Northern Australia Environmental Resources Hub

National Environmental Science Programme

Recommended faunal standards for the rehabilitation of Ranger Uranium Mine

Final report

by Alan N. Andersen

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This report should be cited as: Andersen AN. 2019. *Recommended faunal standards for the rehabilitation of Ranger Uranium Mine.* Charles Darwin University, Darwin.

Cover photographs

Front cover: Some of the animals found in Kakadu National Park, photos Alan Andersen and R.M.T./Shutterstock.com

Back cover: Revegetation site at Ranger Mine, photo Alan Andersen.

This report is available for download from the Northern Australia Environmental Resources (NAER) Hub website at nespnorthern.edu.au

The Hub is supported through funding from the Australian Government's National Environmental Science Program (NESP). The NESP NAER Hub is hosted by Charles Darwin University.

ISBN 978-1-925800-19-7

April, 2019

Printed by Uniprint

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Acronyms

ERA ..... Energy Resources Australia

ERISS ..... Environmental Research Institute of the Supervising Scientist

NESP ..... National Environmental Science Program

NMDS ..... Non-hybrid multidimensional scaling

SSB ..... Supervising Scientist Branch (of the Australian Government Department of the Environment and Energy)

Acknowledgements

I thank Drs Renee Bartolo and Chris Humphrey from the Environmental Research Institute of the Supervising Scientist for their roles in establishing this project, and for providing advice during its development. I am most grateful to Drs Luke Einoder, Brydie Hill and Alaric Fisher from the Flora and Fauna Division of the NT Department of Environment and Natural Resources for their recommended standards for vertebrates, and to Stefanie Oberprieler from the Research Institute for the Environment and Livelihoods, Charles Darwin University, for her work on invertebrate rehabilitation at Ranger. Finally, I thank Prof John Woinarski for valuable discussions on the setting of faunal standards.

Executive summary

A major rehabilitation program is underway at Ranger Uranium Mine, aiming "to establish an environment similar to the adjacent areas of Kakadu National Park", including the establishment of similar faunal assemblages. This report recommends specifications for potential inclusion in the Supervising Scientist Branch's faunal standards for Ranger rehabilitation. It proposes:

1. *Vertebrate and invertebrate taxa to be targeted for assessment*. Einoder et al. (2019) have identified 50 vertebrate species from the dominant lowland savanna woodlands surrounding the Ranger mine that are sufficiently detectable with standard survey methods to be monitored with high confidence, and they are therefore recommended for assessment. They comprise 34 bird, 11 reptile and five mammal species, and include the threatened Partridge Pigeon and Black-footed Tree-rat. Based on Andersen & Oberprieler (2019), ants are recommended as a target taxon for representing ground-active invertebrates. Further research is recommended to identify target invertebrate taxa from the grass layer.

2. *Attributes of these taxa for measurement*. Four attributes are proposed: species diversity (richness and evenness), species composition, functional-group representation, and, for vertebrates, species occupancy.

3. *Appropriate reference conditions*. The dominant vegetation type in Kakadu NP surrounding the Ranger mine is eucalypt-dominated lowland savanna woodland, and this has been identified by SSB-ERISS as the reference ecosystem most closely aligned to that specified in the Environmental Requirements for Ranger rehabilitation. The faunal assemblages of surrounding lowland savanna woodland therefore constitute reference conditions.

4. *Acceptable similarity with reference conditions*. Rehabilitation can be considered acceptable if either: (1) at least 60% of rehabilitation sites achieve at least 80% of the reference metric; or (2) at least 80% of rehabilitation sites achieve at least 60% of the reference metric. Standards are also provided for exotic species.

5. *Robust sampling methodology*. Many faunal species have limited detectability in field surveys, and so sampling must be sufficiently robust to enable a reliable characterisation of faunal assemblages. Species detectability is a particular issue for vertebrates, and a survey protocol based on that now used by the Northern Territory Top End National Parks Ecological Monitoring Program is recommended for adoption.

The details of the recommendations are highly specific to Ranger and its goal to establish ecosystems similar to those in surrounding Kakadu National Park. However, the approach to deriving the specifications is applicable to any agreed reference ecosystem for Ranger, and to minesite rehabilitation more generally.

