PART C

INFLUENCE OF ANTS ON MINESITE RESTORATION

7 Seed-harvesting by ants

7.1 Introduction

Harvester ants, well-known as important granivores in desert ecosystems of the world (Brown et al 1979, Abramsky 1983), are the major post-dispersal seed predators throughout Australia. Although most ants do not eat seeds, harvester species occur in virtually all plant communities, often removing substantial proportions of seed crops (Andersen 1991b). A wide variety of seeds are affected, including grasses, forbs, many myrtaceous shrubs and most eucalypts (Ashton 1979, Briese & Macauley 1981, Andersen & Ashton 1985).

Harvester ants are particularly abundant and diverse in the Kakadu region, with up to 20 species occurring at a single site (Andersen & Lonsdale 1990). These include omnivorous species of *Monomorium* and *Pheidole* which opportunistically eat a variety of plant seeds along with insect material, as well as highly specialised species of *Meranoplus* (*diversus* group) which feed exclusively on the seeds of one or a few plant (mostly grass) species (Andrew 1986). In addition to their influence on the dynamics of native plant communities, harvester ants obviously play a potentially important role in revegetation following anthropogenic disturbance (Majer 1990, Hoffmann et al 1995). The experience elsewhere in Australia is that severely disturbed habitats are frequently colonised by high densities of *Pheidole* species, leading to extremely high rates of seed-removal and often failure of improved pastures (Andersen 1990b).

This chapter examines the distribution of harvester ants and their rates of harvesting at the study sites. A comparison of revegetated waste rock sites with disturbed and native sites will reveal if seed-removal by ants is likely to be a significant impediment to successful revegetation.

7.2 Methods

Rates of removal obviously vary with plant species and the approach here was to use seeds of a single species to provide standardised results for meaningful site comparisons. *Eucalyptus tetrodonta*, a dominant tree widely distributed in the region, was selected for this purpose. Due to the generalised feeding habits of the ants likely to eat *E. tetrodonta* seeds (ie species of *Monomorium* and *Pheidole*), the results are likely to provide a general index of harvesting rates for site comparisons.

Rates of removal of *E. tetrodonta* seeds were measured at each site during November 1992 and November 1993. November is the time of seed fall and therefore natural availability of *E. tetrodonta* seeds. The results of pitfall trapping during each of these periods (section 3.1) were used as measures of the abundance of *Monomorium* (only species of the *rothsteini* and other groups previously referred to as *Chelaner*, as other species of *Monomorium* do not eat seeds (Andersen 1991b) and *Pheidole* species. The position of each pitfall trap was used to define the location of four baiting stations, which were spaced equidistantly around an imaginary circle of 0.5 m radius centred on the trap, giving a total of 60 stations per site. Each station was a thumb-print sized depression in the soil, located within a small (5 cm diameter) clearing in the surface litter, and sprinkled with white sand to aid seed re-location. A single seed was placed at each station immediately after pitfall traps were set and its presence or absence recorded after 48 hours, just before pitfall traps were collected. Baits and traps were operated simultaneously in order to provide directly comparable results.

Missing seeds were assumed to have been removed by harvester ants (or other granivores). In order to control for any movement of seeds by wind or rain, the removal of plastic beads (2 mm diameter, approximately the same size as *E. tetrodonta* seeds) was simultaneously monitored from 24 other baiting stations (12 only during 1992), located between each pair of adjacent pitfall traps on each of the three trapping lines. These stations were identical to those previously described, except that a bead rather than seed was placed at them. The beads had been sprayed with insect repellent in order to deter ants from removing them, which is why they were located separately from the stations with seeds. It was originally envisaged that the rate of disappearance of beads subtracted from the rate of disappearance of seeds would provide a more reliable measure of actual seed-removal by ants. However, on several occasions the ubiquitous northern meat ant *Iridomyrmex sanguineus* was observed removing beads, thereby calling into question the reliability of beads as 'controls'. Therefore, both measures of seed-removal (seed disappearance both before and after subtraction of bead disappearance) were used in analyses.

On a small number of occasions seeds were found to be eaten-out, but not removed. This might have been caused by ants too small to remove the seeds, or possibly by other insects such as gryllid crickets. Such seeds were not counted as missing.

An experiment was established at sites D2 and D3 during early December 1992 in order to: first, document cumulative rates of removal over a longer time period, and second, study the impact of seed harvesting on seedling recruitment. Ants were eliminated from plots within these sites by insecticidal (chlorpyrifos) treatment, with the aim of monitoring the fate of seeds placed at depots. Unfortunately the experiment was washed out by a severe storm soon after it was established and had to be abandoned.

7.3 Results

In 1992, rates of seed disappearance averaged 27% (range 0–48%) at natural sites, 26% (5–45%) at disturbed sites and only 6% (2–17%) at waste rock sites (table 7.1). In 1993, these figures were 32% (10–73%), 28% (13–52%) and 14% (2–35%) respectively. Although average rates of disappearance were similar between years, rates were highly variable between years at individual sites. For example, the highest recorded rate was 73% at N5 in 1993, yet only 15% of seeds disappeared from that site in 1992 (table 7.1). Indeed, disappearance rates at individual sites were not significantly correlated between years ($r = 0.238$, $p>0.05$). Few or no beads disappeared at most sites, but substantial numbers (up to 50%) were missing at some, resulting in a variable difference between seed disappearance rates and adjusted removal rates (table 7.1). However, both measures indicated that average removal rates were similar at natural and disturbed sites, but far lower at waste rock sites. This pattern was consistent between years (table 7.1). Adjusted removal rates at individual sites were also not correlated between years ($r = 0.173$, $p>0.05$).

