mine site area with the potential for use in rehabilitation;
- assess the seed viability of selected species; and
- determine which dormancy mechanisms are present and to trial dormancy breaking treatments to improve germination.

Methods

Seeds were hand-collected on the Ranger minesite then cleaned, sorted and dried. Seed viability was assessed using tetrozolium solution, which stains metabolically active tissue red, applied to the caryopsis and embryo. The degree of stain absorbed, and therefore the level of

[1] Charles Darwin University, Darwin NT.

viability, was visually assessed under a microscope. Germination trials were undertaken by placing the seeds on moist filter papers in Petri dishes. Petri dishes were incubated at 30°C for 30 days and germination monitored. Treatments were applied to seeds to determine the effect of husk removal, seed coat scarification, gibberellic acid, smoke water, potassium nitrate and darkness on germination and dormancy.

Progress to date

A meeting was held in Kakadu in February 2005 to determine which type of grass species would be most suited to rehabilitation at Ranger. Attendees at the meeting included Peter Bayliss (***eriss***), Sean Bellairs (CDU), Peter Christophersen (KNPS), Andrew Speechly (ERA) and Mark Gardner (EWLS). It was decided that the species selected should be perennial and produce light fuel loads to minimise fire risk. Seeds were collected from the Ranger mine site in late April over three days. Five species, *Heteropogon triticeus, Alloteropsis semialata, Eriachne schultziana* and two *Eragrostis* spp. were collected. These species are perennial, have light fuel loads and it was possible to collect a few thousand seeds of each species in a couple of hours. The seeds were then sorted and dried at CDU. Viability was assessed and the results recorded. Germination trials of each of the five species were then undertaken without any specific treatments to test for the presence of dormancy mechanisms. Following this the covering structures were removed from the caryopsis and germination was trialed to see if the covering structures were acting as a dormancy mechanism.

The results from the viability testing show a high level of viability, with at least a quarter of all species appearing to be clearly viable, and a significant proportion being potentially viable (table 1). In the germination trials with out any specific treatments (seeds with glumes, palea and lemma intact), there was no germination besides a small percentage of *Eragrostis* sp. 1 (figure 1). The removal of covering structures appeared to increase germination, particularly in *E. schultziana* and *H. tritceus*

Table 1 Viability of the grass seeds as assessed using tetrazolium – mean (± standard error)

Species	% viable	% possibly viable	% non viable
Alloteropsis semialata	33 (3)	33 (3)	33 (3)
Eragrostis sp. 1	36 (3)	43 (8)	20 (10)
Eragrostis sp. 2	36 (3)	36 (3)	26 (6)
Eriachne schultziana	26 (6)	23 (3)	50 (5)
Heteropogon triticeus	63 (6)	30 (5)	6 (3)

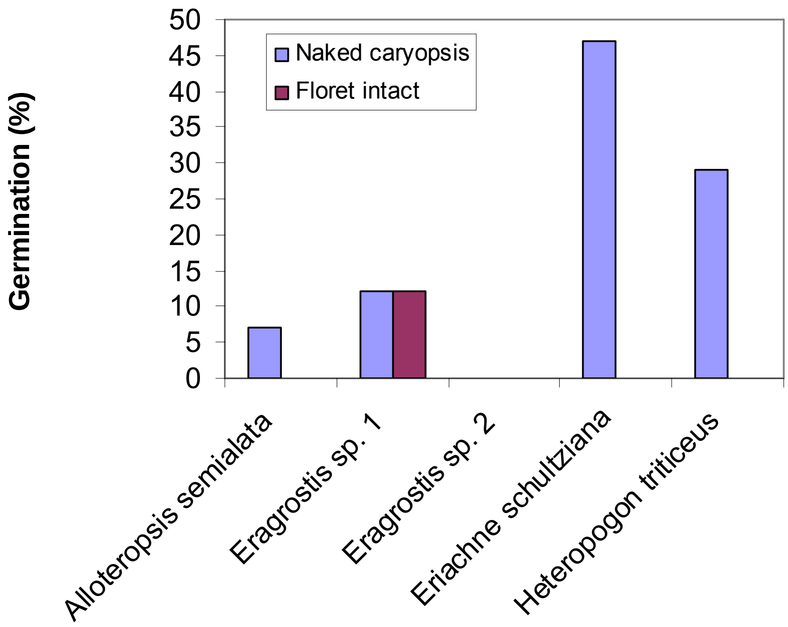

Figure 1 Total germination over 30 days of intact seeds and seed with covering structures removed