The recommended specifications for faunal standards are based on a Western concept of biodiversity, and it is possible that culturally important animal species from surrounding lowland savanna woodland are missing from the target list recommended here and are appropriate for inclusion. This requires further consideration.

1. Introduction

Effective rehabilitation is a major challenge for the many active and legacy mines located throughout northern Australia. Mine-site rehabilitation has historically focused on site stabilisation and the establishment of vegetation cover, but this is often now just the start of a rehabilitation process that is increasingly aimed at ecosystem restoration such that the rehabilitated mine-site becomes sustainably integrated with the surrounding landscape. Successful ecosystem restoration requires the re-establishment of animal as well as plant communities, and also the re-establishment of ecological processes such as nutrient cycling, pollination and seed dispersal, which are often mediated by fauna (Majer 1989; Hughes et al. 2018).

A major rehabilitation program is underway at Ranger Uranium Mine, operated by Energy Resources Australia (ERA), in the Northern Territory, where mining ceased in 2012 and the 79 km^2 Ranger Project Area is due to be rehabilitated by 2026. ERA's obligation will cease when the relevant Commonwealth and NT ministers issue a close-out certificate in respect of the Ranger Project Area (Section 9.3 of Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger Uranium Mine (1999)), after seeking the advice of the Supervising Scientist and agreement from the Northern Land Council (Supervising Scientist 2018). The Ranger mine has a particularly high public profile because it is surrounded by World Heritage-listed Kakadu National Park, and community expectations are that rehabilitation will be of the highest standard. Current revegetation trials are focussing on the establishment of canopy trees, and such tree establishment has been highly successful (cover photo). However, consideration of rehabilitation from a faunal perspective is still at an early stage.

Faunal rehabilitation at Ranger is addressed by NESP Northern Australia Environmental Resources Hub project 2.8, *Rehabilitation of faunal assemblages at Ranger Uranium Mine.* The project's aims are to inform the Supervising Scientist Branch's (SSB) Ecosystem Restoration Standard through: (1) survey ground-foraging terrestrial invertebrates at biodiversity reference sites selected by the SSB-Environmental Research Institute of the Supervising Scientist (ERISS) for establishing benchmarks for successful minesite rehabilitation; (2) identify appropriate vertebrate species for incorporation into rehabilitation standards, and to design a robust sampling methodology for ongoing vertebrate monitoring and assessment; (3) incorporate the above information into recommended specifications for faunal standards for Ranger rehabilitation. These specifications and the processes for developing them, will be broadly applicable to minesite rehabilitation throughout northern Australia.

This report addresses the third aim of the project, the development of specifications for potential inclusion in faunal standards for Ranger rehabilitation. The first two aims of project 2.8 are reported on separately (Andersen & Oberprieler 2019; Einoder et al. 2019).

2. Ranger rehabilitation goals

The overall goal of rehabilitation of the Ranger Project Area is “to establish an environment similar to the adjacent areas of Kakadu National Park such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu National Park” (Section 2.1 of Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger Uranium Mine (1999); Supervising Scientist 2018). Revegetation is required to use “local native plant species similar in density and abundance to those existing in adjacent areas of Kakadu National Park, to form an ecosystem the long term viability of which would not require a maintenance regime significantly different from that appropriate to adjacent areas of the park” (section 2.2(a)).

Ranger’s rehabilitation requirements contain no specifications for fauna, other than that no exotic species should be introduced (section 10.2). However, the Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger Uranium Mine (1999) states that “All aspects of the Ranger Environmental Requirements must be implemented in accordance with BPT” (Best Practicable Technology) (section 12.1). International standards in relation to ecological restoration are described in a recent report by the Society for Ecological Restoration (McDonald et al. 2016a), and they have been reproduced as Australian standards (McDonald et al. 2016b). These standards highlight the need to identify specific and measurable indicators of key ecosystem attributes that underpin successful restoration, and this needs to include measures of faunal composition (McDonald et al. 2016a, p. 14). For a 5-star rating, there must be a “High diversity of characteristic species …., with high similarity to the reference ecosystem” This is consistent with ERA’s rehabilitation objective 2: Established habitats will support faunal communities similar to that in KNP (Ecological Australia 2017).