Four harvesting species of *Monomorium* and 17 species of *Pheidole* were recorded during the study (appendix 1), with their distribution and abundance varying widely across sites. No species were recorded at all at sites N5, N12, N20 and W6, and only a single species (*Pheidole* sp. 3) was recorded at any waste rock site. There was a variable relationship between harvester ant abundance and rates of seed removal. For example, there was negligible seed-removal at sites N12, N20 and W6, but removal was extremely high at N5 during 1993 despite no harvester ants being recorded.

Table 7.1 Rates of removal (R = unadjusted; R' = adjusted for bead removal) of *Eucalyptus tetrodonta* seeds from baiting stations and abundance of harvester ants (species of *Monomorium* and *Pheidole*) in pitfall traps, during 1992 and 1993

	1992					**1993**				
	Harvesting rate (%)		Ant Abundance			**Harvesting rate (%)**		Ant Abundance		
	R	R'	*Mono*	*Pheid*	Total	R	R'	*Mono*	*Pheid*	Total
N1	18	10		3	3	45	32		3	3
N2	50	42		4	4	18	14	4	11	15
N3	20	20		3	3	23	23			0
N4	47	47		6	6	62	62		27	27
N5	15	15			0	73	65			0
N6	0	0		1	1	30	30		2	2
N7	13	5		1	1	33	25		3	3
N8	28	11		8	8	17	9		5	5
N9	30	30		5	5	48	48		1	1
N10	22	5		15	15	33	33		7	7
N11	nd	nd	nd	nd	nd	20	20		10	10
N12	32	0			0	17	0			0
N13	35	27		13	13	15	0			0
N14	47	22	1	47	48	13	5		7	7
N15	12	4		3	3	30	13			0
N16	23	23	1	6	7	28	15		4	4
N17	18	18		12	12	nd	nd		6	6
N18	nd	nd			0	38	38		11	11
N19	48	6	52	19	71	60	47	16	10	26
N20	8	0		2	2	13	0			0
N21	30	22		1	1	10	10			0
N22	48	40	5	25	30	38	13	13	2	15
mean	27.2	17.4	3.0	8.7	11.7	31.6	23.9	1.6	5.2	6.8
D1	45	0	3	29	32	22	22	1		1
D2	13	13	4	8	12	22	22	2	4	6
D3	42	42		1	1	45	41		6	6
D4	28	0	7	12	19	52	48	3	12	15
D5	5	5		9	9	40	40		6	6
D6	18	18		1	1	23	23		2	2
D7	23	23			0	13	5		4	4
D8	22	14		8	8	22	5		2	2
D9	30	22	2	11	13	18	18	2	2	4
D10	35	18	13		13	18	18	5	1	6
mean	26.1	15.5	2.9	7.9	10.8	27.5	24.2	1.3	3.9	5.2

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Table 7.1 Cont'd

	1992					1993				
	Harvesting rate (%)		Ant Abundance			**Harvesting rate (%)**		Ant Abundance		
	R	**R'**	*Mono*	*Pheid*	Total	**R**	**R'**	*Mono*	*Pheid*	Total
W1	2	0		10	10	15	15		26	26
W2	7	0		1	1	10	10		4	4
W3	7	7		4	4	27	27		21	21
W4	3	3			0	35	35		8	8
W5	17	9		3	3	5	5		2	2
W6	3	3			0	2	0			0
W7	2	2			0	5	5			0
mean	5.9	3.4	0.0	2.6	2.6	14.1	13.9	0.0	8.7	8.7

Overall, the abundance of harvester ants in traps explained 29% of the variance in rates of seed disappearance in 1992, and 22% in 1993 (table 7.2, fig 7.1). Harvester ant abundance tended to be more strongly correlated with seed disappearance than with adjusted removal rates, particularly during 1992 (table 7.2), confirming the suspicion that bead removal was an unreliable control for removal by rain or wind. Rates of removal were more strongly correlated with the abundance of *Pheidole* than *Monomorium* species (table 7.2), indicating that the former were the more important harvesters. Total harvester ant abundances in 1992 and 1993 were only weakly correlated with each other ($r^2 = 0.18$, $p<0.005$).

Table 7.2 Relationships between rates of seed-removal and abundance of harvester ants (species of *Monomorium* and *Pheidole*; results from pitfall traps)[Ψ]

		1992	**1993**
Monomorium	R	0.12*	0.07
	R'	0.02	0.01
Pheidole	R	0.25**	0.17**
	R'	0.01	0.24**
TOTAL	R	0.29**	0.22**
	R'	0.01	0.20**

[Ψ] Two measures of removal are used, unadjusted disappearance rate (R) and disappearance rate adjusted for bead disappearance (R'), see section 7.2 for details. Data are r^2 values from correlation analyses (* $p<0.05$ ** $p<0.005$). Results from waste rock sites are not included.

