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Invertebrate assemblages at Ranger Uranium Mine's trial revegetation sites compared with natural reference sites

Report

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Cover photographs

Front cover: Black beauty ant, *Calomyrmex impavidus* (photo Stefanie Oberprieler).

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

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Acronyms

ANOSIM .... analysis of similarity

BPT................ Best Practicable Technology

CS.................. Cryptic Species

CSIRO .... Commonwealth Scientific and Industrial Research Organisation

DD.................. Dominant Dolichoderinae

ERA .... Energy Resources of Australia

GM .... Generalised Myrmicinae

HCS .... Hot-Climate Specialist

KNP .... Kakadu National Park

NMDS............ non-metric multidimensional scaling

O .... Opportunist

SC.................. Subordinate Camponotini

SIMPER......... similarity percentage

SP .... Specialist Predator

SR.................. Seeding and waste rock

SSB .... Supervising Scientist Branch

ST .... Seeding and topsoil

TCS................ Tropical-Climate Specialist

TERC............. Tropical Ecosystems Research Centre

TR.................. Tubestock and waste rock

TT .... Tubestock and topsoil

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Executive summary

Rehabilitation of the Ranger Project Area requires the establishment of ecosystems that support faunal assemblages similar to those in surrounding areas of Kakadu National Park. Assessment of rehabilitation success requires the characterisation of faunal assemblages at appropriate natural reference sites in the surrounding area, along with the development of appropriate sampling protocols that provide suitably robust information on faunal assemblages for comparing rehabilitation sites with reference sites. This report describes a study jointly funded by Energy Resources of Australia (ERA) and the Northern Australia Environmental Resources Hub of the Australian Government's National Environmental Science Program that addresses these issues for terrestrial invertebrates.

The study compared four sites on Ranger's trial landform with seven natural reference sites surrounding the mine. Invertebrates were sampled using pitfall traps on three occasions during the 2018 dry season. Ants, beetles, mutillid wasps and zodariid spiders were targeted for analysis. Ants dominated the catches, contributing the vast majority (99%) of individuals and most (69% of the total 157) species among the target groups. Our surveys recorded 33 species of beetles, 9 zodariid spiders and 7 mutilid wasps.

Species richness was far higher at reference compared with mine sites, and species composition was highly dissimilar. These differences increased with increasing survey effort, indicating that reference sites contain many uncommon species that require higher sampling effort to collect, whereas mine sites do not. Analysis of only larger ants showed high dissimilarity between reference and mine sites, but not as high as when all ant species were considered. Maximum dissimilarity was shown when using just the ant species contributing most to compositional dissimilarity.

The dissimilarity between mine sites and reference sites is to be expected at this early stage of revegetation. However, a promising finding was that overall ant abundance at mine sites was similarly high to that at reference sites. This indicates a high level of restoration of the roles played by ants in soil development and nutrient cycling, both critical processes for ongoing ecosystem restoration.

The crucial issue at this early stage of ecosystem rehabilitation is its trajectory, and this requires ongoing monitoring. The dominance of ants and their strong capacity to discriminate mine sites from reference sites make them an ideal taxon for representing ground-dwelling invertebrates in ongoing monitoring. Instead of other ground-dwelling invertebrates, in addition to ants we recommend sampling one or more representative invertebrate taxa from the grass-layer to provide a complementary perspective of ecosystem rehabilitation in ongoing monitoring.

1. Introduction

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)). This is reflected in ERA's rehabilitation objective 2: *Established habitats will support faunal communities similar to that in KNP* (Ecological Australia 2017), as well as the Supervising Scientist Branch's (SSB) rehabilitation standards, which stipulate that faunal species richness, composition and trophic guilds must be highly similar to, or on a secure trajectory towards, that of the reference ecosystem (http://www.environment.gov.au/science/supervising-scientist/publications/ss-rehabilitation-standards). Such an objective equates to a 5-star rating in international standards of ecological restoration, which requires "*High diversity of characteristic species …., with high similarity to the reference ecosystem*" (McDonald et al. 2016).

Invertebrates are a dominant component of the world's fauna, representing the vast majority of terrestrial animal species, mediating many key ecological processes, and being widely used as bioindicators of the success of mine-site rehabilitation (Majer 1983, McGeoch 1998, Andersen and Majer 2004). They need to be a major focus of rehabilitation at Ranger.

There are two key challenges for operationalising requirements for faunal rehabilitation. The first is to characterise faunal assemblages at appropriate natural reference sites, in order to define the benchmark that rehabilitation aims to achieve. The second is to evaluate the success with which rehabilitation sites have achieved this benchmark. In 2009, ERA established a trial landform and revegetation study that has resulted in successful tree establishment (Figure 2.1 and Figure 2.2). The composition of invertebrates at these trial revegetation sites cannot be expected to be similar to that at reference sites at this early stage. However, an understanding of differences in invertebrate composition compared with reference sites can be highly informative for ongoing monitoring and management of ecosystem rehabilitation.

This report describes a study funded by ERA and the Northern Australia Environmental Resources Hub of the Australian Government's National Environmental Science Program that addresses both the above challenges in relation to invertebrate fauna. The aims of the research are to:

1. Characterise ground-dwelling invertebrate assemblages at appropriate reference sites;
2. Assess the similarity of invertebrate assemblages at revegetation sites on Ranger's trial landform to those at reference sites;
3. Examine how apparent similarity of invertebrate assemblages between revegetation and reference sites varies with sampling intensity;
4. Identify species that contribute most to dissimilarity between invertebrate assemblages at revegetation and reference sites;
5. Recommend protocols for future invertebrate monitoring of ecosystem rehabilitation at Ranger.

2. Methods

2.1 Study location

Ranger Uranium Mine is situated 8 km east of Jabiru and 260 km south-east of Darwin (Figure 2.1). The Ranger project area is approximately 79 km^2 and is surrounded by (but not part of) Kakadu National Park. The environment surrounding Ranger consists of a wide range of habitat types, but predominately eucalypt-dominated lowland savanna woodlands. It also features an extensive sandstone tableland, characterised by rugged rocky ridges and scattered outcrops (Finlayson and von Oertzen 2012). The Ranger region has a mean annual rainfall of approximately 1440 mm, which occurs primarily between November–April.

2.2 Study sites

The study compared four sites on Ranger's trial landform with seven undisturbed natural reference sites surrounding the mine (Figure 2.1). The trial landform of approximately 200 m x 400 m was established in 2009 to assess the design of the rehabilitated final landform following mine closure. It includes four experimental sites with different base material (waste rock only vs waste rock mixed with laterite) and revegetation practices (direct seeding vs tubestock): tubestock and waste rock (TR), direct seeding and waste rock (SR), direct seeding and waster rock/laterite mix (SM) and tubestock and waster rock/laterite mix (TM) (Figure 2.2). Revegetation has focused on the establishment of canopy trees, with substantial success (Figure 2.2).