Preliminary conclusions

The reasonable ease of collection and the reasonably high level of viability in these species supports their potential use in rehabilitation programs. The very low level of germination in the trial with the untreated seeds (seeds intact) indicates that there is some form of dormancy mechanism(s) inhibiting germination in all five species. The increase of germination following the removal of the covering structures suggests that the covering structures are acting as either a mechanical or chemical barrier to germination. It is important to note that the initial viability of the seed lots will need to be considered along with the number of germinates per trial in order to properly determine the success of treatments.

Work to be completed

Work on the dormancy mechanisms present and effective treatments to overcome dormancy will continue to be investigated. The information from these investigations will form part of an Honours thesis completed in November 2005.

Key aspects of native flora seed biology that support Ranger mine rehabilitation goals

Part 2: Progress on Kakadu Native Plant Supplies Project[1]

M Gardener[2], P Christophersen[3] & S McGregor[3]

Summary

The Kakadu native plant project is progressing extremely well, is a model of successful Aboriginal enterprise and is based on collaborations between several industry and government partners. Kakadu Native Plant Supplies (KNPS) have collected, cleaned, catalogued and stored seeds from at least 25 plant species. KNPS have received significant training in aspects of nursery and business management. This training is on going and increases local capacity. By mid August 2005 the nursery will be fully functional and the first seed will be sown in late August. It is expected that KNPS will be able to produce the necessary seedlings by the end of the year to meet their contractual obligations with ERA.

Seed collection

To date Kakadu Native Plant Supplies have collected seed of at least 10 species listed in the contract (seven essential species, two highly desirable species, one other species of interest). These are local provenance seeds collected within a 50 km radius of Ranger mine. A further 15 species that are thought to be useful to revegetation at both Ranger and Jabiluka (Djarr Djarr) have been collected. Seeds have been cleaned and packed for storage. A log has been kept for collected seed and a database is currently being developed. Not all seeds on the contract list have been collected because the project has only been running since April 2005 and many species have yet to produce seeds.

Training

Kakadu Native Plant Supplies has undergone several days of training with Aboriginal Landcare Employment Program at Greening Australia including: plant identification, collection, maturity, cleaning, sorting (figure 1), storage and cataloguing of seeds (figs 1 & 2). They have also covered several units on Occupational, Health and Safety. Furthermore, they have undertaken specific training in grass identification and collection techniques. Training regarding plant propagation, nursery hygiene and maintenance is scheduled for early August 2005.

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[1] This report is based on a visit to Paradise Farm on 22 September 2005, several conversations with Peter Christophersen and with Greening Australia staff (Lesley Alford and Don Duggin).

[2] Earth Water Life Sciences, Darwin NT.

[3] Kakadu Native Plant Supplies, Jabiru NT.

Figure 1 Peter Christophersen at work sorting seeds from eucalypt fruits

Figure 2 A variety of fruits drying before processing

Business management and business support were also identified as key needs. Kakadu Native Plant Supplies has received a four-day training course in a Business Management Program and has adopted the Quick Books software to do all accounting. Kakadu Native Plant Supplies has also purchased a new computer system to support business management.

Nursery

Kakadu Native Plant Supplies has started preparing the ***eriss*** glasshouse facilities for plant propagation. By the middle of August 2005 an irrigation system will be installed, and a system of moveable shade will be erected. All potting medium and pots will be purchased shortly. The only barrier to plant propagation is the use of pesticides and fungicides which are not permitted because of possible interference to nearby ***eriss*** aqua-cultures. Problems with disease should be mostly overcome by good hygiene measures.