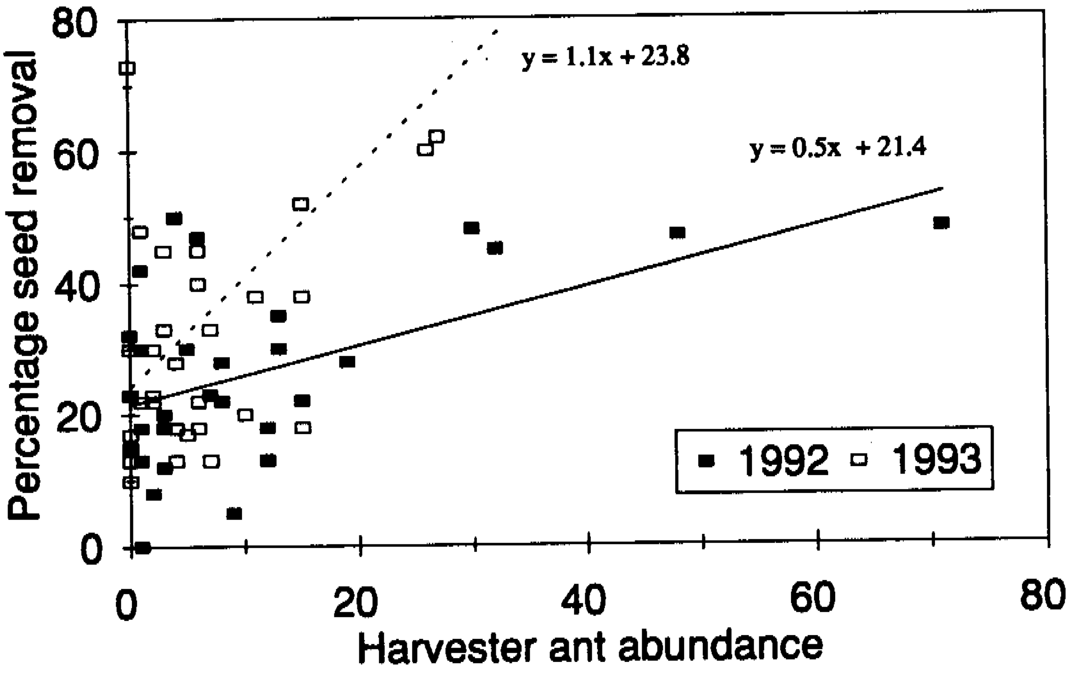

Figure 7.1 Relationships between harvester ant abundance and rates of seed removal during 1992 and 1993

8 Seed dispersal by ants

8.1 Introduction

Myrmecochory is a prominent dispersal syndrome in many habitats throughout the world (Beattie 1983), but is particularly important in sclerophyll vegetation of nutrient-poor soils in Australia (Berg 1975, 1981, Rice & Westoby 1981) and South Africa (Milewski & Bond 1982, Bond & Slingsby 1984). Overseas studies indicate that seed removal by ants has two major benefits for plants: avoidance of seed-predation by rodents (O'Dowd & Hay 1980, Heithaus 1981, Bond & Breytenbach 1985), and dispersal to nutrient-enriched microsites associated with ant nests (Culver & Beattie 1978, Beattie & Culver 1983).

However, the advantages of myrmecochory as a dispersal syndrome in Australian environments are unclear. Predator-avoidance is unlikely, given Australia's generally depauperate fauna of granivorous rodents (Morton 1985), and the fact that ants themselves are the major postdispersal seed predators in most habitats (chapter 9). The suggestion that removal by non-granivorous ants reduces predation by granivorous species (Hughes & Westoby 1992) now appears to be incorrect (L Rogerson, pers comm 1994). Moreover, the observation that elaiosomes of Australian myrmecochores are typically firm and persistent, in contrast to those overseas (Berg 1975), suggests that there is no requirement for rapid removal of seeds from the ground (Westoby et al 1982). Nutrient-enrichment has been shown to be a potential benefit in some cases (Davidson & Morton 1981a,b, Andersen 1988b), but this is not generally so (Westoby et al 1982, Rice & Westoby 1986). Many seed-dispersing ants do not maintain discrete nest middens which can act as sites of nutrient-enrichment (Andersen 1988b), and frequent nest relocation often prevents significant enrichment anyway (Hughes 1991).

There is increasing evidence that dispersal distance *per se* might be an important benefit of myrmecochory in Australia. The benefit is not so much related to spreading into new territory (eg Harper 1977, 54), but to locating 'safe' sites for recruitment within established populations (Andersen 1988a). Although mean dispersal distances generated by ants are typically only 1–2 m (Hughes et al 1994), this might be sufficient to reduce parent-offspring conflict (Westoby et al 1982). Moreover, the shape of dispersal curves generated by ants is potentially a more important factor than simply mean dispersal distance (Andersen 1988a). Such curves tend to have a narrow peak (usually at 1–2 m) and long 'tail' (usually extending over 10 m), which is the optimal shape for distance dispersal when 'safe' sites for seedling recruitment are rare (Green 1983). It is also at a scale appropriate for local variation in microsite suitability for seedling establishment (Antonovics et al 1987).

This chapter examines the effect of disturbance on seed dispersal by ants and the extent to which the ant-seed relationship has re-established at rehabilitated (waste rock) sites. It describes rates of removal by the ant species involved, and the dispersal curves generated by them.