The seven natural reference sites comprise five SSB environmental monitoring sites that were accessible without a helicopter (sites 2, 3, 7, 8, 9), along with two additional sites (N1 and N2) that were established for this study. They were all lowland, eucalypt-dominated savanna woodlands (Figure 2.3 A–G), and have the following coordinates:

- Site 2: -12.61, 132.94
- Site 3: -12.60, 132.94
- Site 7: -12.69, 132.85
- Site 8: -12.63, 132.85
- Site 9: -12.62, 132.86
- Site N1: -12.69, 132.88
- Site N2: -12.70, 132.89

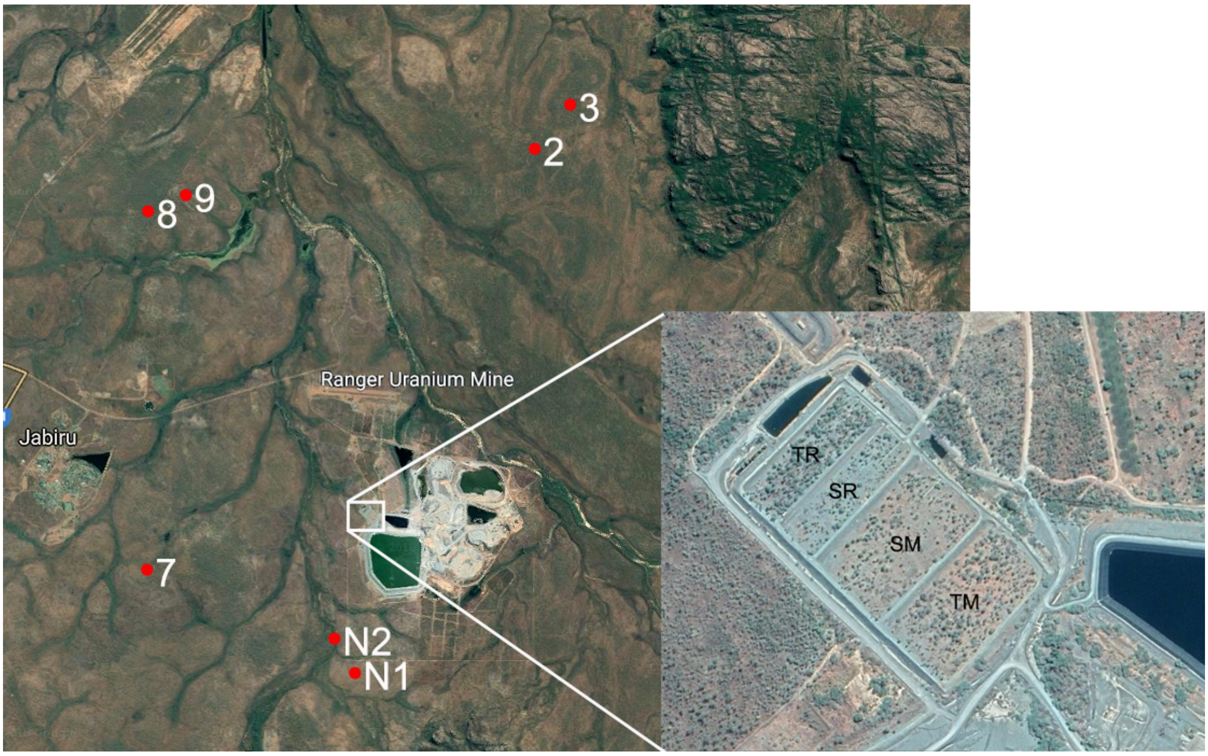

Figure 2.1. Location of the seven natural reference sites surrounding Ranger Uranium Mine and of the four trial revegetation sites; TR = tubestock on waste rock, SR = seeding and waste rock, SM = seeding and mixed rock/laterite, TM = tubestock and mixed rock/laterite.

Figure 2.2. Vegetation at the four Ranger mine trial landform sites, middle dry-season 2018.

Figure 2.3. ***A–G****: vegetation at seven natural reference sites surrounding Ranger (****A–B****: late wet-season 2018,* ***C–G****: middle dry-season 2018);* ***H****: pitfall trap containing ethylene glycol.*

2.3 Sampling

Invertebrates were sampled on three occasions (in June, August and October) during the 2018 dry season. Sampling was conducted using pitfall traps, a standard and effective method for sampling ground-dwelling invertebrates (Southwood 1978, Bestelmeyer et al. 2000, Skvarla et al. 2014). At each site a 5 x 4 grid of 45 mm diameter traps was installed, with traps separated by 10 m. Traps were partly filled with ethylene glycol as a preservative, buried in the ground flush with the soil surface (Figure 2.3H) and collected after 48 hours.

2.4 Sample processing and identification

All invertebrates collected were extracted from the traps and the following key groups were targeted for analysis, based on their taxonomic tractability and broad representation of invertebrate functional diversity: ants (Hymenoptera: Formicidae), beetles (Coleoptera), mutilid wasps (Hymenoptera: Mutilidae) and zodariid spiders (Araneae: Zodariidae). Only adults were identified to species-level. Ant abundances were capped at 50 individuals per species per trap to avoid data distortions due to traps being placed close to nest entrances or foraging trails.

Ant species were named were possible, by reference to named species in the CSIRO Tropical Ecosystems Research Centre (TERC) collection in Darwin. However, most ant species in the Top End are undescribed and these were assigned code numbers that have been used in previous studies of ants in the region (Andersen et al. 2018, Oberprieler et al. 2019). To assist interpretation of differences between reference and mine sites, ant species were classified into functional groups based on responses to environmental stress and disturbance, following Andersen (1995). These groups were: Dominant Dolichoderinae (primarily species of *Iridomyrmex*), Generalised Myrmicinae (species of *Monomorium*, *Pheidole* and *Crematogaster*), Opportunists (primarily species of *Rhytidoponera*, *Tetramorium*, *Nylanderia*, *Tapinoma* and *Paratrechina*), Subordinate Camponotini (species of *Camponotus*, *Polyrhachis* and *Opisthospsis*), Hot-Climate Specialists (primarily species of *Melophorus*, *Meranoplus* and *Chelaner*), Cryptic Species (primarily species of *Solenopsis*) and Specialist Predators (species of *Anochetus*, *Leptogenys*, *Lioponera* and *Pseudoneoponera*). Tropical-Climate Specialists were represented by a single species (*Oecophylla smaragdina*), and so were not analysed separately.