Plant propagation

Plant propagation is scheduled to start at the end of August. This is the latest date to sow some of the more difficult to grow species to produce seedlings by December 2005. Kakadu Native Plant Supplies have a contractual obligation to provide at least 3000 seedlings to ERA by 15 December 2005. It is expected that they will meet this target. It is likely that these 3000 seedlings will form part of the approximately 8000 seedlings required for revegetation of Djarr Djarr camp in Jan 2006. Many species required for the Djarr Djarr revegetation have yet to produce seeds and will not do so before the end of August when seeds are needed for planting to produce January 2006 seedlings. In this case, non-provenance seeds may need to be purchased (eg Top End Seeds). A decision is required by the end of August 2005 as to whether Kakadu Native Plant Supplies will be able to supply all required plants for the Djarr Djarr revegetation project.

Bioaccumulation in traditional Aboriginal bushfoods

B Ryan, A Bollhöfer & P Martin[1]

Introduction

The aim of this project is to assess the radiation exposure to humans via the ingestion pathway and contribute data that will aid in the development of dose assessment models for future users of rehabilitated uranium mine sites and for the general public.

Previous research on bioaccumulation of radionuclides in Aboriginal bushfoods has been carried out primarily for radiological impact assessment purposes in relation to current uranium mining activities in the region. Early studies conducted by ***eriss*** have focused on aquatic animal and plant species (Johnston et al 1984, Johnston 1987, Pettersson et al 1993, Martin et al 1995, Martin et al 1998). This has been due to the identified importance of the aquatic transport pathway during the operational phase of uranium mining operations. Martin et al (1998) have estimated the radiation dose received from the consumption of aquatic foodstuffs due to a simulated releases of RP2 water to Magela Creek, which is dominated by the intake of radium-226 in freshwater mussels due to the high concentration factors and their place in Aboriginal diet. The ingestion pathway has been identified as the major contributor to the mining related radiological dose to humans of the area.

With rehabilitation there will be radiological protection issues associated with the land use by local Aboriginal people and a shift towards terrestrial food sources that may grow on parts of the rehabilitated mines, Nabarlek and Ranger and also the abandoned South Alligator River Valley (SARV) mines. These foodstuffs include both aquatic and terrestrial animals and plants. Recently Ryan et al (2005) published radionuclide data associated with fruit and root vegetables in the ARR. It can be assumed that the highest doses to humans will be received from the consumption of foods from the vicinity of a contamination source. Therefore, the dose assessments need to be site specific, and the radiation dose model has to include local habits and human land use, and land use expectations, of the area.

Methods

In early 2005 SSD, in conjunction with Traditional Owners from the SARV, collected fruit and yam samples from the abandoned SARV mill site (figure 1). Traditional Owners for Nabarlek and SSD staff also spent time discussing traditional diets and collecting fruit samples for analyses at the rehabilitated Nabarlek mine.

As part of the dietary information that is needed to update dose assessments a questionnaire has been developed, under the guidance of the SSD Aboriginal Communications Officer, for distribution to local Aboriginal people. The information gathered from the discussions, analyses and questionnaire will help resolve issues relating to the rehabilitation of the Ranger mine site and update our dietary knowledge of the people living in the vicinity of the mine.

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[1] Formerly SSD; now Agency's Laboratories Seibersdorf, IAEA, A-1400, Vienna, Austria.

Figure 1 SSD employee at the abandoned SARV mine site with Traditional Owners and Parks Australia North Ranger digging for yams

Results

To aid in the identification of knowledge gaps associated with the assessment of the radiation health risk to humans via the biophysical pathway, SSD has begun collecting and reviewing all available information, both in hard and electronic form, from the Alligator Rivers Region. This information comprises more than two decades of radionuclide analyses and results including activity concentrations and concentration factors for key radionuclides in both aquatic and terrestrial animals and plants. Water and sediment data have also been included where relevant, and data quality has been checked when possible. Table 1 shows a summary of the available data. From this table it is apparent that more information is needed on radionuclide concentration and concentration factors for terrestrial flora and fauna, specifically adjacent to the Ranger mine.