8.2 Methods

Myrmecochory is a very generalised relationship between ants and seeds—the seeds of myrmecochores are removed by a suite of omnivorous ants with little or no species specificity (Berg 1975). For example, studies of two myrmecochores in the Sydney region showed that seed species accounted for only 4% of variation in removal rates (Hughes & Westoby 1990). Distance dispersal curves generated by myrmecochory are therefore characteristic of the local site (ie ant species present) rather than being peculiar to any particular seed species under investigation. Studies of a single seed species can therefore be used to characterise the general ant-seed relationship at any site (Andersen 1988a). The seed species used for such purpose in this study was *Acacia holosericea*, which is widely distributed naturally in northern Australia (Brock 1988) and is used extensively in revegetation programs throughout the region.

The methodology for identifying ant species responsible for removal, and the dispersal curves generated by them, followed Andersen (1988a). Seed depots were located in two 6 × 6 grids with 2 m spacing, located immediately adjacent (on opposite sides) to each of the ten representative sites, during the 1993 Dry season.

The fate of seeds placed at depots was monitored during three 3 hour sessions: morning (0730–1030 hrs), afternoon (1500–1800 hrs) and night (2000–2300 hrs). Observations were not made during the middle of the day, when temperatures were high (>30°C) and there was little ant activity. At the beginning of each session, one seed was placed at each depot. Ant species removing seeds were recorded, their nests mapped, and the dispersal distances (displacements) measured. These measurements were used to generate myrmecochorous dispersal curves. Any other interactions between ants and seeds were noted. If seed removal occurred but was not observed, then the seed was replaced.

8.3 Results

The removal of seeds from depots to ant nests is illustrated for each plot in appendix 10. On numerous occasions ants (particularly *Monomorium* spp.), and occasionally gryllid crickets, cockroaches and tenebrionid beetles, were observed feeding on arils *in situ*, often eating the entire aril (appendix 11). Such seeds were replaced, but not counted as removed. At plot N4b a gryllid cricket was observed removing a seed 50 cm into its nest (a simple hole in the ground), and an unidentified spider removed a seed at plot D6a. Otherwise ants were the only observed agents of removal.

Removal rates (over 3 hrs) averaged 29% over all sites, ranging from 15% at N11b to 52% at W4b (table 8.1). There was often substantial variation between the two plots at a single site (eg 17% and 47% at N6, 19% and 52% at W4). Removal rates were highest (35%) during the morning and lowest (23%) at night.

Ants were observed removing seeds in 25% of the above cases (154 records). A total of 22 species were observed removing seeds (table 8.2), the most common being *Rhytidoponera aurata* (53 records), *Monomorium (rothsteini* gp) sp. 1 (14), *Iridomyrmex sanguineus* (13), *Iridomyrmex* sp. 14 (12) and *Pheidole* sp. 3 (10). These four species were responsible for 66% of all observed removals.

Dispersal distances varied markedly between ant species (table 8.2). *Iridomyrmex sanguineus* had both the highest mean (7.25 m) and maximum (13.08 m) dispersal distances. *Rhytidoponera aurata*, *R.* (*turneri* gp) sp. 3 and *Monomorium* (*rothsteini* gp) sp. 1 also had high (>3.5 m) mean dispersal distances. Species of *Pheidole* typically dispersed seeds less than 0.5 m, whereas *Meranoplus*, *Monomorium* and *Tetramorium* spp only moved seeds a few centimetres.

Table 8.1 Total numbers of *Acacia holosericea* seeds removed in myrmecochory trials during mornings (M), afternoons (A) and nights (N). Ants were directly observed removing seeds in only 25% of these cases (see table 8.2).

				TOTALS	
	M	**A (n=36)**	**N**	**Plot (n=108)**	**Site (n=216)**
N4a	22	15	5	42	
N4b	15	8	10	33	75
N6a	24	17	10	51	
N6b	5	10	3	18	69
N11a	5	3	10	18	
N11b	11	3	2	16	34
N14a	20	11	11	42	
N14b	18	9	7	34	76
D1a	11	0	14	25	
D1b	2	10	6	18	43
D2a	10	10	2	22	
D2b	10	13	11	34	56
D3a	6	8	5	19	
D3b	19	21	11	51	70
D6a	20	19	10	49	
D6b	4	10	8	22	71
W3a	12	10	6	28	
W3b	9	7	12	28	56
W4a	4	3	13	20	
W4b	25	19	12	56	76
TOTAL	252	206	164	626	626

The overall dispersal curve generated by ants was a logarithmic decay function (fig 8.1), with 30% of all observed removals involving distances less than 0.5 m and the mean dispersal distance being 2.61 m.

Different ant taxa generated markedly different dispersal curves (fig 8.2), including humped (eg *Rhytidoponera aurata*; fig 8.2c), positively skewed (eg *Iridomyrmex sanguineus*; fig 8.2f) and negatively skewed (eg *Monomorium* (*rothsteini* gp) sp. 1; fig 8.2e) patterns. The dispersal curves characteristic of each site also varied markedly (fig 8.3), due to the different composition of seed-dispersing ants (table 8.2). The curve was strongly skewed for natural sites, relatively uniform for disturbed sites and at waste rock sites all observed removals involved distances less than 0.5 m. The mean dispersal distance at disturbed sites (3.91 m) was significantly higher than at natural sites (2.19 m; $t = 3.724$, $df = 132$, $p < 0.001$), and was extremely low (17 cm) at waste rock sites.

