Part 5: General Alligator Rivers Region

Contents[1]

5.1 Landscape scale analysis of impact

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[1] List of papers grouped by Key Knowledge Need.

Mangrove response to environmental change, especially climate change

K Pfitzner

Introduction

A collaborative project between the University of New South Wales (UNSW), University of Wales, Aberystwyth, and SSD was established in 2001 to use remote sensing techniques for an analysis of mangrove response to coastal environmental change. The aims of the project were to establish for Kakadu National Park, past and present baselines of mangrove extent, species/community composition, structure and biomass based on, for selected mangroves, a combination of remotely sensed data and field sampling.

Progress to date

Stereo aerial photography, Compact Airborne Spectrographic Imager (CASI) data, and NASA JPL Synthetic Aperture Radar (AIRSAR) data were acquired and investigated for their potential to generate baseline datasets of the extent, height, density, species/community composition and biomass of mangroves within Kakadu National Park.

Stereo aerial photography, acquired in 1991, were used to derive digital elevation models (DEMs) using the procedure outlined by Lucas et al (2002), generating baseline data of mangrove extent (Mitchell et al 2005a & b, Mitchell 2004, Mitchell et al 2003, Mitchell & Pfitzner 2003). Compact Airborne Imaging Spectrometer (CASI) data, obtained over the West Alligator Head Region in 2002, were used to map species composition and assess change in mangrove extent against the 1991 data (Lucas et al 2005, Mitchell 2004) (see figure 1). Radar data from AIRSAR were used to estimate biomass (Mitchell 2004) of the mangrove environment. To support the interpretation of remote sensing data and validation of data products, field measurements relating to the structure, biomass and species/community composition of mangrove forest were required. Anthea Mitchell (UNSW), Kirrilly Pfitzner and Gary Fox (SSD) and Peter Brocklehurst and Chris Mangion (NRETA) conducted one week field sampling at West Alligator Head.

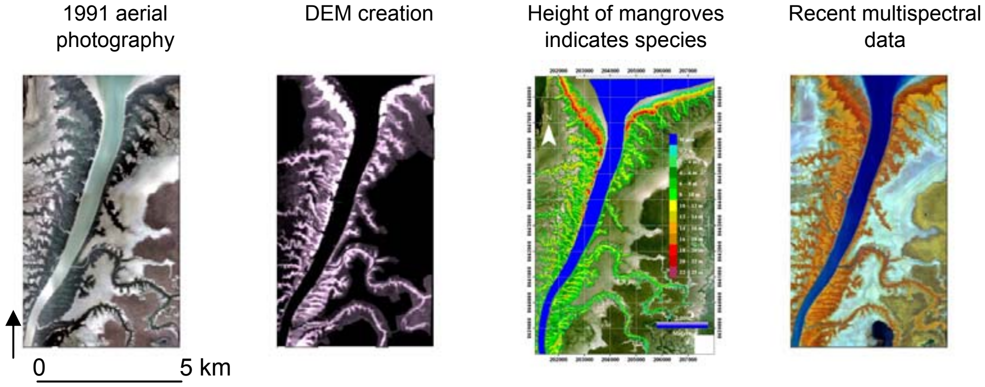

Figure 1 Examples of remotely sensed data of the West Alligator head subset. 1991 stereo aerial photography was used to create a DEM to indicate height of mangrove species (complete for Kakadu National Park). Multispectral CASI data was obtained in 2002 to assess change.

In addition to the references provided, results have been presented at the 2004 International Geoscience and Remote Sensing Symposium (IGARSS04) and ‘Mangroves 04’ conference. Stakeholders were invited to an SSD seminar on 8 July 2005 for dissemination of results obtained.

In summary, the use of airborne remote sensing data for generating baseline datasets of mangrove extent, height, density, species/community composition and both total and component biomass against which to assess change were demonstrated and a significant and continuing response of mangrove within the ARR to coastal environmental change has been observed (Mitchell 2004).

A meeting was held on 8 July 2005, between Dr Richard Lucas (University of Wales), Dr Anthea Mitchell and Prof Tony Milnes (UNSW), Associate Prof Colin Woodroffe (University of Wollongong) and Dr Kirrilly Pfitzner and John Lowry (SSD) to propose an ARC Linkage grant for further research.

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Ecological risk assessment of Magela floodplain to differentiate mining and non-mining impacts

P Bayliss, R van Dam, J Boyden & D Walden

Introduction

The aims of the 'Landscape-scale analysis of impacts' project is to help differentiate mining and non-mining impacts, and to contribute to the broader assessment of the World Heritage (WH) values of Kakadu National Park (KNP). The analysis framework, underlying conceptual models and quantitative approaches are outlined in detail by Bayliss et al (2003, 2004) and van Dam et al (2004a). This report combines the progress summaries of four projects and is in two parts. Part 1 encompasses an assessment of the condition of, and threats to, susceptible World Heritage values on the Magela floodplain, downstream of Ranger uranium mine. It is basically a first-cut quantitative ecological risk assessment (ERA) of non-mining threats to key WH values. Similarly, Part 2 reports a first-cut quantitative ERA of four key chemical contaminants released from Ranger, and focuses on the surface water pathway mapped out in the conceptual contaminants pathways model (Finlayson & Bayliss 2003, van Dam et al 2004a). A framework is being developed that combines both mining and non-mining ecological risk assessments and is similar to a Bayesian Network (BN). Hence, different degrees of belief with respect to risk, ranging from expert opinion to quantitative estimates derived from frequentist probability models (via probability density functions, pdfs), can be integrated and then communicated with simple influence diagrams and decision trees (see Hart 2004 & @RISK 2002). Stochastic process-based ecosystem models are being developed also to facilitate risk assessment over different time frames and spatial scales. Such models will be driven by rainfall-discharge submodels of the Magela catchment, with direct causal links to the population dynamics of indicator plant and animal species.

Part 1: Landscape

The status of past and current ecological values (assets) and threats on Magela floodplain were mapped in a GIS to facilitate spatially explicit ERAs. Shape-file data layers were converted to raster or grid-cell data format at appropriate levels of spatial resolution (here 250 m x 250 m cells). The spatial and temporal scope of many data sets extend beyond the Magela catchment to include KNP and the ARR in general. An SSR is being drafted that details metadata and data QA/QC protocols associated with all geo-spatial datasets.