Species of beetles and mutilid wasps were identified to the lowest taxonomic level possible using the TERC reference collections, Lawrence and Britton (1991) and Brown (2009). Zodariid spiders were identified to genus using Jocqué (1995) and Baehr (2003, 2004). Where species-level identification was not possible, systematic code names were assigned.

3. Data analysis

To assess differences in mean richness of species between reference and mine sites, clustered column graphs were constructed with standard error bars using Microsoft Excel 2010. For ants, comparisons of mean species richness were done separately for the first sample, the first two samples combined, and all samples combined, representing a gradient of increasing survey effort and therefore sampling intensity. For other groups, analysis was restricted to all samples combined.

Multivariate analysis was used to examine differences in species composition between reference and mine sites using Primer-E 7.0 (Clarke and Gorley 2015). For each invertebrate group, similarity in composition was calculated between every pair of sites using Bray-Curtis similarity measures based on presence/absence data. To visualise similarity in species composition across all eleven sites, an ordination scatterplot was created from the resemblance matrices using non-metric multidimensional scaling (NMDS). In the resulting scatter plots, the proximity of samples reflects their relative similarities in terms of species composition. The separation of reference and mine sites was then statistically tested using analysis of similarity (ANOSIM) under the Spearman Rank method (999 permutations). For ants, this was done separately for the first sample, the first two samples combined, and all samples combined, whereas for other groups analysis was restricted to all samples combined.

To determine the key species contributing most to differences in community composition between reference and mine sites, similarity percentage (SIMPER) analysis was used based on the presence/absence similarity matrices from combined data across all samples.

The great abundance and diversity of even a subset of invertebrates can make the processing of samples extremely time-intensive. Several approaches have been proposed for simplifying invertebrate assessment whilst maintaining reliability. One approach is to restrict processing and analysis to larger species only (which are more readily identifiable and easier to process than are small species), as has been successfully done for environmental impact assessment using ants (Arcoverde et al. 2018). Another approach is to identify a subset of target taxa based on taxonomically tractable families or functional groups, which exhibit the same patterns in species richness and composition as do all species surveyed. Using NMDS plots (based on presence/absence similarity matrices, as described above) the degree of separation between reference and mine sites identified using all ant species was compared with that using only large ant species (see Appendix 1 for list of large species). This was also done for other invertebrate groups, using two subsets of taxa: only beetles and only the three dominant beetle families, Curculionidae, Elateridae and Tenebrionidae.

4. Results

4.1 Faunal overview

A total of 157 invertebrate species from the target groups were identified from the surveys. Ants dominated the catches, contributing the vast majority (99%) of individuals and most (69%) species (Appendix 1). The richest ant genera were *Monomorium* (20 species), *Melophorus* (10), *Tetramorium* (9), *Meranoplus* (8), *Pheidole* (6), *Camponotus* (6), *Iridomyrmex* (6) and *Rhytidoponera* (6). The most common ant species was *Iridomyrmex* sp. 1 (*anceps* gp.) with >4000 individuals, followed by *Iridomyrmex pallidus, Iridomyrmex sanguineus* and *Monomorium* ?*fieldi* with >3000, and the introduced species *Paratrechina longicornis* with >2000.

Our surveys recorded 33 species of beetles, 9 zodariid spiders and 7 mutilid wasps (Appendix 2) from a total of 116 specimens. The four dominant beetle families were Curculionidae (6 species, 17 individuals), Tenebrionidae (5, 41), Elateridae (5, 16), and Ptinidae (6, 12). Zodariid spiders and mutilid wasps totalled only 11 and 8 individuals, respectively.

4.2 Ants

Surveys from the reference sites yielded 105 ant species from 25 genera, while those from the mine sites yielded 31 species from 16 genera. Mean species richness at the reference sites pooled across all survey sessions was much higher (23–26) than that at the mine sites (9–13). When successively pooling the three survey sessions, the differences in mean species richness progressively increased (Figure 4.1).

Reference sites also had a higher mean species richness than did mine sites for all ant functional groups, most notably Hot-climate Specialists (9 vs 1), Generalised Myrmicinae (11 vs 4) and Opportunists (9 vs 3) (Figure 4.2). These three groups accounted for 68% of total species richness.

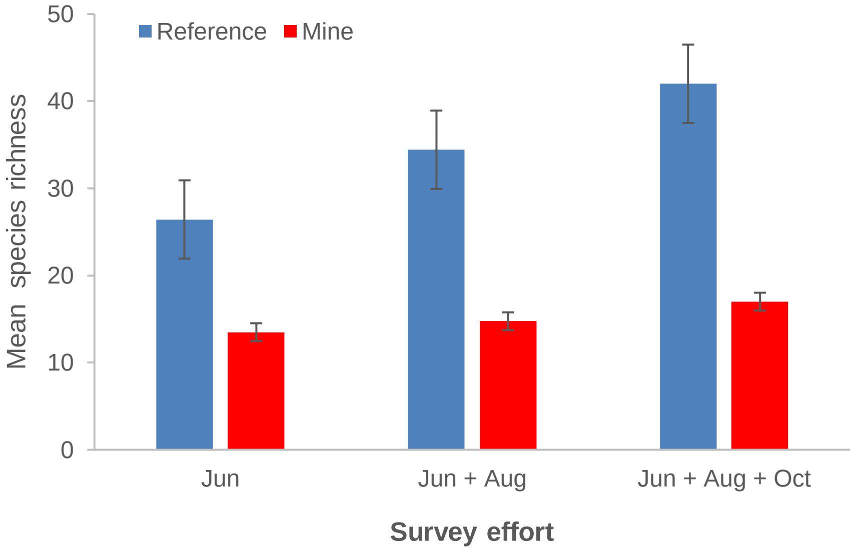

Figure 4.1. Mean (with standard error) ant species richness with increasing survey effort at reference and Ranger mine sites.