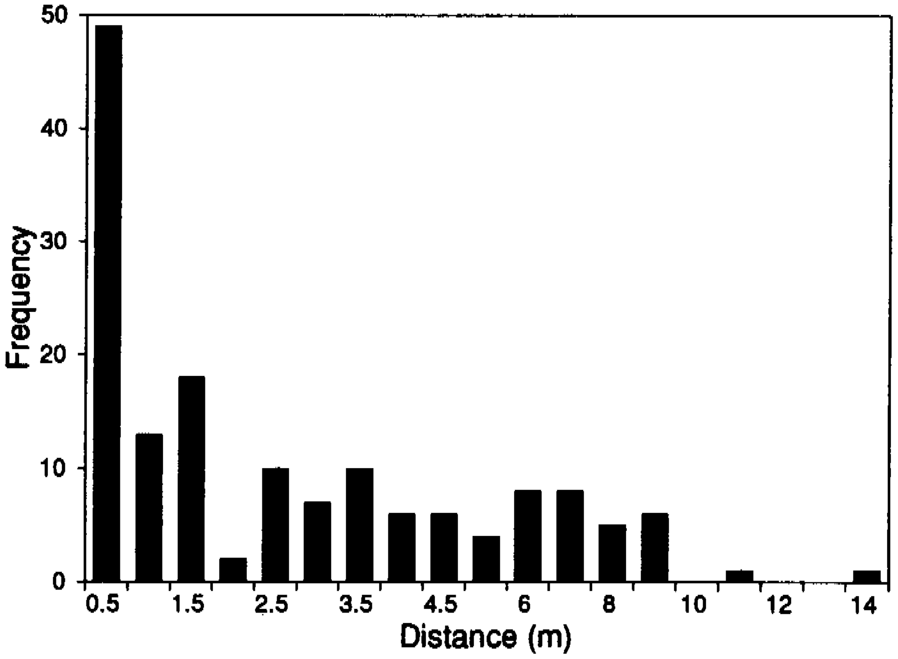

Figure 8.1 Overall dispersal curve generated by ants during myrmecochory trials (data pooled across all ant species and all sites)

Table 8.2 Ant species observed removing Acacia seeds during myrmecochory trials and the distances moved by them. The number of observed removals are given for each site (pooled over time periods) as well as time period (pooled over sites: M = morning, A = afternoon, N = night).

	Number of observed removals														**Distance removed (m)**	
	N4	**N6**	**N11**	**N14**	**D1**	**D2**	**D3**	**D6**	**W3**	**W4**	**M**	**A**	**N**	**TOTAL**	**Mean**	**Max**
PONERINAE																
Bothroponera sp. 3		1										1		1	1.30	1.30
Rhytidoponera aurata	15	7		11	2		18				34	14	5	53	3.48	8.58
R. reticulata								2				1	1	2	1.27	2.03
R. trachypyx	7						1				4	4		8	0.65	2.36
R. (turneri gp) sp. 3	5					2					2		5	7	3.83	6.25
R. (tenuis gp) sp. 9	1							2			1	2		3	1.11	1.54
MYRMICINAE																
Meranoplus sp. 4		1											1	1	0.06	0.06
Monomorium sp. 11				1							1			1	0.02	0.02
Monomorium sp. 17		1			1							2		2	0.03	0.05
M. (rothsteini gp) sp. 1						11		3			3	11		14	3.93	8.70
Pheidole sp. 1								1			1			1	0.02	0.02
Pheidole sp. 3									4	6	5	3	2	10	0.25	0.45
Pheidole sp. 8							1				1			1	0.10	0.10
Pheidole sp. 13	4	1					1	2			4	2	2	8	0.33	0.67
Tetramorium sp. 1									3		2	1		3	0.02	0.02
T. lanuginosum		1							6		5	2		7	0.14	0.39

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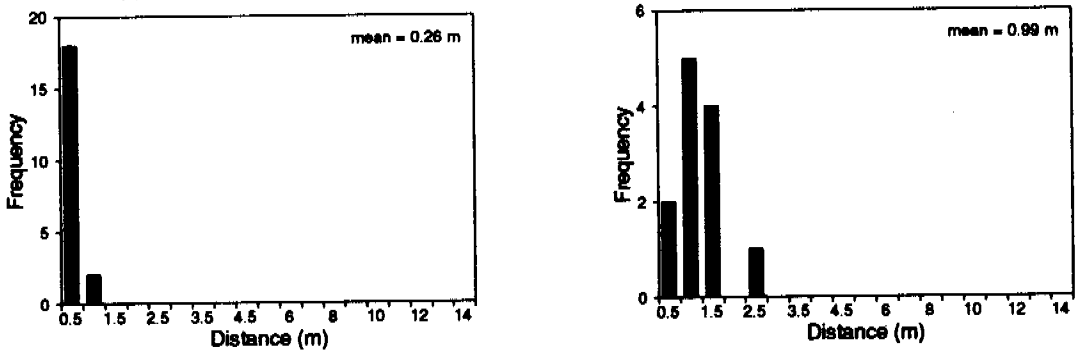
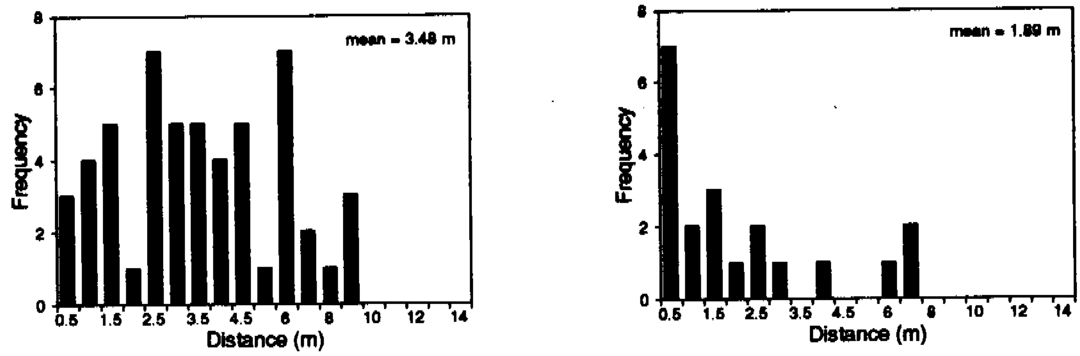
Table 8.2 Cont'd