Choice of World Heritage values

The two key 'susceptible' WH (& Ramsar) values chosen for assessment are waterbirds (Bellio et al 2004) and wetland vegetation. An assessment of change in their 'condition' was undertaken using spatial and temporal data obtained between 1981 and 2003 (Finlayson 1989 & Lowry et al in prep for vegetation; Bayliss & Yeomans 1990, Morton et al 1990 & PWCNT 2003 for waterbirds). Our initial focus has been on changes in the abundance of 'indicator' species of plants and waterbirds. Future work will examine possible changes in biodiversity. For vegetation we focussed on: weeds; important bush foods of Traditional Owners (eg the red lily); key habitat components of waterbirds for nesting and food (wild rice & *Eleocharis* sedge); and riparian trees susceptible to saltwater intrusion (Melaleucas). For waterbirds, the iconic magpie goose and egrets were chosen for initial analysis because they are the most seasonally abundant plant and fish eaters that use Magela floodplain, respectively. Additionally, the magpie goose is an important part of the diet of Traditional Owners (TOs) in the ARR. Analysis of changes in the distribution and abundance of waterbirds was undertaken using sampling and modelling methodologies developed by Bayliss (1989 & 1990). Long-term changes in fish and aquatic invertebrates communities will be reported in detail at ARRTC16 by C Humphrey and co-workers. Basically, between 1989 and 2005 (16 years) the chequered rainbow fish and two species of glass fish at the Mudginberri monitoring site downstream of Ranger exhibited long-term declines in abundance (13% pa on average) that are apparently unrelated to potential mining impacts. Three key correlates and associated working hypotheses proposed by Humphrey et al (pers comm) that could explain these declines are:

1 increases in mean wet season flow leading to lower water solute concentrations known to be harmful to larval rainbowfishes;

2 decreases in the period of annual drying of the floodplain potentially leading to reduced release of nutrients upon floodplain re-wetting (flood-pulse theory), and thereby reducing fish production in this important breeding and recruitment zone; and

3 increases in the extent of floodplain grasses, including para grass, thereby reducing habitat availability and pathways for upstream migration of fish recruits.

Choice of landscape-scale threats to WH values

Four major categories of landscape-scale threats to the above selected WH values were identified as: invasive species, specifically the wetland weeds mimosa, para grass and salvinia (Walden & Bayliss 2003), and the feral pig (classified as a 'Threatening Process' under the EPBC Act); unmanaged fire; infrastructure; and potential climate change impacts (rising sea level & concomitant salination of freshwater ecosystems, increasing intensity & frequency of storms). Medium to long-term climate change threats, although highly relevant, cannot be adequately addressed in the scope of this study. The ability of wetland weeds to dominate and completely alter aquatic ecosystems has been well documented. The Magela floodplain fortunately remains free of mimosa because of an active 'search and destroy' program by Kakadu rangers, and the impact of the floating fern salvinia has been greatly reduced by biological control. Hence, para grass is the primary focus of our risk assessment of weeds. Ground disturbance damage caused by feral pigs has been ascertained across Kakadu during systematic aerial surveys in 1985, 1995 and 2003 (Bayliss & Yeomans 1990, J Russell-Smith pers comm), and damage to natural and cultural Parks values documented by Whitehead et al (2004). Dry season fire on the Magela floodplain can be viewed either as a cultural asset if part of an Indigenous burning regime, or as a threat if unprescribed by TOs or Park management. To determine which would require detailed ethnoecological knowledge beyond the scope of the present study. However, such a study was completed at the Boggy Plain non-mining reference site as part of the ISP (Independent Science Panel) Landscape program. Infrastructure in the vicinity of the Magela floodplain comprise mostly roads, tracks and fence lines, and these may facilitate the spread of weeds and possibly erosion and siltation. Additionally, the minesite and associated township are sources of weeds for the Magela catchment and Kakadu in general.

Progress

Vegetation

The following eight classes of native vegetation were used to analyse change between 1983 and 2003, representing monocultures that may be less influenced by classification bias: *Eleocharis* spp, *Oryza* spp, *Pseudoraphis spinescens*, *Hymenachne acutigluma*, *Melaleuca* spp, *Nelumbo nucifera*, *Nymphoides* spp and *Leersia hexandra*. Relative change in abundance was measured by change in percentage cover since 1983 (fig 1a & b). Most plant classes changed little except for the following: Nymphoides and Leersia were not recorded in 1983; Eleocharis, an important dry season food of magpie geese, decreased by 57%; Melaleucas decreased by 10%; and Nelumbo decreased by 85%. The 10% relative change in paperbark forest and woodland is significant because on an absolute basis this corresponds to 5km^2 or 3% of the floodplain. Mimosa has been kept under control since the early 1980s through an annual investment (& in perpetuity) of approximately $0.5 million by Kakadu management, and para grass and salvinia have since colonised the floodplain (see fig 1a & b).

Waterbirds

The abundance of magpie geese that occupy Magela floodplain in the late dry season between 1981 and 2003 (22 years) has decreased on average by 7% pa (fig 2c). In the wet seasons of the early 1980s magpie geese used the central portion of Magela floodplain for nesting, an area now occupied by an extensive patch of para grass (figs 1a & b, fig 2a). Additionally, in contrast to the early 1980s, areas now colonised by para grass are used less extensively by magpie geese in the late dry season for feeding (fig 2b). Similarly, fish eating egrets decreased on average by 9% pa since 1981 and also altered their dry season distribution by 2003. However, although the floodplain is about 200 km^2 it is difficult to interpret long-term changes in the abundance of highly mobile waterbird species in isolation from regional and national trends, particularly in relation to anthropogenic changes (see arrows in fig 2c).

Fortunately concurrent national and regional survey data of magpie geese exist, surveys which first commenced in 1958 (Tulloch & McKean 1983) and continued to the present (Bayliss & Yeomans 1990, Saalfeld pers comm). Analyses at increasing spatial scales show that trends observed in the abundance of magpie geese in the late dry season on Magela floodplain were highly concordant with similar trends for the same time period across the ARR and the ‘Top End’ of the NT (fig 2d), the latter area encompassing most of the Australian population. The NT surveys provide 45 years of almost continuous data that suggest cycles of magpie geese numbers over decadal time scales (20–25 year periods, solid trendline in fig 2e). The population dynamics of magpie geese are driven to a large extent by deviations in mean annual local rainfall in river catchments (Bayliss 1989), which itself exhibit similar decadal cycles (see Johnston & Prendergast 1999 for the ARR). The proximate driving variable of magpie geese population dynamics is wetland vegetation (food & nesting material), which is highly correlated to flow, water depth and rainfall. Rainfall and flow are highly correlated, and the dashed curve in figure 2e is the smoothed ‘decadal’ cycle for mean monthly flow at GS8210009 (009) over 35 years. Time series and CSUM analysis are currently being undertaken for all historical rainfall and flow data in two NT catchments (ARR & Daly River), in order to determine possible relationships between population cycles of other biota (eg other waterbirds, fish, commercial fish catch) and flow as part of the Tropical Rivers Program. Hence, because of the possibility of large-scale ‘external’ ecological drivers, any meaningful assessment of WH values of waterbirds and other water-dependent ‘indicator’ species on Kakadu needs to focus on the condition of their seasonal *in situ* habitats and not trends in abundance. This argument may also apply to fish and, possibly, macroinvertebrate communities (see ARRTC16 summary paper by C Humphrey et al).