The existing data are being collated and organised by location, species, radionuclide activity and concentration factor and are currently being incorporated into a Geographical Information System (GIS). This system offers descriptive attributes in tabular form and graphical information that are associated with spatial features (figure 2). The bushfood GIS will also be used for the presentation of results to stakeholders and to provide some assistance to SSD in the gap analysis of the data.

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Table 1 Summary of SSD bushfood collection sites and samples

Location	Animals				Plants	
	mussel collections	fish collections	other aquatic	terrestrial	aquatic	terrestrial
Barralil			1			
Bowerbird	1		2			
Buffalo BB	1					
Cannon Hill	2					
Cooper Ck	2					
Corndorl BB	1					
Catfish Ck		3				
Deaf Adder Gorge						
Djalkmarra					4	1
Drum Ck				1 (Buffalo)		
East All. Ranger St.						2
Flying Fox Ck	1					
Georgetown BB	8	6	3		1	
Goomadeer	2					
Gurnirdal		2	6			
Jabiluka						
Leichhardt BB	1					
Lightning Dreaming	1					
Long Harry BB	1					
Magela Xing		1				
Magela west				6 (wallaby/geese)		
Maningrida			1	3 (geese)		
Mudginberri BB	9	8	3		1	
Mamukala						1
Nabarlek						
Nourlangie						
Ranger Lease		2				3
Red Lily				2 (buffalo)		
Sth. A. Ranger St.						1
Sth. A. Valley	3	2				9
Sandy BB	3					
Terminator Ck				1 (pig)		