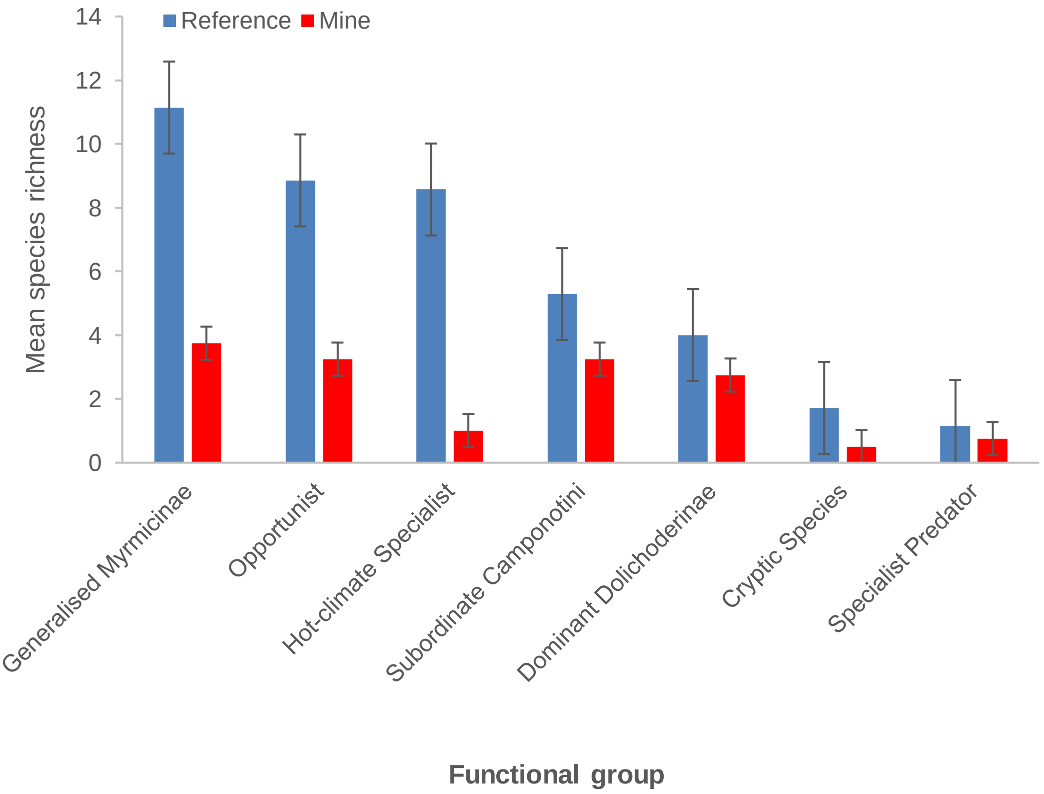

Figure 4.2. Mean (with standard error) species richness across ant functional groups from all survey sessions combined at reference and Ranger mine sites.

The four most common ant species at reference sites — *Iridomyrmex* sp. 1*, I. pallidus*, *I. sanguineus* and *Monomorium* ?*fieldi* — were all highly abundant at trial revegetation sites (Appendix 1). However, overall species composition was highly dissimilar, as shown by the clear separation between reference and mine sites in NMDS space (Figure 4.3). The degree of separation increased with increasing sampling effort (Figure 4.3). Eight of the top ten species contributing most to this dissimilarity were found exclusively at reference sites: *Melophorus* sp. 1 (*aeneovirens* gp.), *Melophorus* sp. 10 (Group D), *Melophorus postlei, Melophorus* sp. 13 (*biroi* gp.), *Pheidole* sp. 3 (*variabilis* gp.), *Monomorium* sp. 37 (*nigrius* gp.), *Paraparatrechina* sp. 2 (*minutula* gp.) and *Rhytidoponera trachypyx*. *Tetramorium lanuginosum* and *Paratrechina longicornis* were indicative of the mine sites, the former not sampled at any reference sites and the latter only by a single specimen each from reference sites 3 and 7. *Paratrechina longicornis* was abundant at all mine sites, most notably at site TR, where it accounted for 62% of total ant abundance. Restricting analyses to these ten species revealed complete separation (ANOSIM R = 1.0) between reference and mine sites in terms of species composition (Figure 4.4A).

Analyses restricted to large ants shows clear separation between reference and mine sites, but to a lesser extent than when considering all ants (Figure 4.4B). The large-ant only data comprised one-third of the species (38 species) of the full data set, and the separation of reference and mine sites was similar to that of the single June sampling session for all ants (Figure 4.3C).

