PART B

ANTS AS BIOINDICATORS

4 Invertebrate assemblages

This chapter examines the relationship between the five measures of ant community composition (recorded in pitfall traps) and the ordinal composition of invertebrate assemblages in the soil, on the ground and on ground-layer vegetation.

4.1 Methods

4.1.1 Sampling

Soil invertebrates

Invertebrates were extracted from soil samples collected from the ten representative sites during the Wet seasons of 1992/93 (sites N6, D1, D2, D3, D6, W3 and W4 during February 1993, and sites N4, N11 and N14 during April 1993) and 1993/94 (January and March 1994 respectively). Soil was sampled by removing surface leaf litter and collecting all soil and humus from a 15 × 15 cm area to 3 cm depth. Five such samples were randomly collected from each site on each occasion. Samples were returned to the laboratory, and invertebrates extracted using Tulgren funnels over 48 hour periods. Specimens were sorted to ordinal levels (mites, spiders, springtails, beetles etc.).

Ground-foraging invertebrates

All other invertebrates collected in ant pitfall traps (section 3.1.1) were recorded at higher taxonomic levels. Ants were an overwhelmingly dominant group, accounting on average for 72% (range 30–95%) of total individuals at natural sites, 67% (51–80%) at disturbed sites, and 52% (25–65%) at waste rock sites. They were not included in the data set which, therefore, represents the composition of ground-foraging invertebrates other than ants.

Invertebrates on ground-layer vegetation

Invertebrates associated with ground vegetation were sampled during the Wet season with sweep nets at sites N4, N6–8, N11–20, and all disturbed and waste rock sites. The remaining natural sites were not sampled due to their inaccessibility. Sampling was conducted on two occasions, during 1993 (April for sites N11–14, February for all others) and 1994 (March for sites N11–14, January for all others). At each site, five sub-samples of 30 strokes of a sweep net were taken while walking along parallel transects spaced by 5 m, overlaying the pitfall trapping grid. All specimens were sorted at higher taxonomic levels, except for ants and beetles, (see section 5.1), which were sorted to species. Ants were a significant component of the fauna (overall mean of 7% of total invertebrates), and were excluded from analyses of invertebrate composition.

4.1.2 Analysis

Data were pooled across sampling periods to produce a single site x higher-taxon abundance matrix for each of the three above assemblages. Using PATN, a Bray-Curtis site association matrix was constructed for each of the three data sets, and Mantel tests were used to determine the correlations between each association matrix and those produced by each of the five ant community data sets (section 3.1.2).

4.2 Results

4.2.1 The assemblages

Soil invertebrates

The most abundant soil invertebrates were mites and springtails, which together accounted for about half of all individuals recorded (table 4.1). The relative abundance of different groups varied widely across sites, although mites and springtails were always among the commonest taxa. The composition of soil invertebrates was similar across years, except that no termites were recorded in 1994 (table 4.1).

A total of ten species of ants were recorded in soil samples: *Acropyga* sp. 2 (site N11), *Discothyrea* sp. 1 (W3), *Hypoponera* sp. 1 (D2), *Monomorium* sp. 22 (D1), *Monomorium* sp. 24 (N6, W3), *Pheidole* sp. 13 (D2), *Quadristruma* sp. 2 (W3), *Quadristruma* sp. 4 (N4), *Solenopsis* sp. 1 (N11, W3) and *Solenopsis* sp. 2 (D3, D6, W3, W4). The species of *Acropyga* and *Quadristruma* were never recorded in pitfall traps at any site (appendix 1). Ants were never a common component of the soil invertebrate fauna, representing only 3% of total individuals recorded (table 4.1).

Ground-foraging invertebrates

The numbers of invertebrates (other than ants) recorded in pitfall traps are given in table 4.2. Total numbers were similar across natural, disturbed and waste rock sites, averaging 360, 424 and 385 respectively. Overall composition was also remarkably similar at the three sets of sites (fig 4.1), with the mean relative abundances of major invertebrate groups varying as follows: springtails 31–34%, mites 11–12%, silverfish 8–14%, beetles 6–11% and spiders 6–11%.

Invertebrates on ground-layer vegetation

The most abundant groups of invertebrates in sweep samples at natural sites were flies, spiders, orthopterans and beetles, as was the case at disturbed sites (table 4.3, fig 4.2). Invertebrate abundances were markedly different at waste rock sites, where flies and spiders were unusually abundant, and orthopterans were relatively uncommon.