3. Recommended specifications for faunal standards

Despite the goal of faunal rehabilitation at Ranger being conceptually clear (to establish faunal assemblages similar to those in surrounding Kakadu National Park), this needs to be translated into formal standards that signal successful faunal rehabilitation.

There are few precedents for developing faunal standards for ecosystem rehabilitation, either in Australia or elsewhere in the world. Measures of rehabilitation success typically focus on vegetation and soil development, with little or no consideration given to fauna (Cristescu et al. 2012; Gatica-Saavedra et al. 2017). This is despite potential mismatches between revegetation and faunal recolonization (Wolf et al. 2018). A notable exception is the widespread use of invertebrates, especially ants, as indicators of minesite rehabilitation in Australia (Andersen & Majer 2004). Ants have been used to assess rehabilitation success at minesites throughout northern Australia, including at Ranger's early revegetation trials established on waste rock in the 1980s (Andersen 1993). These early ant assessments at Ranger indicated that succession had soon stalled due to the dominance of fast-growing species of acacia that had been planted to achieve rapid revegetation (Andersen 1993). Ranger's current revegetation trials have avoided such acacia dominance and have successfully established canopy trees; however, the trials are at an early stage, and ant communities are still highly dissimilar to those at reference sites (Andersen & Oberprieler 2019). Studies elsewhere in Australia have shown that it is possible to restore highly diverse ant communities within 15 years following mining (Andersen et al. 2003).

Studies of vertebrate colonisation of rehabilitated minesites in Australia generally show limited success (Cristescu et al. 2012). However, vertebrate assessments at Ranger's early revegetation trials found that a wide range of taxa colonised these sites within five years (Corbett 1999). Mammal assemblages have been successfully restored following bauxite mining in the northern jarrah forest of southwestern Australia, although the rehabilitation of reptile assemblages has been less successful (Craig et al. 2018).

None of the above studies of faunal recolonisation of rehabilitated minesites attempt to develop comprehensive faunal standards for assessing rehabilitation success. The development of such standards has been described as "the next challenge in restoration ecology" (Cristescu et al. 2012).

The translation of Ranger's rehabilitation goal of 'similar faunal assemblages to those in surrounding Kakadu NP' into specified standards requires the following issues to be addressed:

1. Faunal taxa to be included in the standards
2. Attributes of these taxa to be measured
3. Specification of appropriate Kakadu NP reference conditions
4. Specification of appropriate level of similarity with reference conditions
5. Development of a robust methodology for comparing rehabilitation sites with reference conditions

3.1 Faunal taxa

3.1.1 Vertebrates

Einoder et al. (2019) have identified 50 vertebrate species from the dominant lowland savanna woodlands surrounding the Ranger mine that are sufficiently detectable with standard survey methods to be monitored with high confidence. These are the recommended vertebrate taxa for incorporation into faunal standards for rehabilitation. They comprise 34 bird, 11 reptile and 5 mammal species, and include the threatened Partridge Pigeon and Black-footed Tree-rat (Table 3.1).

Table 3.1. Vertebrate species identified by Einoder et al. (2019) and recommended for incorporation into faunal standards for rehabilitation at Ranger Uranium Mine.