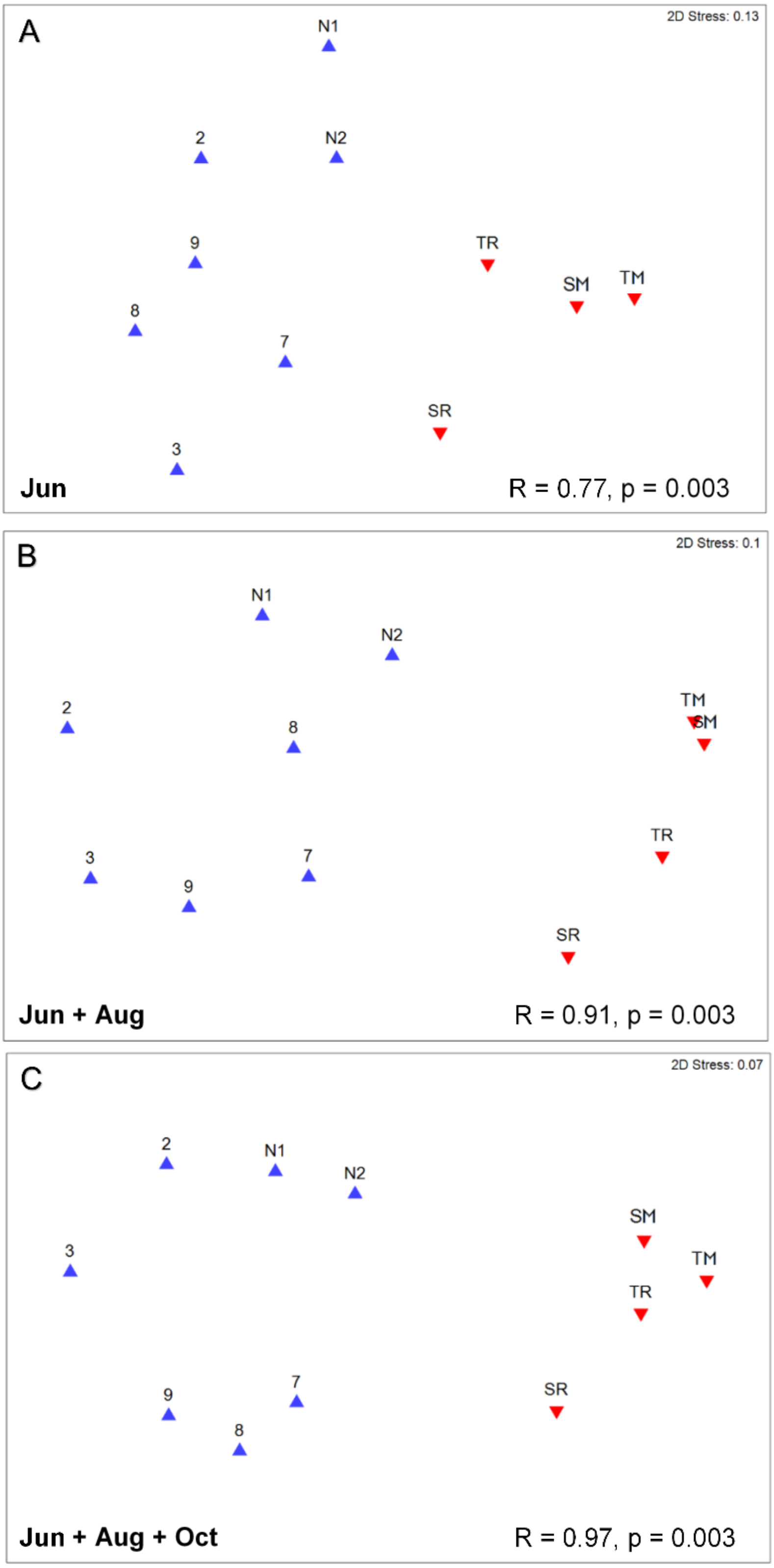

*Figure 4.3. Ant species composition (Bray-Curtis) from three progressive survey sessions at reference (▲) and Ranger mine (▼) sites; **A**: June; **B**: June + August; **C**: June + August + October. Based on presence-absence data. ANOSIM R value close to 1 indicates high separation between factors, while R value close to 0 indicates no separation. 2D Stress refers to the level of mismatch between the underlying data and the distances between points in the ordination.*

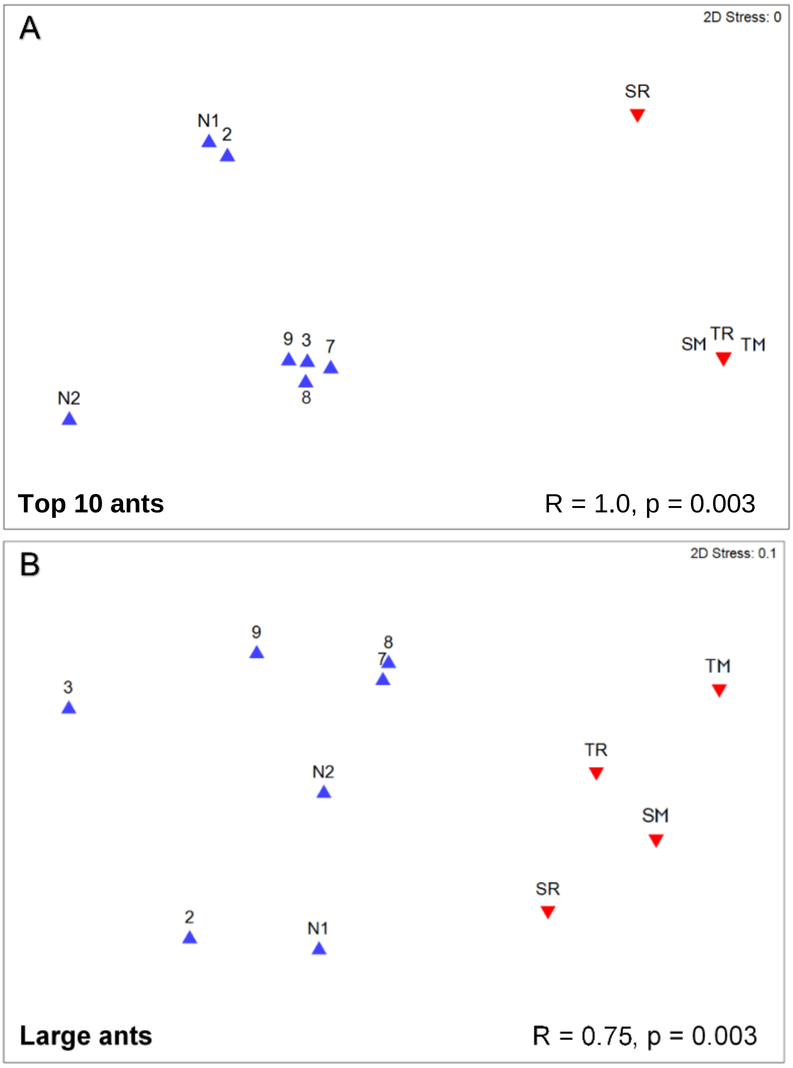

*Figure 4.4. Ant species composition (Bray-Curtis) from all survey sessions combined (June + August + October) at reference (▲) and Ranger mine (▼) sites; **A**: top ten ant species, identified by SIMPER; **B**: large ant species (see Appendix 1 Table 1 for list of species). Based on presence-absence data. ANOSIM R value close to 1 indicates high separation between factors, while R value close to 0 indicates no separation. 2D Stress refers to the level of mismatch between the underlying data and the distances between points in the ordination.*

4.3 Other invertebrates

The reference sites yielded 37 species from the other target invertebrate groups compared to only 10 at the mine sites. The mean number of beetle species was more than three times higher at reference sites, but numbers of species of mutilid wasps and zodariid spiders were similarly low at all sites (Figure 4.5). Totals of only 8 and 11 individual mutillid wasps and zodariid spiders respectively were sampled, and so these groups were not considered further.

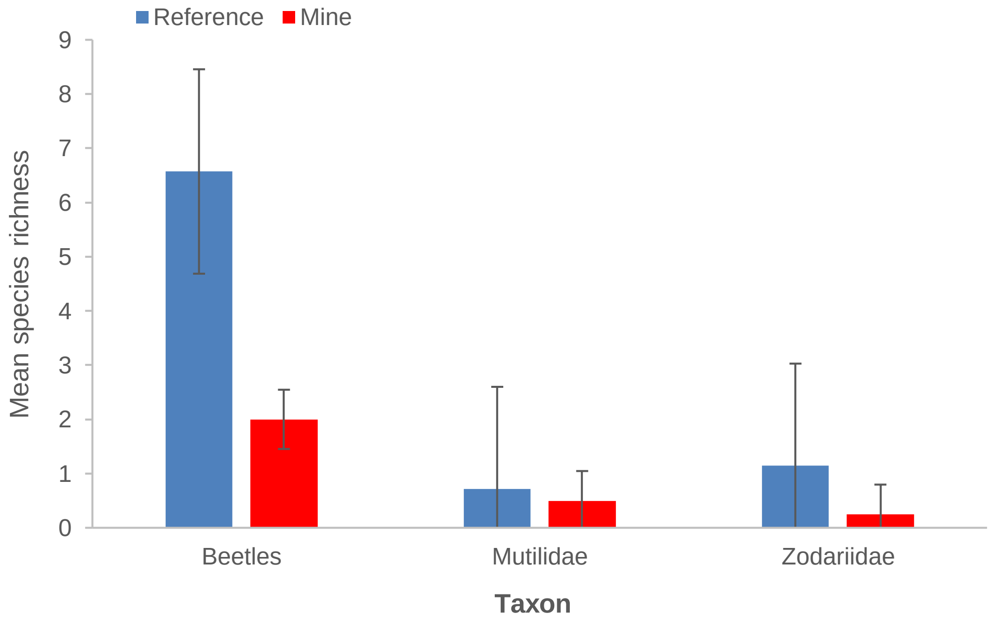

Figure 4.5. Mean (with standard error) species richness of beetles, mutilid wasps and zodariid spiders at natural reference and Ranger mine sites.