(a) 1983

(c)

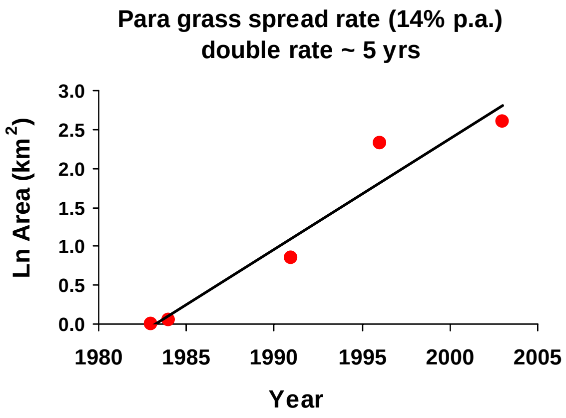
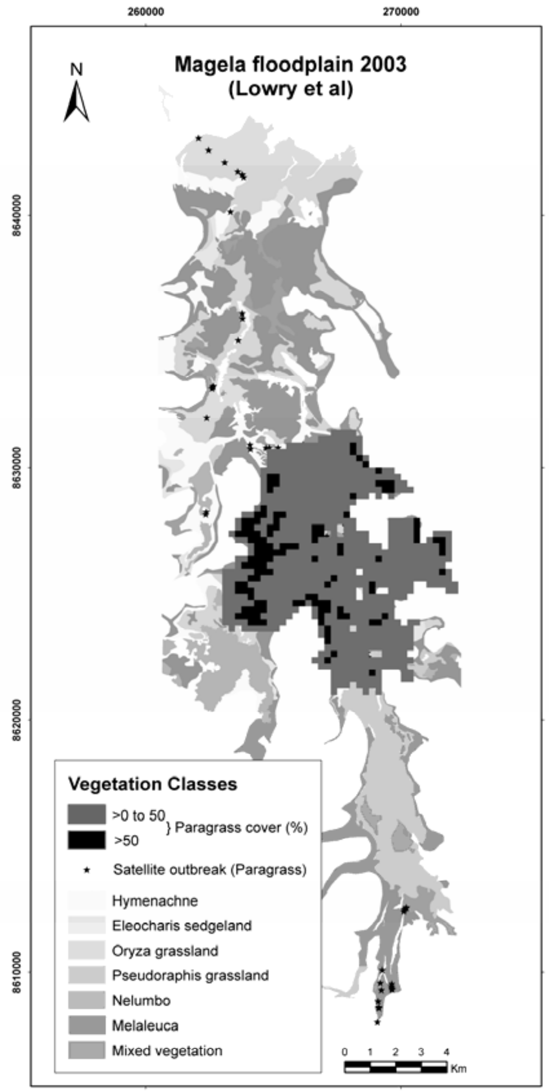


Figure 1 Vegetation change on the Magela floodplain between (a) 1983 and (b) 2003, and the increasing time trend (c) in extent (km^2) of para grass (R^2 = 69%, P<0.04). Legend in (b) also applies to (a).