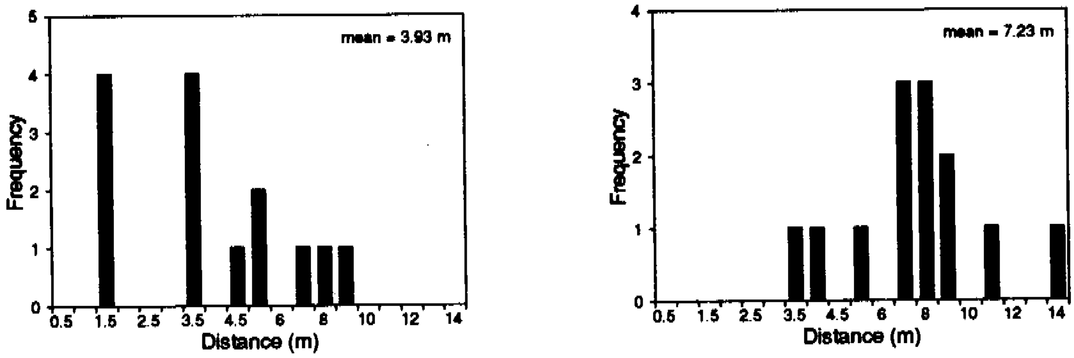
	Number of observed removals														Distance removed (m)	
	N4	N6	N11	N14	D1	D2	D3	D6	W3	W4	M	A	N	TOTAL	Mean	Max
DOLICHODERINAE																
Iridomyrmex sp. 2			1								1			1	0.36	0.36
Iridomyrmex sp. 14	2			8			2				6	5	1	12	0.99	2.35
I. sanguineus		4				6	1	2			8	5		13	7.23	13.08
Papyrius sp. 1			4								1	2	1	4	0.48	1.10
FORMICINAE																
Oecophylla smaragdina			1								1			1	2.87	2.87
Paratrechina longicornis									1			1		1	0.45	0.45
TOTAL	34	16	6	20	3	19	24	12	14	6	80	56	16	154	2.57	13.08


(a) *Pheidole* spp

(b) *Iridomyrmex* sp. 14


(c) *Rhytidoponera aurata*

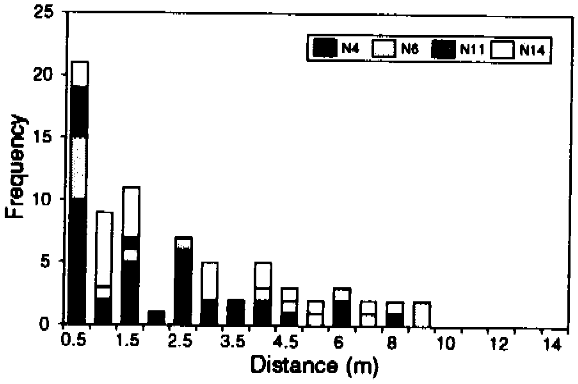
(d) other *Rhytidoponera*


(e) *Monomorium (rothsteini)* sp. 1

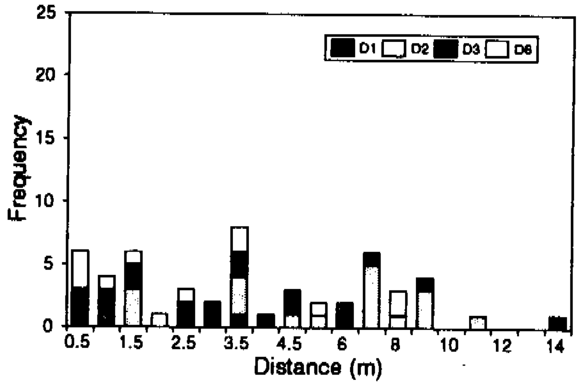
(f) *Iridomyrmex sanguineus*

Figure 8.2 Dispersal curves generated by different ant taxa (data pooled across sites)

(a) Natural sites



(b) Disturbed sites



(c) Waste rock sites

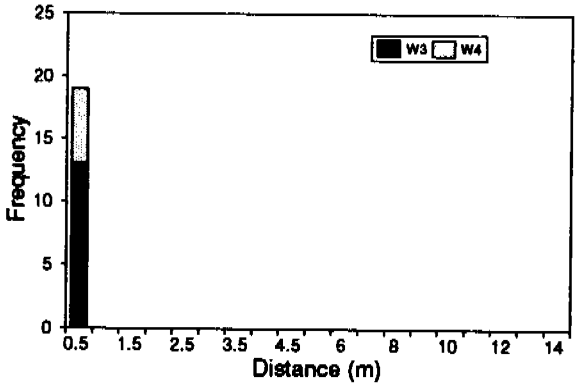


Figure 8.3 Dispersal curves generated by ants at different sites (data pooled across ant species)

9 Conclusion

9.1 Ants as bioindicators

This study represents the first systematic test of the reliability of ants as indicators of the general environment in which they occur. The overwhelming conclusion is that ants are remarkably good bioindicators in the Alligator Rivers Region.