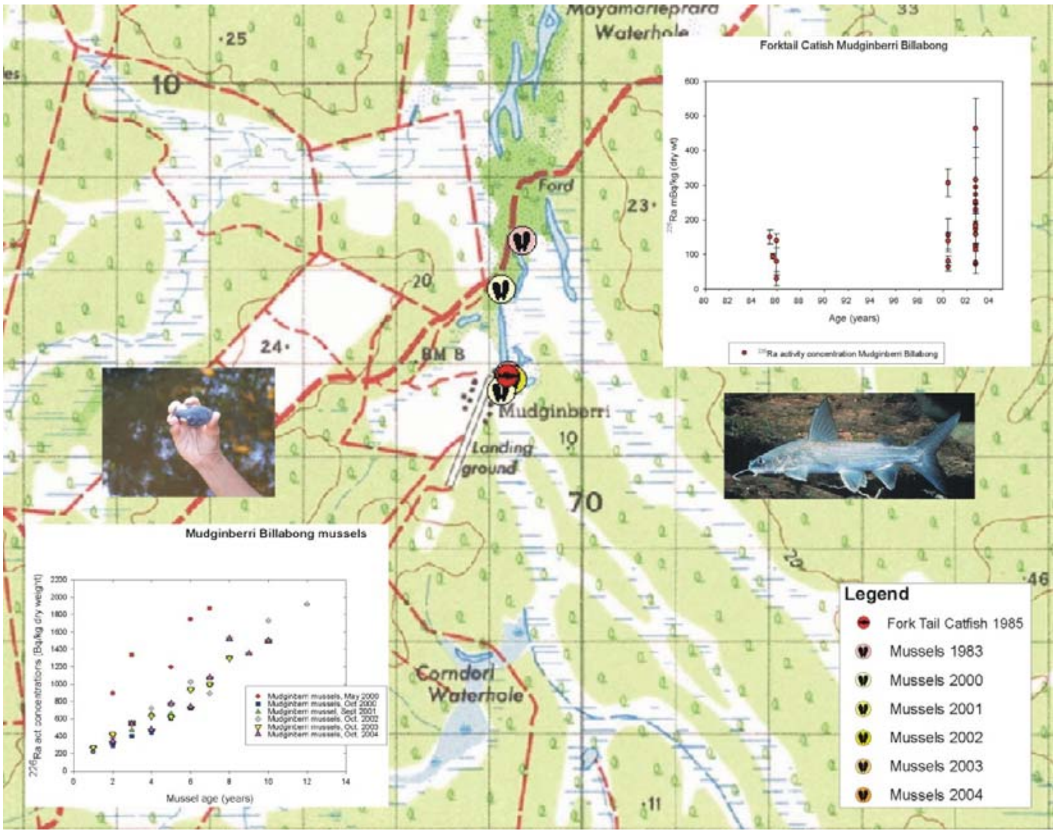

Figure 2 Screen shot of bushfood GIS showing Mudginberri Billabong sample details

Assess Quickbird data for weed mapping and monitoring at Ranger

K Pfitzner

Introduction

Weed mapping on the Ranger and Jabiluka leases currently involves intensive ground surveys that are conducted annually. Although ground surveys may provide accurate information on weed species present and their distribution and intensity of infestation in the areas surveyed, they are expensive in terms of human resources and restricted to areas accessible by road. Whilst helicopter surveys overcome problems of accessibility, they are expensive and entail observer errors associated with detection and identification.

High-resolution satellite imagery, such as DigitalGlobe 'Quickbird' data, launched in 2002, offers potential for the mapping of weeds. Vegetation assessment and weed identification at the Nabarlek minesite using Quickbird data and field sampling has shown promising results. The aim of this study was to investigate the utility of Quickbird satellite imagery for mapping and monitoring of weed distribution for input into the ERA Weed Management Strategy. In addition, the objective was to assess the suitability of such data for monitoring the success of the re-vegetation phase of the Ranger uranium mine.

EWLS acquired Quickbird multispectral and panchromatic images for the Ranger mine site in February 2003 and April 2004, and corresponding ground survey data in March 2003 and April 2004, respectively. These datasets from different times of year facilitate the investigation of the potential effect of seasonal variation on spectral signatures. Such extensive survey data provided the opportunity to test the suitability of remotely sensed data, providing ground-truthing points representing specific weed species and densities.

The objectives of this project were to: combine image data (transformations, vegetation indices and image statistics) in conjunction with field-based data (location and description); extract Quickbird spectra of weed and native vegetation endmembers and determine their separability; use a variety of classification parameters to map separable vegetation types; produce a contingency matrix from the field-data for accuracy assessment; and produce a location map of vegetation cover that may be exported to vector format for GIS compatibility. In addition to the above spectral analyses, predictive modelling was to be explored combining spectral data and other data collected during the field survey.

Progress to date

Preliminary findings of an investigation into the applicability of Quickbird satellite imagery for mapping dominant weeds at the Ranger minesite are reported (Pfitzner et al 2004, Welch et al 2004). In summary, a thorough analysis was not possible due to unplanned limitations of the ground-based data and the satellite product supplied. The ground data were inappropriate for correlation with the remotely sensed data. The ground data were characterised by wide abundance class ranges and heterogenous covers. For example, high, dense infestations of weeds were characterised in the field data, with a range from 26–100% cover. Field sampled data also included canopy cover as well as ground cover. Field data of 100% homogenous cover are required for remote sensing feasibility studies of cover separability. In addition, the satellite product obtained was map-orientated (only) and not pan-sharpened. The implications were that: pure stands of weeds could not be discriminated from the ground data supplied; ground data were often comprised of areas smaller (such as linear occurrences along roads) than the Quickbird multispectral resolution (~2.5m); the geometric inaccuracy of the image data supplied meant that accurate association between image data and ground features could not be established; and without pan-sharpened data (~60 cm pixel size) analysis was limited to the 2.5 m pixel.