Birds	Bar-shouldered Dove	Mistletoebird	Sulphur-crested Cockatoo
	Black-faced Cuckoo-shrike	Northern Fantail	Torresian Crow
	Black-tailed Treecreeper	Partridge Pigeon*	Varied Triller
	Blue-faced Honeyeater	Peaceful Dove	Weebill
	Blue-winged Kookaburra	Pied Butcherbird	White-bellied Cuckoo-shrike
	Brown Honeyeater	Rainbow Bee-eater	White-gaped Honeyeater
	Brush Cuckoo	Rainbow Lorikeet	White-throated Honeyeater
	Dusky Honeyeater	Red-backed Fairy-wren	White-winged Triller
	Grey Shrike-thrush	Red-winged Parrot	Willie Wagtail
	Grey-crowned Babbler	Rufous Whistler	Yellow Oriole
	Leaden Flycatcher	Silver-crowned Friarbird	
	Little Friarbird	Striated Pardalote	
Reptiles	**Skinks**	**Geckos**	**Dragons**
	Carlia amax	*Gehyra australis*	*Diporiphora bilineata*
	Ca. gracilis	*Heteronotia binoei*	
	Ca. munda		
	Cryptoblepharus metallicus		
	Cr. plagiocephalus		
	Ctenotus arnhemensis		
	Ct. essingtonii		
	Morethia storri		
Mammals	Agile Wallaby	Black-footed Tree-rat*	Northern Brown Bandicoot
	Antilopine Wallaroo	Dingo	

*Threatened species

3.1.2 Invertebrates

Invertebrates, especially insects, represent the vast majority of terrestrial faunal species, and the Kakadu region has an exceptionally rich invertebrate fauna that is of outstanding biogeographic and conservation significance (Andersen et al. 2014). In addition to their contribution to biodiversity, invertebrates play particularly important roles in the facilitation of ecosystem restoration, including the promotion of soil development and nutrient cycling (Majer 1989; Hughes et al. 2018).

Ants are the overwhelmingly dominant ground-foraging invertebrate group in the Kakadu region, and, combined with their proven value as indicators of ecological restoration, are recommended for representing ground-foraging invertebrates in faunal rehabilitation standards for Ranger (Andersen & Oberprieler 2019). The understory is of critical importance to Ranger rehabilitation (Supervising Scientist 2018), and it is recommended that one or more representative invertebrate taxa from the grass layer, to be determined by additional research, also be included in the closure criteria (Andersen & Oberprieler 2019).

3.1.3 Exotic species

The Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger Uranium Mine (1999) specifies that no exotic species should be introduced (section 10.2; Supervising Scientist 2018). Exotic species therefore need to be incorporated into the faunal standards. It is recommended that this includes the feral animals that occur in surrounding Kakadu NP, in addition to new exotic animal species. Particular attention needs to be paid to highly invasive ant species that threaten biodiversity elsewhere in northern Australia, particularly the African big-headed ant (*Pheidole megacephala*; Hoffmann et al. 1999) and the Yellow crazy ant (*Anoplolepis gracilipes*; Hoffmann & Saul 2010).

3.2 Attributes to be measured

Einoder et al. (2019) identify four attributes of vertebrate assemblages for incorporation into faunal standards: (1) species diversity; (2) species composition; (3) functional diversity through trophic guild representation; and (4) species occupancy at the site-scale.

3.2.1 Species diversity

Two measures of species diversity are recommended: (1) Species richness, the simple count of number of species; and (2) Species evenness, a measure of how evenly abundance is distributed among species (higher evenness equates to higher diversity). Species evenness requires a sufficient number of species for meaningful measurement – among vertebrates it is recommended for birds only. The commonly-used measure of overall species diversity, the Shannon Index, combines these measures. However, it has been severely criticised as being ecologically insensitive and even misleading, because it confounds two very different concepts (MacDonald et al. 2017; Santini et al. 2017). It is not recommended for use.

3.2.2 Species composition

Species composition is readily assessed through multivariate ordination, with non-hybrid multidimensional scaling (NMDS) based on Bray-Curtis dissimilarity recommended (Andersen & Oberprieler 2019; Einoder et al. 2019). Differences in species composition

between rehabilitated and reference sites can be assessed through Analysis of Similarity (ANOSIM).

3.2.3 Functional diversity

Einoder et al. (2019) identify 14 trophic guilds among the 50 targeted vertebrate species, and they recommend that the number of these guilds at 1-ha sites be included in faunal standards for Ranger rehabilitation. This provides a measure of functional diversity, which is not always strongly related to species diversity (Petchey & Gaston 2002; Safi et al. 2011; Arnan et al. 2017). Restoration of functional diversity is often more predictable than that of species diversity (Laughlin et al. 2017). Such an approach is recommended here. Particular attention should be given to guilds requiring specific habitat features such as fruiting plants and tree hollows.