(b) 2003



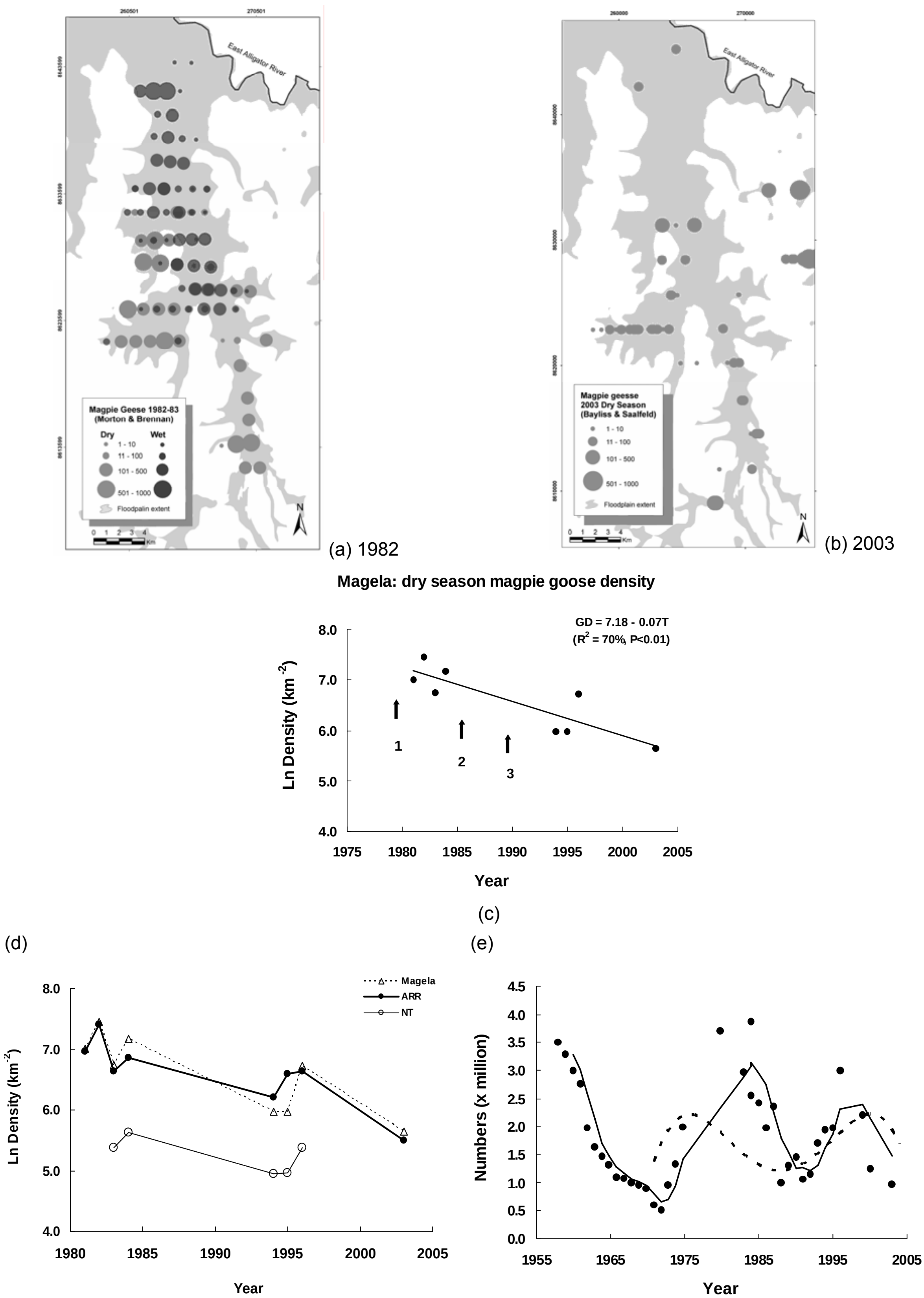


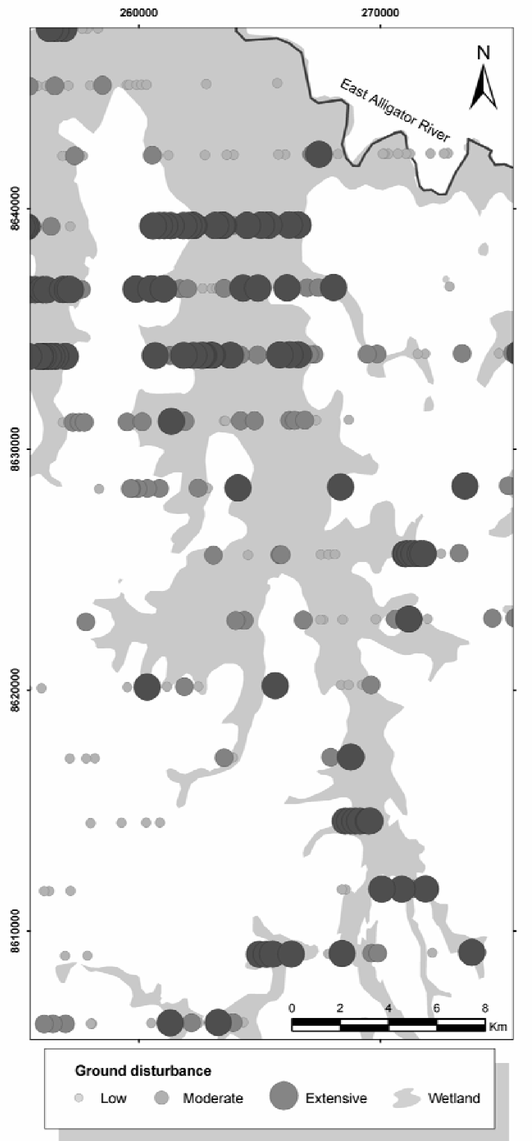
Figure 2a–e Distribution and abundance of magpie geese in the (a) 1982 wet and dry seasons and the (b) 2003 dry season. (c) Declining dry season magpie geese density (Ln km^{-2} floodplain) on Magela (1981–2003; R^2= 70%, P<0.01). Arrows are: 1 – mining; 2 – increase in pig density; 3 – increase in extent of para grass. (d) Concordant trends in dry season density (1981–2003) for the Magela, ARR and the Top End of the NT. (e) Estimated numbers of Magpie Geese in the NT between 1958 and 2003 (solid trendline) and smoothed mean monthly flow at Magela Creek (009) (dashed curve).

Weeds

In the early 1980s para grass had only a small presence on Magela. In the mid 1990s, Knerr (1998) showed that, in the vicinity of the largest infestation, it spread from 132 to 422 ha in five years (1991–1996). This core patch of para grass occupies the centre of the floodplain (fig 1b) and is expanding at 14% p.a. (see regression in fig 1). Put another way, the extent of para grass is doubling every 5 years and, at this rate and in the absence of a strategic control program, the entire floodplain will be lost in 15 to 20 years. However, this time frame may be the 'best case scenario' because satellite patches of para grass have spread along the length of Magela and so that it now occupies about 1250 ha, with new outbreaks occurring in inaccessible dense Melaleuca woodland. The increase in area of para grass between 1991 and 1996 showed a corresponding decrease in area of a community of wild rice, (*Oryza meridionalis*) (Knerr 1998) and Eleocharis sedge (this study). Wild rice and Eleocharis are important food resources for pre-fledging and adult magpie geese, respectively (Bayliss & Yeomans 1990). A Bayesian Habitat Suitability Model (HSM) is being developed with Keith Ferdinands (CDU 2005), and will be used to predict future distribution and potential impacts on native vegetation. This ERA technique has already been successfully applied to the Mary River floodplain (Ferdinands pers. comm.). Additionally, the model will incorporate data from high resolution Quickbird satellite imagery to provide more reliable information on para grass distribution and abundance over different temporal and spatial scales. The methodology developed to date provides a valuable cost-effective monitoring tool for Park managers. Cost-of-control functions have been developed for mimosa (Walden & Bayliss 2004) and now para grass, and are critical for evaluating the benefits and costs of any invasive species management program, which are essentially risk management programs.

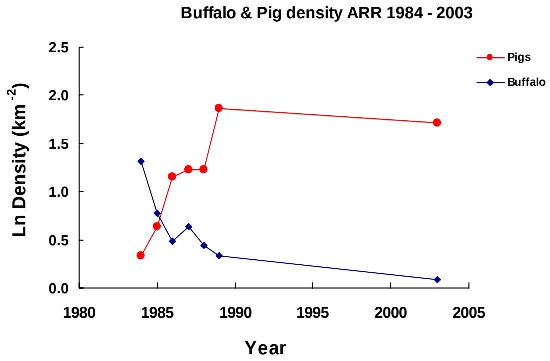
Pigs

This section characterises pig density and damage across floodplains in the ARR and is assumed to be representative of trends on the Magela floodplain. Pig damage was recorded in four damage classes (zero, low, intermediate & high) along aerial survey transects divided into 2 km or 5 km units depending on transect spacing. The frequency of occurrence data were then used to estimate probabilities of damage. No damage was recorded in 1985, corresponding to low pig densities during the early 1980s (Bayliss & Yeomans 1989) when buffalo densities were high. In contrast, extensive pig damage now occurs across the whole of Kakadu, particularly on floodplains such as Magela (fig 3a). These changes corresponded to a rapid increase in pig numbers following sustained commercial harvesting of buffalo in the 1970s followed by the BTEC between 1985 and 1989. During this period pig densities increased at a rate close to their maximum rate of population increase (27% pa, fig 3 top left graph). There is a highly significant negative correlation between the density of buffalo and pigs since 1983 (fig 3, top right graph). In 1989 Kakadu commenced a pig control program in the northern section of the Park, reducing numbers to about 20% by 2003, however, most likely representing 'sustained-yield'. Although ground disturbance damage caused by pigs was only systematically recorded in three of a dozen aerial surveys across the ARR since 1985, damage and density are nevertheless correlated (fig 3 bottom graph). Control cost functions have been developed for pigs in Kakadu (Bayliss & Walden 2003), and a spatially explicit population dynamics model. Pig control data provided by Park managers were used to validate estimates of absolute density.

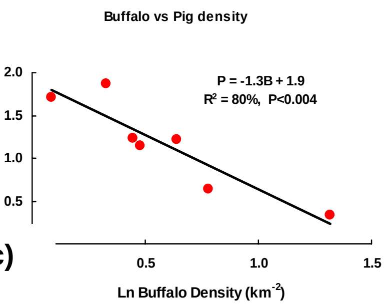


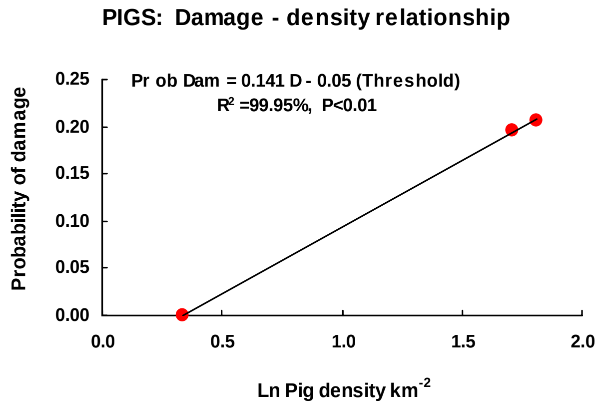
(a) 2003

(b)



(c)





(d)

Figure 3a–d (a) Distribution and intensity (low, medium & high) of ground disturbance damage caused by feral pigs on Magela floodplain (Nov 2003). (b) trends in buffalo and pig density between 1985–2003 in the ARR (top left graph); (c) The inverse relationship between the density of buffalo and pigs in the ARR (top right graph). (d) The threshold relationship between pig damage and density (probability of damage vs Ln (density + 1)).