In order to undertake a robust test of the suitability of Quickbird data for weed mapping at Ranger, Pfitzner et al (2004) recommend that remotely sensed data be obtained that are orthorectifed and spatially sharpened, and that field-based data on weed coverage be specifically designed for the purpose of the remote sensing analysis.

Strategic research commitment is needed to develop remote sensing methods for mapping weeds and to monitor revegetation progress. Experience from Nabarlek suggests that a future survey design, which combines ground-based and remote sensing methods, would overcome the limitations of both and still be cost-effective. An assessment of the data ***eriss*** obtained from the DeBeers Hyperspectral Mapper in 2004 should follow any thorough assessment of Quickbird multispectral data in order to compare spectral separabilities of both remotely sensed data types for discriminating and mapping weeds.

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Quantify stream sediment transport characteristics for Gulungul Creek to assess the impact of mine site erosion and rehabilitation performance of Ranger mine

DR Moliere, MJ Saynor & KG Evans

Introduction

The catchment area upstream of Gulungul Creek, a small left bank tributary of Magela Creek, contains part of the Ranger mine tailings dam. Once rehabilitation of the Ranger mine commences, earthworks associated with construction of the the rehabilitated landform, including removal of the tailings dam and subsequent erosion, may elevate sediment movement in Gulungul Creek. It is important that the hydrology and sediment transport characteristics in the Gulungul Creek catchment are investigated to establish baseline before rehabilitation at the mine site occurs.

The aims of this project are (1) to monitor and determine baseline stream fine suspended-sediment and bed sediment movement characteristics in the Gulungul Creek system to assess minesite impact and rehabilitation success; and (2) to monitor and determine the hydrology characteristics of the Gulungul Creek system as the underlying driver behind impact assessment.

To establish an on-going data collection system, this project has four tasks:

1 Install a gauging station network in Gulungul Creek upstream and downstream of the Ranger mine,

2 Implement a cross-section monitoring network in Gulungul Creek,

3 Calibrate *in situ* turbidimeters in Gulungul Creek to measure fine suspended-sediment concentration on a continuous basis, and

4 Derive long-term hydrological characteristics for the Gulungul Creek catchment, including a flood risk assessment.

Progress

Task 1

A gauging station was installed upstream of Ranger mine (Gulungul Creek upstream – GCUS) (fig 1) in November 2003. The station G8210012 (fig 1), which was operated by DIPE between 1971 and 1993, was also re-instrumented by ***eriss*** in November 2003. A third gauging station was installed downstream of Ranger mine (Gulungul Creek downstream – GCDS) (fig 1) in November 2004. Rainfall and streamflow are collected at all three stations on an almost continuous basis. Stream suspended sediment is monitored both upstream and downstream of the mine (GCUS and GCDS) using turbidimeters installed at the two stations. Automatic pump samplers were installed prior to the 2004–05 wet season at the two stations to collect water samples for a range of flow conditions in order to calibrate the turbidimeters to measure mud concentration.

Task 2

A cross-section monitoring network (fig 1) was established in the dry season of 2002 to assess channel stability and change in particle size distribution of bed sediments. The cross sections are surveyed and bulk bed material samples are collected annually. At some cross sections, scour chains have been installed in the bed to measure amounts of scour and fill during each wet season. The data from 2002 are contained in Crossing (2002) and the data from 2003 and 2004 are contained in Saynor et al (2005). Data interpretation with respect to establishing baseline conditions will commence after several more years of sampling.