A measure of functional diversity is readily applied to assessments of ant communities through a widely-used system of ant functional groups in relation to environmental stress and disturbance (Andersen 1995). Indeed, such ant functional diversity is included as part of Australian standards for the practice of ecological restoration (Appendix 4 in McDonald et al. 2016b). There are nine such groups, all occurring in Kakadu NP: 1. Dominant Dolichoderinae; 2. Generalised Myrmicinae; 3. Opportunists; 4. Subordinate Camponotini; 5. Hot-climate specialists; 6. Cold-climate specialists; 7. Tropical-climate specialists; 8. Cryptic species; and 9. Specialist predators. The number of these groups sampled at lowland savanna woodland sites surrounding the Ranger mine ranged from 5-8 (mean of 7.1), compared with 6-7 (mean of 6.8) at Ranger's trial revegetation sites (calculated from data in Andersen & Oberprieler 2019). This indicates that the number of ant functional groups present is an overly coarse measure. A more appropriate measure is recommended – the number of species present in key functional groups (Table 3.2).

Table 3.2. Range (and mean) of number of species within selected ant functional groups sampled at Kakadu reference and Ranger trial revegetation sites (calculated from data in Andersen & Oberprieler 2019).

Functional group	Kakadu	Ranger
Dominant Dolichoderinae	3-5 (4.0)	2-4 (2.8)
Subordinate Camponotini	1-9 (5.0)	3-4 (3.3)
Hot-climate specialists	3-12 (8.1)	0-2 (1.0)
Specialist predators	1-3 (1.7)	0-1 (0.8)

3.2.4 Species occupancy

The final recommended attribute of vertebrate assemblages for incorporation into faunal standards is species occupancy – the proportion of sites at which a species is recorded (Einoder et al. 2019). This attribute could also be applied to invertebrate assemblages, although this would first require the identification of species that are sufficiently common and detectable to be able to be monitored with confidence, as has been done for vertebrates (Einoder et al. 2019). My recommendation is that this is not necessary, and that the attributes of species diversity, species composition and functional composition are sufficient for characterising the invertebrate fauna.

3.3 Appropriate reference conditions

The dominant vegetation type in Kakadu NP surrounding the Ranger mine is eucalypt-dominated lowland savanna woodland, and SSB-ERISS has identified such savanna woodlands as ecosystem types meeting the Environmental Requirements of 'similar to the adjacent areas of Kakadu National Park'. The faunal assemblages of surrounding lowland savanna woodland therefore constitute reference conditions. Einoder et al. (2019) used assemblages occurring in lowland savanna woodland in the northern half of Kakadu as reference conditions for vertebrates, and Andersen & Oberprieler (2019) used assemblages occurring in lowland savanna woodland immediately surrounding the Ranger mine (including five SSB-ERISS environmental monitoring sites) as reference conditions for invertebrates. However, it needs to be noted that the savanna woodlands immediately surrounding Ranger occur on loams and sands, substrates that are very different to those of Ranger's rehabilitated landform, which is formed from waste rock. The capacity of the rehabilitated landform to support vegetation typical of the immediate surrounds is uncertain, and so what constitutes appropriate reference ecosystems is open to further consideration.

3.4 Acceptable similarity with reference conditions

The term 'similar' in the context of establishing an "environment similar to the adjacent areas of Kakadu National Park" requires appropriate quantification for specification in rehabilitation standards. Such specification needs to be developed in the context of the extent of natural variability among reference sites. For any mean value for a target metric at reference sites, about half of the reference sites will have a lower value, and for a substantial proportion it will be far lower. The specification of 'similarity' can therefore be seen as having two dimensions, one relating to the proportion of the reference metric that has been achieved at a rehabilitated site, and the other to the proportion of rehabilitation sites achieving this.