Fire

The NT Bushfires Council (A Edwards & J Russell-Smith pers comm) provided 25 years of Landsat based fire-scar maps for the NT (1980–2004), which were used to estimate fire occurrence on the Magela floodplain and surrounding Eucalypt woodland. Shape-files were rasterised to a grid of 250 m by 250 m cells. The frequency of fire over 25 years in each cell was converted to probabilities for risk assessment. Although we lack knowledge of the nature of floodplain fires over that period, we resort to expert opinion reflected in the overall Park management goal of obtaining fire frequencies not less that 1 in 4 years. Hence, if the risk of fire in any given location on the floodplain was greater than 0.25, we classified it as a threat to biodiversity values because of the potential to depress the abundance of fire sensitive plant species. However, little is known about the impacts of dry season fires (frequency, intensity, duration) on the structure and composition of wetland vegetation on Magela. Nevertheless, results from the Boggy Plain fire study show clearly that the diversity of wetland plant species increased with Traditional burns if vegetation composition was dominated by monocultures of grasses, such as Hymenachne, and particularly if time since last burnt was greater than 5 years. Therefore, in our ERA for fire we incorporated uncertainty by setting the effects probability at 0.50 (ie hedging bets either way). The floodplain and surrounding woodland have markedly different fire risk profiles (see histograms in fig 4). Floodplain fire occurs on average once every 5 years (mean P=0.20, median =0.125) and, in contrast, the surrounding Eucalypt woodland burns on average once every two years (mean P=0.52, median 0.53). A comparison of the shapes of their PDFs show clearly that fire risk is greater in the woodland because it is more uniformly spread across the entire probability range.

Landscape-scale ERA

A Bayesian Network (BN) is being constructed to link groups of similar landscape-scale ecological risks for an overall assessment. Refined Monte Carlo simulation techniques and sensitivity analysis that rank negative and positive contributions of all inputs are used (Burgman 2005, @Risk software 2002). The end product is a probability density function (pdf) that characterises all landscape-scale ecological risks in combination which can be compared to a similar quantitative risk profile for potential mine-related impacts (see below). The BN approach enables integration of the subjective domain knowledge of experts with risks that can be quantified objectively, hence making all uncertainties transparent as best as possible (Nadkarni & Shenoy 2004). To enhance this process, influence diagrams and decision trees will eventually be used. In the interim, preliminary results for landscape-scale risks that can be quantified and which rely less on expert opinion are reported below (ie climate change and infrastructure risks are temporarily ignored). These are: (i) weeds (para grass, mimosa & salvinia), (ii) feral pigs and (iii) fire. The analytical steps were:

a. for each risk group derive a pdf for exposure probabilities (P_{exp}) based on spatially derived frequency data in each 250m cell across the floodplain. Only para grass and salvinia will be assessed here as mimosa exposure is < 1%;

b. similarly, derive a pdf for effects probabilities (P_{eff}) of each risk group based on expert knowledge, the literature, experiment, frequency and/or empirical data. If completely unknown set the uncertainty level to 0.50. For this report all effects probabilities besides fire (set to 0.50) are arbitrarily set to 1.0. Hence, comparison of risk will be weighted towards exposure.

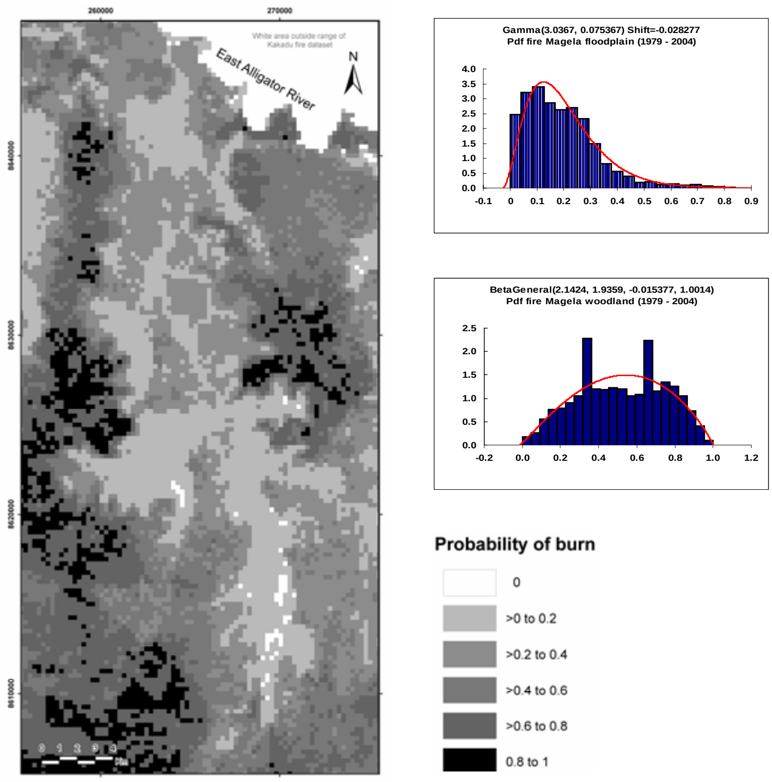


Figure 4 Risk of fire on the Magela floodplain & surrounding woodland (1980–2004). Histograms are probability density functions (pdfs) for frequency of fire occurrence on Magela floodplain (top) and surrounding woodland (bottom).

c. for each group derive ecological risks ($P_{risk} = P_{exp} \times P_{eff}$) from the exposure and effects pdfs above using Monte Carlo simulation (10,000 simulations), essentially characterising the risk profile of each group.

d. combine the risk profiles of all groups using conditional probability theory exemplified below for 3 classes. If P_w = the ER of all weeds combined, P_p = ER pig damage and P_f = ER of frequent unmanaged fires, the combined ER P_c is conditionally derived (using Bayes Theorem) as:

$$P_c = P_w + P_p + P_f - P_wP_p - P_wP_f - P_pP_f + P_wP_pP_f$$

simplified to

$$\{1-[(1-P_w)(1-P_p)(1-P_f)]\}$$

e. use sensitivity analysis to rank the contribution of each risk group to total risk, and ascertain the dependencies between and within groups to total risk.