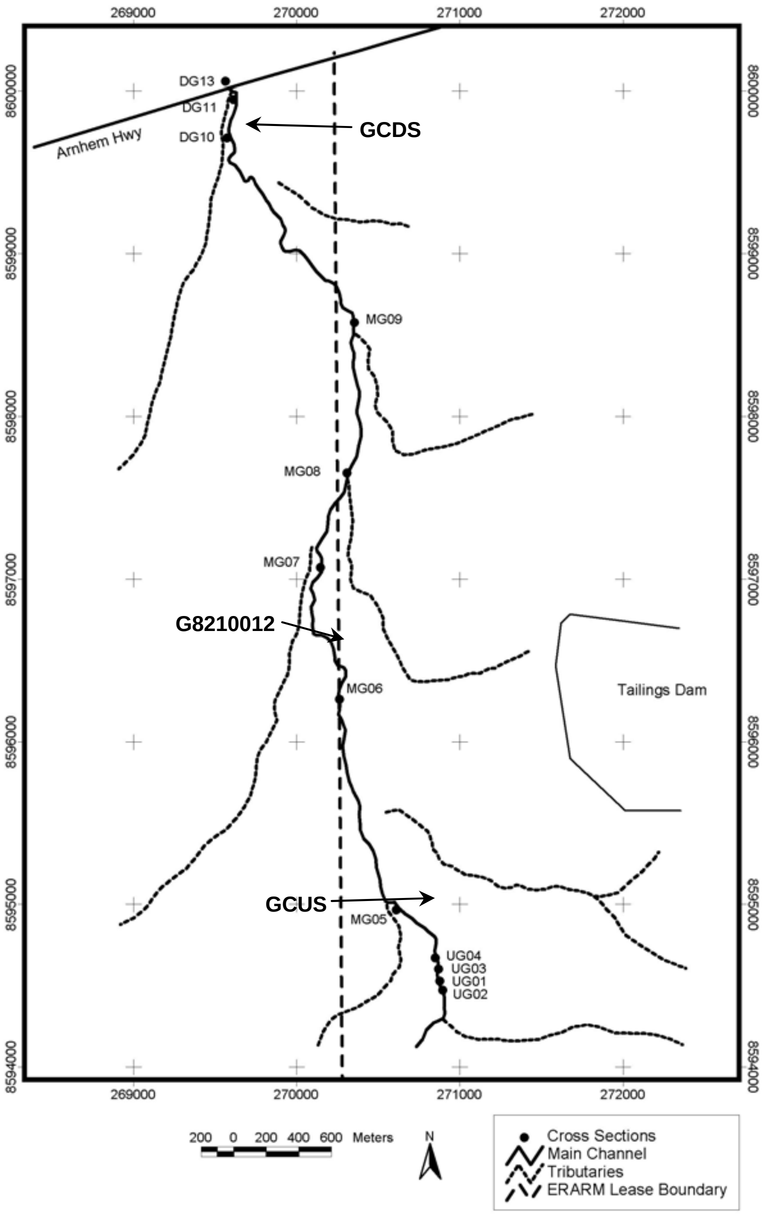

Figure 1 Location of gauging stations and cross sections along Gulungul Creek

Task 3

As mentioned in Task 1 above, water samples collected by the stage-activated pump sampler will be used to calibrate the turbidimeters to measure mud concentration. It is planned that mud concentration data will be monitored using *in situ* turbidimeters over the next few years to develop an understanding of the fine sediment movement characteristics within the catchment before rehabilitation at the mine site occurs. A significant relationship between turbidity and mud concentration has been fitted for the station upstream of Ranger (GCUS) using data collected during the 2004–05 wet season (fig 2). However, instrumentation problems at GCDS during 2004–05 meant that flow data collected prior to mid-March were considered unreliable. As a result, an insufficient number of water samples were collected during the year to fit a turbidity-mud concentration relationship for GCDS.