There was clear separation in beetle species composition between reference and mine sites in NMDS space. Ranger mine site TR was notably separate from all other sites because it yielded only one beetle species, Chrysomelidae sp. A., which was not recorded elsewhere (Figure 4.6A). Results from all beetles were replicated when considering only the three dominant beetle families, Curculiondae, Elateridae and Tenebrionidae (Figure 4.6B), which comprised 53% of beetle species, along with 8 of the top 10 beetle species contributing most to dissimilarity between reference and mine sites.

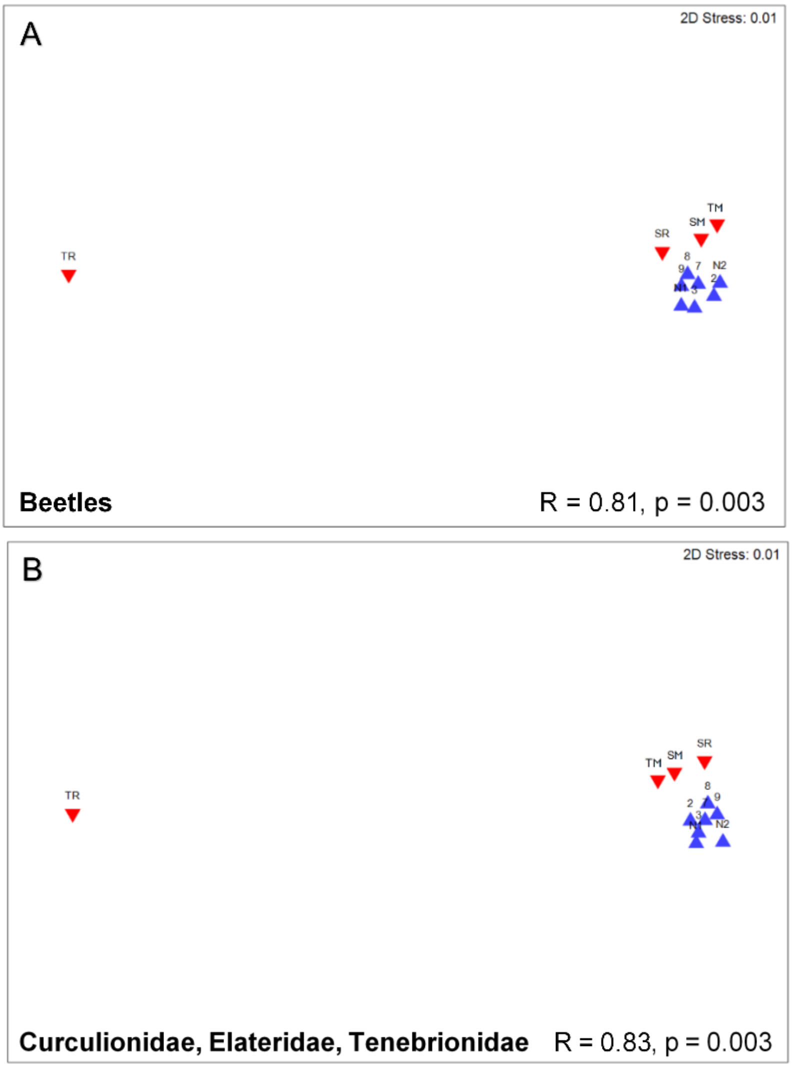

Figure 4.6. Beetle species composition (Bray-Curtis) from all survey sessions combined (June + August + October) at reference (▲) and Ranger mine (▼) sites; ***A****: all beetles;* ***B****: three dominant beetle families, Curculionidae, Elateridae and Tenebrionidae. Based on presence-absence data. ANOSIM R value close to 1 indicates high separation between factors, while R value close to 0 indicates no separation. 2D Stress refers to the level of mismatch between the underlying data and the distances between points in the ordination.*

5. Discussion

The ground-active invertebrate fauna at both reference and Ranger mine sites is overwhelmingly dominated by ants. As to be expected given the young age of the Ranger trial revegetation sites, ant species richness and composition at them is not similar to that in surrounding Kakadu National Park. The differences in species richness occurred across all common functional groups. Many ant species that were abundant at reference sites were absent from the mine sites, and two species were identified as being indicative of mine sites: *Paratrechina longicornis* and *Tetramorium lanuginosum*. The former is an introduced species that occurs throughout northern Australia, but it is only abundant in association with human settlement (Andersen 2000). *Tetramorium lanuginosum* is also a widespread tramp species, but it is native to northern Australia, where it is characteristic of sites of low ant diversity, typically shady habitats with heavy litter (Andersen 2000).

Ants have been used to assess rehabilitation success at mine sites throughout northern Australia (Andersen & Majer 2004), including at Ranger's early revegetation trials established on waste rock in the 1980s (Andersen 1993). These earlier revegetated sites were first colonised by species of *Iridomyrmex*, including *I. sanguineus*, *I. pallidus*, and *Iridomyrmex* sp. 1 (*anceps* gp.), which were all among the most abundant ants at the current revegetation trial sites (as well as reference sites). A broad range of ant species colonised the early trials after two years, but succession soon stalled due to the dominance of fast-growing acacias that had been planted to achieve rapid revegetation, which produced heavy shade and a deep litter layer (Andersen 1993). After eight years only 12 species were recorded (compared with 33–35 at unmined control sites), and the most abundant was the exotic *P. longicornis*. The introduction of fire reduced acacia and litter cover, and substantially enhanced ant recolonization (Andersen 1993). The current revegetation trials do not have the problem of high acacia and litter cover, and this is reflected by the high abundance of thermophilic species of *Iridomyrmex*.

Despite the major differences between mine sites and reference sites in ant species richness and composition, overall ant abundance was similarly high. This indicates that the ecological roles related to levels of ant activity, such as soil development and nutrient cycling, have to a substantial extent been restored. These are critical processes for ongoing ecosystem restoration.

A notable finding of the current study was that differences in ant species richness and composition between reference and mine sites increased with increased survey effort. This is because reference sites contain many uncommon species that require substantial sampling effort to collect, whereas mine sites do not. This has important implications for sampling effort in ongoing monitoring.