The details of this process will be reported later, initial results are presented below. Examples of typical pdfs are provided above for the occurrence of fire on the Magela floodplain and surrounding woodland (fig 4). The mean landscape ER is 0.24 (fig 5a), with pig damage ranking first, uncontrolled fire second, and para grass third (fig 5b). Another way of visualising and comparing contributions to overall landscape ER is to overlay individual cumulative probability curves for each (fig 5c).

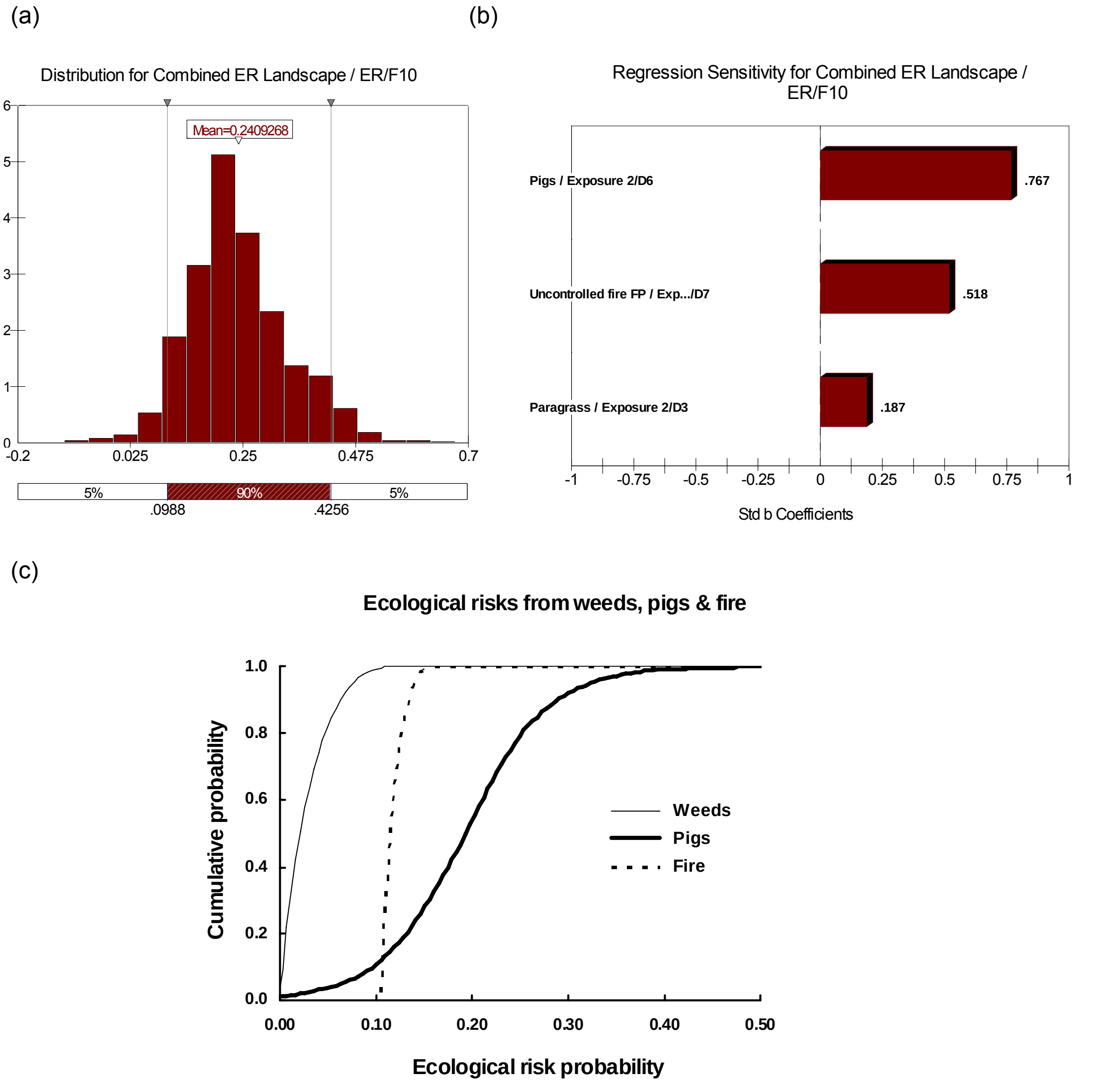


Figure 5a–c. (a) Distribution of combined ecological risks for landscape threats, (b) a Tornado diagram illustrating the relative contributions of each risk group to the combined ERA for landscape threats, and (c) the cumulative probability curves for each landscape ecological risk (para grass, fire & pigs).

Part 2: Ranger – surface water pathway of chemical contaminants

A similar ERA process was adopted for four key chemicals found in diluted effluents discharged from Ranger uranium mine into the surface waters of Magela Creek during the wet seasons between 1998 and 2005. These are uranium (U), magnesium (Mg), sulfate (SO_4) and manganese (Mn). Weekly point sample data at the statutory monitoring site (MG009) were used to characterise off-lease exposure probabilities to aquatic ecosystems downstream of Ranger on Kakadu National Park (Iles 2004). Ecotoxicological end points for U and Mg were used to derive Species Sensitivity Distribution (SSD) models in order to predict the contaminant concentration (Trigger Values, TV) that protect 99% of susceptible aquatic species (van Dam et al 2004a). The models contain a small yet strategic sample across trophic levels and, nevertheless, currently comprise the most robust quantification of ecological effects by any single hazard to date. Although the Mg effects model is complex because Ca ameliorates the toxicity of Mg, use of a ‘safe’ 9:1 Mg:Ca threshold effects ratio was tractable because van Dam (2005, summary to ARRTC16) developed SSD models for Mg at low background Ca (~ 0.2 mg/L) and with Ca added such that the Mg:Ca ratio was maintained at 9:1. A pdf for Mg:Ca exposure ratios was derived and simulated values that were > or = 9 were combined with the appropriate effects pdf. The TV of 1200 ug/L for Mn recommended by the NWQG (ANZECC & ARMCANZ 2000) is based on ecotox end points so is adopted as an interim value for 99% species protection. A 'low reliability' TV of 15 mg/L for sulfate was adopted based on limited site-specific effects data (van Dam pers. comm.). Best-fit exposure pdfs were: U (Exponential distribution); Mg:Ca ratio (Inverse Gaussian): SO_4 (Log Normal); and Mn (Log Logistic). Best fit effects pdfs were: U (Log Logistic); Mg with no Ca (Exponential); Mg with a Mg:Ca ratio < 9 (Inverse Gaussian). The details of this process will also be reported later, and initial results are presented below. The mean minesite ER of one simulation with 10 000 iterations was 2.7 x 10^{-4}. In contrast to the normal-like distribution of the combined landscape risk profile (fig 5a), the combined pdf for minesite risks is approximately bimodal with 90% of values clustered closed to zero (fig 6a). Note that U exposure and effects had extremely small negative and positive contributions to the combined ER, respectively. Similarly, all other chemicals posed insignificant risks because exposure probabilities never exceeded the 1% species-affected, or other relevant, effects thresholds (fig 6b).