First, ant communities have close habitat relationships, with ant species richness highly correlated with plant species richness (fig 3.1), and ant community composition highly correlated with plant species composition (table 3.3). Indeed, ant species composition is far more strongly correlated with plant species composition than are any of the invertebrate assemblages or other insect communities sampled (table 9.1).

Table 9.1 Correlation coefficients (r) between association matrices based on invertebrates and those on plant species*

	Plant species (all)	Plant species (woody only)
Ant species-abundance (39)	0.638	0.665
Ant genus-abundance (39)	0.568	0.626
Ant genus-species (39)	0.590	0.643
Ant functional group-abundance (39)	0.495	0.539
Ant functional group-species (39)	0.492	0.556
Soil invertebrates (10)	0.231	0.340
Ground invertebrates (39)	0.284	0.360
Ground-vegetation invertebrates (31)	0.467	0.442
Beetles (31)	0.568	0.570
Grasshoppers (27)	0.427	0.357
Termites (39)	0.318	0.208

* Numbers of sites are given in parentheses

Second, ant community composition is highly correlated with the composition of ground-foraging invertebrates and, especially, invertebrates on ground vegetation (table 4.4). The correlation with the general soil invertebrate fauna is much poorer, but this may have been influenced by low sample size (only 10 sites sampled).

Third, ant community composition is highly correlated with the composition of beetle, grasshopper and, to a lesser extent, termite species (table 5.2). Ant species richness is also highly correlated with the species richness of beetles and termites, but not grasshoppers (figs 5.1–5.3).

Finally, ant species richness is correlated with soil microbial activity (fig 6.2). In the context of ecosystem restoration following disturbance, it is noteworthy that this correlation is particularly high at disturbed and waste rock sites (fig 6.2b).

9.2 Rapid assessment using functional groups

Ant functional groups have formed the basis of a predictive understanding of the responses of ant communities to stress and disturbance (Andersen 1995a), and it has been suggested that, in the context of biological monitoring, ant composition at the functional group level provides a reliable measure of ecological change (Andersen 1990b, 1993a). Targetting functional group abundance would greatly simplify ant monitoring programs, as specimens would need only be sorted to genus. As well as saving a considerable amount of time, this would circumvent the problem of poor species-level taxonomy of Australian ants, and the frequent co-occurrence of numerous, morphologically similar, congeneric species (Andersen 1995b). It is therefore important to examine the performance of ants as bioindicators when considered at the functional group level, rather than at the species level. Such a comparison is presented in table 9.2.

Table 9.2 Reliability of ant communities as biological indicators when considered at the functional group compared with species level*

	Ant species abundance	Ant functional group abundance
Total plant species	0.638	0.495
Woody plant species	0.665	0.539
Soil invertebrates	0.194	0.220
Ground-foraging invertebrates	0.341	0.323
Invertebrates of ground vegetation	0.471	0.675
Beetles	0.533	0.426
Grasshoppers	0.412	0.454
Termites	0.185	0.233

* Data are correlation coeffients comparing Bray-Curtis association matrices

Functional groups give a lower correlation with floristic composition than do ant species, but the correlation is still very high. Moreover, it is generally higher than those provided by invertebrate assemblages and other insect species (table 9.1). In terms of providing an indication of the composition of other invertebrate assemblages, ant functional groups perform similarly, and in one case (invertebrates of ground vegetation) markedly better, than do ant species.

These results strongly support the use of functional groups in ant monitoring programs. Site classification based on ant functional groups (fig 9.1) produce site groupings based on clear differences in ant composition (table 9.3).

9.3 Influence of ants on minesite restoration

A secondary aim of this study was to investigate the potential influence of ants, through their interactions with seeds, on minesite restoration. The experience from elsewhere in Australia, where severe disturbance often leads to increased rates of seed harvesting by ants (Andersen 1990b), does not appear to apply in the Ranger uranium mine region. There was no evidence of disturbance leading to a proliferation of harvesting species of *Pheidole*. Rates of seed harvesting by ants at disturbed sites were similar to those at natural sites, and were substantially lower at waste rock sites (table 7.1). It is therefore concluded that harvester ants do not pose a serious threat to revegetation following mining.

Disturbance was shown to have a marked effect on seed dispersal by ants, primarily through its influence on the distribution and abundance of ant species. In particular, normal patterns of distance dispersal by ants have failed totally to establish at rehabilitated sites, where no seeds were transported more than 50 cm. However, the influence of this on seedling establishment is unknown.