We compared compositional differences between reference and mine sites based on all ant species with those based on larger ants only, and with those based only on the ten species contributing most to compositional dissimilarity. Analysis of only larger ants showed high dissimilarity between reference and mine sites, but not as high as when all ant species were considered. Maximum dissimilarity was shown when using just the ten species contributing most to compositional dissimilarity, and so this is the most sensitive measure.

Differences in invertebrate richness and composition between reference and mine sites was also shown by beetles, although the number of beetles collected was low. Numbers of zodariid spiders and mutillid wasps were too low for meaningful analysis.

6. Recommendations and conclusions

The numerical dominance of ants and their strong capacity to discriminate mine sites from reference sites make them an ideal taxon for representing terrestrial invertebrates in ongoing monitoring. Other ground-active invertebrate groups occur in much lower abundance, and even when they are informative (as was the case for beetles), we do not believe that they add sufficient value to be used for ongoing monitoring. Instead, in addition to ants we recommend sampling one or more representative invertebrate taxa from the grass-layer to provide a complementary perspective of ecosystem rehabilitation.

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Appendix 1: List of ant species

Species of ants (Hymenoptera: Formicidae) sampled across all three survey sessions at Ranger Uranium mine and natural reference sites. Functional groups: CS = Cryptic Species; DD = Dominant Dolichoderinae; GM = Generalised Myrmicinae; HCS = Hot-Climate Specialist; O = Opportunist; SC = Subordinate Camponotini; SP = Specialist Predator; TCS = Tropical-Climate Specialist. Larger ant species are indicated with an asterisk, *.

Species	Functional group	Reference							Mine				Total
		2	3	7	8	9	N1	N2	TR	SR	SM	TM	
Dolchoderinae													
Iridomyrmex pallidus	DD	470	97	211	47	547	217	1515	149	437	168	105	3963
*Iridomyrmex sanguineus**	DD	7	664	150	10	472	440	179		353	798		3073
Iridomyrmex sp. 1 (*anceps* gp.)	DD	582		49	147	210	404	763	182	566	610	717	4230
Iridomyrmex sp. 28 (*mjobergi* gp.)	DD	269	258	365	276	141	7			67			1383
Iridomyrmex sp. 35 (*coeruleus* gp.)	DD	1											1
Iridomyrmex tenuiceps	DD					1							1
Ochetellus sp. 1 (*glaber* gp.)	O		1										1
Tapinoma sp. 1 (*minutum* gp.)	O		1	1	3		1						6
Tapinoma sp. 2 (*minutum* gp.)	O				2			3					5
Tapinoma sp. A (*minutum* gp.)	O	2				1					1		4
Dorylinae													
*Lioponera ?brevis**	SP							1					1
Lioponera sp. 4 (*singularis* gp.)*	SP							1					1
Lioponera sp. 8 (*clarki* gp.)*	SP	41					1	1					43
Lioponera sp. 22 (*brevis* gp.) *	SP				1								1
Ectatomminae													
Rhytidoponera nr. *aurata**	O	47	99				5						151
Rhytidoponera nr. *dubia**	O		1										1
*Rhytidoponera reticulata**	O				1		4						5
*Rhytidoponera trachypyx**	O		2	21	4	6		11					44
Rhytidoponera sp. 5 (*reticulata* gp)*	O	18	101	1	86								206
Rhytidoponera sp. 9 (*tenuis* gp)*	O		3			4	27	23					57
Formicinae													
*Camponotus crozieri**	SC			1	1		22	5	3		13	37	82
*Camponotus novaehollandiae**	SC	2	9	8	5	5		19	2	17			67
Camponotus sp. 4 (*pellax* gp.)*	SC		2			1							3
Camponotus sp. 7 (*subnitidus* gp.)*	SC					1							1
Camponotus sp. 8 (*discors* gp.)*	SC		1			1		1					3
Camponotus sp. 9 (*novaehollandiae* gp.)*	SC			1	11						8	1	21
Melophorus postlei	HCS	8	7	122	29	4	17						187
Melophorus sp. 1 (*aeneovirens* gp.)*	HCS	21	15	41	18	33	3	9					140
Melophorus sp. 2 (*aeneovirens* gp.)*	HCS				7	2							9

Melophorus sp. 5 (Group A)	HCS	2					141	2					145
Melophorus sp. 6 (*froggatti* gp.)	HCS			16	9				38	14		2	79
Melophorus sp. 10 (Group D)	HCS	57	21	194	75	60	132	160					699
Melophorus sp. 11 (fieldi gp.)	HCS			64	46	94	35						239
Melophorus sp. 13 (*biroi* gp.)	HCS		1	31	3	60							95
Melophorus sp. 15 (Group J)	HCS			22		11							33
Melophorus sp. 16 (*froggatti* gp.)	HCS	9	8	24			5			1			47
*Oecophylla smaragdina**	TCS			18	25	10	29	1	25	3	1	84	196
*Opisthopsis haddoni**	SC			28	15	5	5	34	4	2	4		97
*Opisthopsis rufoniger**	SC			2				8					10
Opisthopsis sp. 1 (*haddoni* gp.)*	SC			9	2	1		2	2			1	17
Nylanderia sp. 3 (*obscura* gp.)*	O											1	1
Nylanderia sp. 4 (*vaga* gp.)	O				1		2	1			3	6	13
Paraparatrechina sp. 1 (*minutula* gp.)	O							54			1	10	65
Paraparatrechina sp. 2 (*minutula* gp.)	O		117	113	193	21		2					446
Paratrechina longicornis	O		1	1					1864	106	59	73	2104
*Polyrhachis inconspicua**	SC			2			1						3
*Polyrhachis io**	SC			2									2
*Polyrhachis senilis**	SC		4	2	2	1				1			10
Myrmicinae													
Carebara sp. 1	CS										1		1
*Chelaner bifidum**	HCS	1											1
Chelaner sp. 5 (*insolescens* gp)*	HCS						3						3
Chelaner sp. 7 (*insolescens* gp)*	HCS	2											2
Crematogaster queenslandica	GM		2	1	10	10	2						25
Crematogaster sp. 17 (*cornigera* gp.)	GM						1						1
Meranoplus ?aureolus	HCS					1							1
*Meranoplus ajax**	HCS	1	4	1									6
*Meranoplus berrimah**	HCS					2							2
Meranoplus mjobergi	HCS			5	1								6
Meranoplus sp. 8 (Group F)	HCS			1									1
Meranoplus sp. 10 (Group C)	HCS				1		1						2
Meranoplus sp. 14 (*aureolus* gp.)	HCS			1	33								34
Meranoplus sp. 15 (Group C)	HCS				1								1
Monomorium anderseni	GM		3										3
Monomorium disitigerum	GM	37	20	25									82
Monomorium ?donisthorpei	GM		4										4
Monomorium ?fieldi	GM			88	78	1154	168	358	485	535	444	204	3514
*Monomorium topend**	HCS		2			103							105
Monomorium sp. 8 (*carinatum* gp.)	GM	2	1			39	1	13	1				57
Monomorium sp. 9 (*nigrius* gp.)	GM			1	1								2
Monomorium sp. 13 (*nigrius* gp.)	GM			30	176			77		6			289
Monomorium sp. 14 (*nigrius* gp.)	GM			1		29							30
Monomorium sp. 18 (*nigrius* gp.)	GM		34				3		52		66	257	412