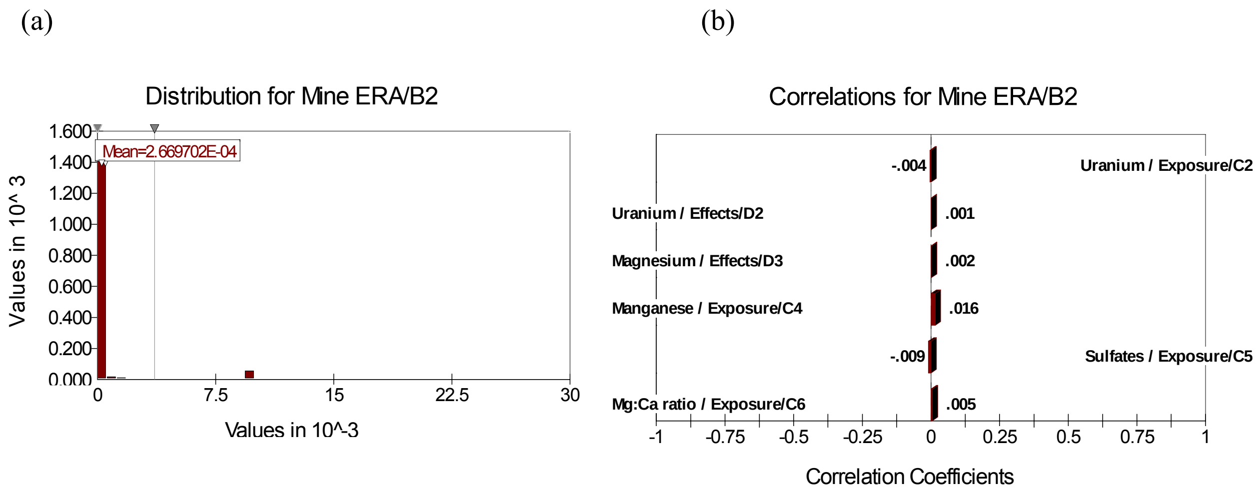


Figure 6 a & b (a) Distribution of combined ecological risks for minesite chemical threats, and (b) a Tornado diagram illustrating the relative contributions of each chemical to the combined ecological risk in the surface water pathway.

Comparison of mining and non-mining ecological risks

Non-mining landscape risks and minesite risks were combined into an overall ERA for Magela floodplain. Results highlight the obvious, in that the significant landscape-scale non-mining risks (fig 7a) effectively swamp the insignificant risks to the surface water pathway posed by chemicals released from the mine (fig 7b). The purpose of the combined simulation was to rank mining and non-mining contributions to overall ecological risk to Magela floodplain to gain clear perspective for risk management recommendations. An appropriate next step would be to compare management investments for both classes of risk given their relative rankings. Future ERA work will: (i) incorporate the above statistical models into influence diagrams and decision trees, in order to explicitly identify all uncertainties; (ii) model different scenarios (eg use of focus and action levels for water quality management cf trigger levels, and model risks from effluents cf with single chemical constituents, see van Dam et al. 2004b); (iii) introduce relevant expert opinion and develop methods to weight varying degrees of belief; (iv) examine other pathways in the conceptual contaminants pathway model; (v) combine ERA models with ecosystem process models (see Guisan & Zimmermann 2000, Lamon & Stow 2004) to examine risks over different time frames and under different management scenarios; and (vi) communicate results to stakeholders.

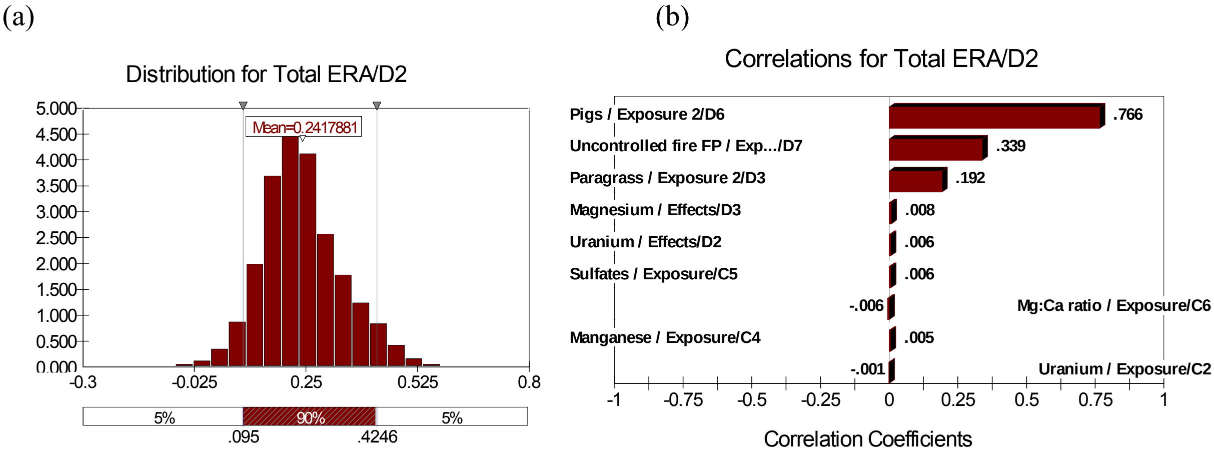


Figure 7 a & b (a) Distribution of combined ecological risks for minesite and non-minesite threats, and (b) a Tornado diagram illustrating the relative contributions of each category of risk to the combined ecological risk to Magela floodplain.

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Significant habitats and species in the Alligator Rivers Region

C Humphrey

Background

This project is being conducted in response to a specific recommendation of the IUCN and the World Heritage Committee. Their concern was that there might be endemic species of animals that, while not at risk from direct contaminant pathways associated with any development at Jabiluka, could be affected by indirect secondary pathways.

Surveys have been conducted on the aquatic fauna of seeps and springs in the stone country of KNP, including in the vicinity of Jabiluka, and western Arnhem Land. Particular attention is being paid to the crustacean groups, the isopods (family Amphisopodidae), freshwater crabs (family Sundalphusidae) and prawns and shrimps (families Atyidae and Kakaducarididae) that occur in these habitats. The results obtained in these surveys are being provided to taxonomists to distinguish and describe new species collected from the sites. If species are identified that are only found in the vicinity of Jabiluka, consideration will be given to pathways for potential impact and possible monitoring programs.

In addition, these endemic species may be vulnerable to the invasion of cane toads and their life stages, through either toxicity (direct contact or from consumption) or competition with tadpoles for food and space.

This work is also relevant to other ARRTC Key Knowledge Needs, including:

3.2.1 *Jabiluka: Research required prior to any development*.

5.3.1 *Baseline studies for biological assessment in West Arnhem Land*. Isopod and shrimp material for taxonomic description includes collections from Arnhem Land. Resulting analyses will contribute information towards mining exploration activities in Arnhem Land

5.4.1 *Baseline monitoring program for Koongarra*. Isopod material for taxonomic description includes collections from Koongarra area.