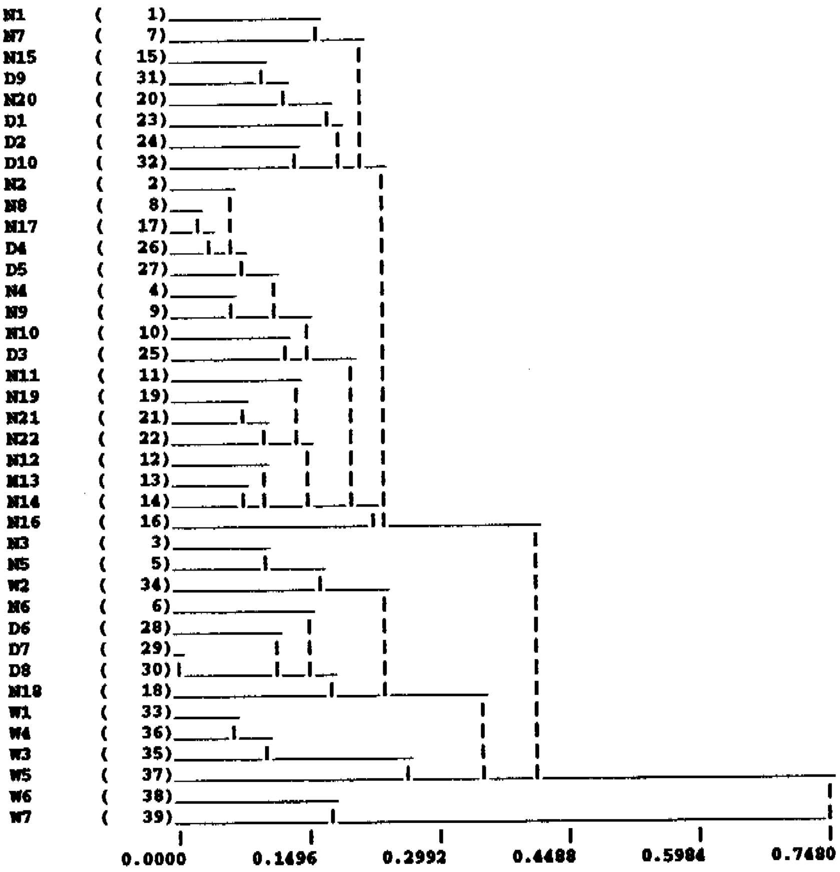


Figure 9.1 Dendrogram illustrating classification of study sites, using flexible UPMGA, based on the abundance of ant functional groups

Table 9.3 Key to site groups produced by flexible UPMGA of functional group-abundance data (fig 9.1)*

HCS abundant (total ant abundance often >400)	DD abundant (>50)	Total ant abundance <250		**1**	N1, N7
		Total ant abundance 250–500	'Others' absent or nearly so	**2**	N15, N20, D1, D2, D9, D10
			'Others' reasonably well-represented	**3**	N2, N4, N8, N9, N10, N17, D3, D4, D5
		Total ant abundance >500		**4**	N11, N12, N13, N14, N19, N21, N22
	DD not abundant (<50)			**5**	N16
HCS not abundant (total ant abundance always <400)	GM abundant	DD abundant	DD, O and GM the only ants present	**6**	N3, N5, W2
			other functional groups present	**7**	N6, N18, D6, D7, D8
		DD not abundant (GM + O >80% total ants)	O<50% total ants	**8**	W1, W3, W4
			O>50% total ants	**9**	W5
	GM absent (all ants DD or O)			**10**	W6, W7

* Functional group abbreviations (from figure 3.2) are: DD = Dominant Dolichoderinae; SC = Subordinate Camponotinae; HCS = Hot Climate Specialists; O = Opportunists; GM = Generalized Myrmicinae

9.4 Recommendations

This study has two major findings. First, ant communities in the Ranger uranium mine region provide a very good indication of the general state of the ecosystems in which they occur. In particular, they reflect the responses of a wide variety of other invertebrates to ecological change. Second, the indicator performance of ants at the functional group level is in most cases comparable, and sometimes superior, to that at the species level.

It is therefore recommended that ants be included in the biological monitoring of restoration programs following mining in the region. Ideally, ant communities should be analysed at both the species and functional group levels, as this would provide information on both species richness and community composition. However, the use of functional groups alone would be a legitimate, cost-effective measure.

The following sampling protocol is recommended. Pitfall traps are a simple and reliable means of providing standardised, quantitative information on ant species richness and community composition (Andersen 1991c), and are therefore ideal for biological monitoring programs. The trapping protocol used in this study (4 cm diameter traps arranged in a 5 x 3 grid with 10 m spacing, and operated for 48 hour periods) is recommended, as it has been proven to be effective throughout northern Australia (eg Andersen 1993a, 1993b). Annual sampling would be adequate for long-term monitoring. Sampling should be conducted during the middle of the Dry season, so as not to be influenced by variable weather conditions. The extensive baseline information on ant community composition collected during this study, obviates the need for numerous control sites. However, it is recommended that two or three such controls be included in monitoring programs.

If information is sought at the species level, then considerable expert assistance from an ant specialist is required, at least during the early stages. With such assistance, an inexperienced worker can soon be trained to operate the sampling program with reasonable independence. The maintenance of a pinned collection of voucher specimens would be absolutely essential for this. For rapid assessment at the functional group level, specimens need only be identified to genus. This would obviously require less expert assistance, and reduce the need for a comprehensive reference collection of voucher specimens. A comprehensive classification of ant genera into functional groups has been provided by Andersen (1995a). Despite the reduced need for expert assistance, it is strongly advised that any ant functional group monitoring program has input from an ant specialist, particularly during its early stages.