Monomorium sp. 23 (*laeve* gp.)	GM	6				36	1				2		45
Monomorium sp. 24 (*laeve* gp.)	GM	1	6	181			2	60	188				438
Monomorium sp. 28 (*carinatum* gp.)	GM			34	1								35
Monomorium sp. 32 (*laeve* gp.)	GM	1	1	2	29	35	3	14		4	39	187	315
Monomorium sp. 33 (*laeve* gp.)	GM		78		27								105
Monomorium sp. 37 (*nigrius* gp.)	GM	16	2			9	2	103					132
Monomorium sp. 46 (*laeve* gp.)	GM				1								1
Monomorium sp. E (*nigrius* gp.)	GM					134		25					159
Monomorium sp. L (nr.*disitigerum*)	GM					3							3
Monomorium sp. M (*carinatum* gp.)	GM	1											1
Pheidole sp. 3 (*variabilis* gp.)	GM	10	6	1	47	11	1						76
Pheidole sp. 9 (Group B)	GM	1		1	1				2				5
Pheidole sp. 13 (*ampla* gp.)	GM		15	3	4	12							34
Pheidole sp. 20 (Group A)	GM				1	8	2						11
Pheidole sp. 35 (Group E)	GM						1						1
Pheidole sp. H (Group A)	GM					1		1					2
Solenopsis sp. A	CS					20	2					1	23
Solenopsis sp. 2	CS	2											2
Solenopsis sp. C	CS			1	32	2		2					37
Solenopsis sp. D	CS	3			13								16
Solenopsis sp. E	CS			5									5
Tetramorium lanuginosum	O								35		3	16	54
Tetramorium nr. *sjostedti**	O			5	1	1							7
Tetramorium sp. 1 (*striolatum* gp)	O	1	4	5									10
Tetramorium sp. 2 (*striolatum* gp.)	O	7		2			3	1					13
Tetramorium sp. 5 (*spininode* gp)*	O			2	4	10	16						32
Tetramorium sp. C (*striolatum* gp)	O				1								1
Tetramorium sp. 36 (*striolatum* gp)	O						6	1					7
Tetramorium sp. 16 (*spininode* gp)*	O		1										1
Tetramorium sp. H (*striolatum* gp)	O					1							1
Ponerinae													
*Anochectus rectangularis**	SP			1						1	3	7	12
Hypoponera sp. 1	CS				4								4
Hypoponera sp. 2	CS							3					3
*Leptogenys exigua**	SP	23				3							26
Odontomachus nr. *turneri**	O	4	20				11	2					37
Pseudoneoponera sp. 7 (*sublaevis* gp.)*	SP	1											1

Appendix 2: List of beetle, wasp and spider species

Species of beetles (Coleoptera), mutilid wasps (Hymenoptera) and zodariid spiders (Araneae) sampled across all three survey sessions at Ranger Uranium mine and natural reference sites.

Species	Reference							Mine				Total
	2	3	7	8	9	N1	N2	TR	SR	SM	TM	
COLEOPTERA												
Anthicidae												
Anthicus sp. A										1		1
Carabidae												
Harparlinae *Phorticosomus* sp. B												0
Harparlinae *Phorticosomus* sp. C						1						1
Harparlinae *Phorticosomus* sp. D					1							1
Chyrsomelidae												
Cryptocephalinae *Clytrini* sp. A			1									1
Curculionidae												
Entiminae Gen. nov. sp. C			1	1								2
Entiminae Gen. nov. sp. D				6	1							7
Molytinae Cryptorhynchini sp. A	1	1										2
Molytinae Cryptorhynchini sp. B		2		1								3
Molytinae Cryptorhynchini sp. F					1							1
Scolytinae *Xyleborus* sp. E					1				1			2
Elateridae												
Pyrophorinae *Agryptus* sp. A	3		1		1							5
Pyrophorinae *Agryptus* sp. B		1	1		2	1						5
Pyrophorinae *Agryptus* sp. D						1						1
Pyrophorinae *Conoderus* sp. C										3	1	4
Pyrophorinae *Conoderus* sp. F									1			1
Melyridae												
Gen. indet. sp. A			1									1
Nitidulidae												
Gen. indet. sp. B	1											1
Ptinidae												
Ptininane Ectrephini *Diplocotes* sp. A							1					1
Ptininane Ectrephini *Diplocotes* sp. D									2			2
Ptininane Ectrephini *Diplocotes* sp. F							4					4
Ptininane Ectrephini *Polyplocotes* sp. B	1		1				1					3
Ptininane Ectrephini *Polyplocotes* sp. C				1								1
Ptininane Ectrephini *Polyplocotes* sp. E				1								1
Scarabaeidae												
Melolonthinae *Cholpochila* sp. A	1											1

Melolonthinae *Hetronyx* sp. B					1						1
Melolonthinae *Liparetrus* sp. C							1				1
Staphylinidae											
Staphylininae *Eupines?* sp. A			1								1
Tenebrionidae											
Diaperinae *Ectyche bicolor*	5	6	1	1	4	4	2				23
Pimeliinae *Thorictosoma* sp. B			1	8	2						11
Tenebrioninae *Caedius* sp. A	2			1							3
Tenebrioninae *Palorus* sp. C				1					1	1	3
Tenebrioninae *Sobas* sp. E		1									1
HYMENOPTERA											
Mutilidae											
Mutilinae *Trogaspidia?* sp. B								1			1
Mutilinae *Trogaspidia?* sp. D											0
Sphaeropthalminae *Australotilla* sp. C	1										1
Sphaeropthalminae *Ephutomorpha* sp. A					2				1		3
Sphaeropthalminae *Ephutomorpha* sp. E			1								1
Sphaeropthalminae *Ephutomorpha* sp. F			1								1
Sphaeropthalminae *Ephutomorpha* sp. G		1									1
ARANEAE											
Zodariidae											
Habronestes sp. A										1	1
Habronestes sp. B		1		2		1	2				6
Habronestes sp. C											0
Habronestes sp. D			1								1
Habronestes sp. E											0
Habronestes sp. F	1										1
Masasteron? sp. C						1					1
Masasteron? sp. G				1							1
Gen. indet. sp. E											0

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