Progress to date

Work to date on this project is confirming that the freshwater macro-crustacean fauna of stone country in KNP and western Arnhem Land comprises a substantial and significant endemic component. The fauna includes an endemic family of shrimps, the Kakaducarididae, comprising two endemic genera (Bruce 1993, Bruce & Short 1993), as well as an endemic genus of phreatoicidean isopod (*Eophreatoicus*) that has exceptional species-level diversity (Dr G Wilson, Australian Museum, pers comm). Most of these macro-crustacean species have very restricted distributions, often limited to single streams, seeps or springs. This diversity and endemism is believed to be a consequence of the antiquity and persistence of the plateau/escarpment and associated perennial streams, springs and seeps, and isolating mechanisms including fragmentation of habitat (long-term climate changes, erosion) and the generally poor dispersal characteristics of these crustacean groups (Humphrey 1999).

In 2004–05, the following tasks were undertaken:

1 Sampling of critical sites around Jabiluka was completed, leading to closure of KKN 3.2.1. Isopod material was provided to specialists for taxonomic determination (see item 2).

2 The Australian Museum and ***eriss*** have received a research grant from ABRS, to describe isopods of KNP and western Arnhem Land (genus *Eophreatoicus*). To enhance this study and molecular genetics work, a collection of the type material from the King River, in Arnhem Land, was conducted. This trip also contributed to KKN 5.3.1. The formal descriptions of this species flock will adopt local cultural place names in the scientific nomenclature.

3 Small consultancies were established with Prof Jane Hughes (Griffith University) and Dr John Short (BioAccess Australia) to determine the molecular genetics and morphological differentiation of kakaducaridid shrimps.

The molecular genetics work referred to in 2 and 3 above is progressing. The results are confirming the exceptional species-level diversity and restricted distributions of these groups. Even populations of the same (shrimp) species found in various ARR streams are genetically very isolated, which has profound implications for the conservation values of the sites and resident faunas.

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Radiological case study: South Alligator River

B Ryan, P Martin[1], A Bollhöfer & K Pfitzner

Introduction

After seasonal road works in 1999 along the Gunlom Falls access road, an inspection of the site by an OSS employee discovered that the road machinery had exposed tailings directly opposite the old South Alligator Mill tailings dam area. This finding initiated a field gamma survey that was conducted in 1999 followed by an airborne gamma survey that was flown in 2000 (Pfitzner & Martin 2000, Pfitzner et al 2001a,b). Data were evaluated for the Rockhole tailings site and the remaining portion of the South Alligator Valley to quantify the magnitude and extent of radiological contamination in the South Alligator Valley from the mining activities in the 1950s and 1960s and attempt a complete radiological dose assessment of the area (Bollhöfer et al 2002). Results from the study have recently also been published in the *Position* magazine for remote sensing (Pfitzner 2005) as an example of how technology can make a difference to communicating radiological risk.

As the diet of local Aboriginal people of the region is made up of both traditional and shop bought foods (Ryan et al 2005) the ingestion of radionuclides in traditional food items from the area can contribute significantly to the radiological risk. Due to the high concentration factor for ^{226}Ra in freshwater mussels (Johnston et al 1987) the contribution to radiological dose from the ingestion of mussels needed to be determined.

Methods

As part of the radiological investigation and dose assessment studies, samples of freshwater mussels, *Velesunio angasi*, were collected in November 2000 from the South Alligator River (SAR), near and at the confluence of Rock Hole Mine Creek (RMC), and adjacent to the exposed tailings (Ryan et al 2005). Collection sites for mussels, sediments and water were selected following consultations with Parks Australia North (PAN) staff and local Aboriginal people. Radionuclide activity concentrations and activity ratios were determined by alpha and gamma spectrometry. Concentrations of a number of elements (including heavy metals) and stable lead isotopes were determined by ICP-MS. The complete set of results is now available and published (Ryan et al 2005).

The old South Alligator Mill tailings area may be a source of radionuclides and heavy metals washing into SAR in the wet season, and RMC is known to be polluted by acid rock drainage emanating from an old mine adit associated with the abandoned workings of the Rockhole Minesite. In total, 177 mussels, 4 water and 6 sediment samples were jointly collected by ***eriss***, PAN and Aboriginal Traditional Owners from sites either potentially exposed (downstream) or unexposed (upstream) to mine waste contaminants.

The age of each mussel was determined by placing the shell over an incandescent light source and counting the (annual) dark bands (annuli). The dried and ground flesh of the mussels were combined according to age class and site, and a composite sample of each age class was cast in

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epoxy resin for determination of radioisotopes of lead (^{210}Pb), thorium (^{228}Th) and radium (^{226}Ra & ^{228}Ra) by gamma spectrometry. Mussels ≤ 1 year of age, or an age class with insufficient mass for analysis by gamma spectrometry, were analysed by alpha spectrometry.

A sub-sample of dried and ground composite material of each age group from each site was analysed by ICP-MS for aluminium (Al), arsenic (As), barium (Ba), cadmium (Cd), calcium (Ca), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), nickel (Ni), potassium (K), rubidium (Rb), selenium (Se), sodium (Na), strontium (Sr), uranium (U) and zinc (Zn). Sub-samples of a range of age class composites from each site were analysed for stable lead isotopes with ICP-MS.

Figure 1 A freshwater mussel, *Velesunio angasi*, from the South Alligator River. Counting of the distinctive dark bands (annuli) is used to determine the age of the mussels.

Results

The radionuclide and metal concentration measurements indicate that downstream RMC and the tailings area some contamination, although relatively small, has occurred. In particular the ^{226}Ra/^{228}Ra activity ratios in the mussel flesh indicated that mussels from the potentially exposed sites have accumulated relatively more ^{226}Ra compared to mussels of the same ages from sites upstream of RMC and the tailings area.

Using the age, weight and proportional information gleaned from our study and a hypothetical collection of freshwater mussels by local Aboriginal people we estimated the committed effective dose for a 10-year-old child from the ingestion of freshwater mussels. The resulting total committed effective dose of 0.08 mSv, assuming the child ate 2 kg of mussels in a year, is based upon average activity concentrations of ^{226}Ra and ^{210}Pb from all sites and age groups in the collected samples from the upper South Alligator River. This estimate is somewhat lower than an earlier estimate given in Bollhöfer et al (2002) and also includes the dose originating from radionuclides accumulating naturally in the mussels.

The corresponding doses arising from ^{238}U intake are extremely low because the uranium concentration factor, and thus the uranium concentration in mussel flesh, and the dose conversion factor are much lower. For example, assuming a 10-year old child eating 2 kg (wet weight) of flesh from mussels from where the tailings enter the South Alligator River, the committed effective dose from the intake of uranium would only be 0.0001 mSv. For comparison, the dose limit for a member of the public that applies to a practice (such as an operating uranium mine) is 1 mSv per year additional dose to the natural background.

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