Einoder et al. (2019) present a similarity-assessment matrix based on these two dimensions, which is followed here. Rehabilitation is considered acceptable if either: (1) at least 60% of rehabilitation sites achieve at least 80% of the reference metric; or (2) at least 80% of rehabilitation sites achieve at least 60% of the reference metric. For example, if mean species richness at reference sites is 50, then rehabilitation is assessed as acceptable if either ≥60% of rehabilitation sites have a richness ≥40, or ≥80% of rehabilitation sites have a richness ≥30. Einoder et al. (2019) recommend that at least one of the two threatened vertebrate species targeted for assessment (Partridge Pigeon and Black-footed Tree-rat) should attain ≥60% of the occupancy of reference sites, and this recommendation is supported here.

In addition to the proportion of rehabilitation sites that have high similarity with reference conditions, it might also be appropriate to specify a maximum number of sites that show very low similarity. For example, having 60% of sites with very high (≥80%) similarity with reference sites leaves the potential for 40% of sites to have very low similarity. The appropriateness of a specification for the maximum proportion of poorly-performing sites requires further consideration. The setting of such specifications would require further analysis of variability among reference sites.

Recommendations for exotic species are:

1. The density of any feral animal species in the overall project area should not be higher than maximum densities in lowland savanna woodland in surrounding Kakadu NP; and
2. No exotic animal species should occur in the project area that does not occur in surrounding Kakadu National Park.

3.5 Robust sampling methodology

Unlike the situation for perennial plants, data from field surveys of fauna are highly confounded by the issue of detectability – an animal species might occur at a site but not be recorded. Indeed, unless sampling is sufficiently robust then only a very limited proportion of animal species is likely to be recorded. For example, mean ant species richness from a single survey of reference sites adjacent to the Ranger mine was only about 60% of that from three surveys (Andersen & Oberprieler 2019). Importantly, sampling limitation can have differential effects at reference and rehabilitation sites, and therefore have a direct impact on assessment of rehabilitation success. Common, and therefore readily detectable, species are often the first to colonise rehabilitation sites, and at early stages such sites typically lack the long tail of rare (and therefore more difficult to detect) species that is characteristic of highly diverse faunas at reference sites. Consequently, limited sampling intensity can record markedly different proportions of total species at reference and rehabilitation sites, and thereby provide an unreliable indication of the extent of differences between them (Andersen & Oberprieler 2019). Assessments of faunal rehabilitation therefore need to be based on robust sampling methodologies.

The issue of detectability is especially important for vertebrates, because they tend to occur in lower numbers than do invertebrates, and, aside from birds, their field survey is heavily dependent on trapping that has strong biases. Einoder et al. (2019) provide clear guidelines for the robust survey of target vertebrate assemblages using a range of sampling methods (including camera trapping, live trapping, and direct observations), based on the most-recent survey protocol used by the Northern Territory Top End National Parks Ecological Monitoring Program (this program includes many sites in Kakadu NP). These guidelines should be followed during ongoing assessment of rehabilitation of the vertebrate fauna at Ranger.

4. Closing remarks

This report develops recommended specifications for faunal standards for ecosystem rehabilitation at Ranger Uranium Mine. It covers:

1. Vertebrate and invertebrate taxa to be targeted for assessment;
2. Attributes of these taxa for measurement;
3. Appropriate reference conditions;
4. Acceptable similarity with reference conditions; and
5. Robust methodologies for comparison with reference conditions.

The details of the recommendations are highly specific to Ranger and its goal to establish ecosystems similar to those in surrounding Kakadu National Park. However, the approach to deriving the specifications is applicable to any agreed reference ecosystem for Ranger, and to minesite rehabilitation more generally.

The recommended specifications are based on a Western concept of biodiversity, but there is increasing recognition that ecological restoration should also consider broader social values and cultural practices (Wehi & Lord 2017; Fernandez-Manjarres et al. 2018; Urgenson et al. 2018). This is especially relevant to Ranger because the surrounding land in Kakadu National Park is Aboriginal-owned. The need to consider the distinct cultural values of local Aboriginal people is recognised by ERA's planning for rehabilitation and closure (energyres.com.au/ uploads/general/Ch_13_Rehabilitation_and_Closure.pdf). It is possible that culturally important animal species from surrounding lowland savanna woodland are missing from the target list recommended here and should be included. This requires further consideration.

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