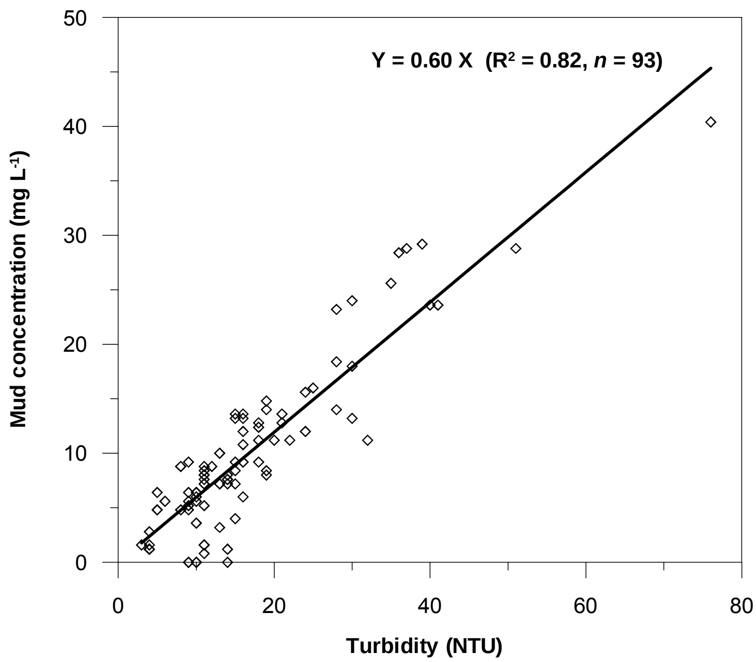

Figure 2 Fitted relationship between turbidity and mud concentration at GCUS using 2004–05 data

Task 4

Long-term runoff characteristics have been derived for Gulungul Creek based on flow data collected at G8210012 (fig 1) between 1971 and 1993 (Moliere 2005). However, because this station is neither entirely upstream nor downstream of the Ranger mine site influence, it is also important to determine the runoff characteristics at GCUS and GCDS, particularly before rehabilitation at the mine site commences. It is unlikely that these two stations (GCUS and GCDS) will have a significant runoff record for risk analysis by the time rehabilitation at Ranger mine is initiated. Therefore, it is important to investigate whether or not the long-term runoff record at station G8210012 can be used to extrapolate the record at the new station locations. If a significant regression relationship between observed peak discharges at the two new stations with corresponding peak discharges at G8210012 can be established using the next few years of runoff data, the relationship could be used to estimate values at the two new stations for the period of record available at G8210012 (1971–1993). Flood frequency curves could then be established for GCUS and GCDS using the extended runoff record.

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Feasibility study of implementation of sediment monitoring system in Corridor and Magela creeks upstream and downstream of Ranger mine

DR Moliere & MJ Saynor

Introduction

Once rehabilitation of the Ranger mine commences, earthworks associated with construction of the rehabilitated landform and subsequent erosion may elevate sediment movement in nearby Corridor Creek and also Magela Creek.

The aim of this project is to determine whether it is practical to set up sediment monitoring systems along Corridor Creek and Magela Creek. Such a system is currently in place within the Gulungul Creek and Ngarradj catchment areas. Gauging stations have been installed along these creeks to monitor flow and sediment concentration upstream and downstream of the mine sites. Flow at these stations is generally less than 2 m deep and is contained within a single channel. Flow within Corridor Creek is similar to Gulungul Creek and Ngarradj in terms of water depth but has a series of weirs installed along the channel that could influence sediment movement. Magela Creek has multiple channels and significantly higher flows than Gulungul Creek and Ngarradj which could make sediment monitoring difficult along this creek.

Progress

Preliminary observations have been made along Magela Creek during wet season flows to try and map the channels that have active flow in them, although no firm decision on the location of the sediment monitoring system in Magela Creek has been made. As part of a continuous monitoring program, SSD will be installing three continuous monitoring stations in Magela Creek prior to the 2005–06 wet season. One of these will be located along Magela Creek upstream of Ranger (MCUS) and the other two will be located downstream of Ranger near gauging station G8210009 in the central and western channel. These stations will be equipped to collect basic water parameters, including turbidity (which can be used to monitor suspended sediment movement). The data obtained by these stations will be assessed after the wet season to determine whether it is necessary to install automatic water samplers at each station to collect suspended sediment concentration data.

No progress has been made on whether or not a similar gauging station network should be established within the Corridor Creek catchment.