Forty species of ants were recorded in sweep samples, with 23 recorded only from natural sites (appendix 6). The most common species at natural sites were *Opisthopsis haddoni*, *Iridomyrmex sanguineus*, *Polyrhachis* sp. 17 and *Rhytidoponera* sp. 8. Except for *Rhytidoponera* sp. 8, these were also the most common ants at disturbed sites. None of these were abundant at waste rock sites, where only two species (*Oecophylla smaragdina* and *Camponotus* sp. 9) were at all common. Five species recorded in sweeps (*Tetraponera punctulata*, *Crematogaster* sp. 5, *Tetramorium bicarinatum*, *Plagiolepis* sp. 1 and *Polyrhachis* sp. 9) were not recorded in pitfall traps (appendix 1).

4.2.2 Ants as indicators

The ant community association matrices were only marginally correlated with the matrix based on soil invertebrate composition, but were highly correlated with those based on invertebrate composition on the ground, and especially on ground-layer vegetation (table 4.4). In both of the latter cases, ant functional group–abundance data produced the highest correlation coefficients. Indeed, the correlation coefficient between ant functional group-abundance and invertebrate composition on ground-layer vegetation (0.675) was higher than any of the correlations between any measure of ant community composition and plant species composition (where r ranged from 0.492 to 0.665, table 3.3).

Table 4.1 Soil invertebrates recorded from representative sites during 1993 and 1994. Data are total numbers of individuals recorded.

	N4	N6	N11	N14	D1	D2	D3	D6	W3	W4	1993	1994	TOTAL
Mites	10	206	27	13	20	14	13	47	82	139	279	294	573
Spiders	2	15	1	1	2	2	2	2	3	2	17	15	32
Pseudoscorpions	2	12	1	0	0	2	7	0	0	0	11	13	24
Springtails	26	75	46	19	109	23	31	13	17	22	219	162	381
Termites	2	0	0	5	7	0	7	0	15	0	36	0	36
Homopterans	2	1	6	10	0	2	4	1	1	0	18	9	27
Heteropterans	2	5	1	4	0	1	1	1	2	0	9	8	17
Flies (adult)	6	2	13	14	5	2	4	14	14	19	38	55	93
Beetles (adult)	3	5	10	2	11	7	6	9	12	14	22	57	79
Beetles (larvae)	7	31	46	18	12	13	17	3	14	16	44	133	177
Ants	1	5	3	0	1	2	1	2	36	8	47	12	59
Others	8	33	23	17	17	21	17	37	33	36	83	159	242
TOTAL	71	392	177	103	184	89	110	129	229	256	823	917	1740

Table 4.2 Numbers of invertebrates other than ants collected in pitfall traps (data pooled across the three sampling periods)

	Natural sites																						
	N1	**N2**	**N3**	**N4**	**N5**	**N6**	**N7**	**N8**	**N9**	**N10**	**N11**	**N12**	**N13**	**N14**	**N15**	**N16**	**N17**	**N18**	**N19**	**N20**	**N21**	**N22**	**Mean**
Beetles	59	34	68	47	47	20	17	8	40	22	8	9	3	9	21	26	34	44	14	24	9	35	27
Spiders	28	18	30	19	24	19	8	22	33	29	25	19	20	12	13	10	18	31	26	17	29	40	22
Homopterans	16	19	18	7	11	9	10	10	10	7	7	4	3	10	11	6	4	26	8	2	0	4	9
Heteropterans	6	6	23	2	3	2	3	2	7	0	0	0	0	0	1	0	2	4	0	1	0	2	3
Flies	136	50	59	38	34	18	36	37	60	21	27	19	25	21	37	7	14	58	30	39	42	40	39
Wasps	10	12	27	17	38	11	9	4	9	7	9	2	1	2	7	8	13	33	6	9	0	5	11
Caterpillars	1	1	13	6	1	0	1	5	6	0	1	0	5	8	8	0	10	1	0	0	3	0	3
Springtails	115	70	161	132	59	449	372	107	733	21	33	8	3	2	59	41	51	99	76	79	24	15	123
Mites	27	31	83	47	36	17	26	50	44	37	28	24	19	14	54	37	33	87	34	56	46	49	40
Crickets	18	13	15	23	15	6	14	1	12	23	6	2	4	6	11	6	11	19	1	17	5	11	11
Termites	15	3	0	19	0	6	18	16	104	2	0	5	5	11	15	12	35	17	20	2	10	7	15
Silverfish	17	17	48	27	17	30	98	34	30	25	24	16	6	9	29	16	82	19	20	22	33	16	29
Others	27	32	39	33	18	30	20	18	37	27	14	9	12	18	28	26	38	53	40	31	29	36	28
TOTAL	475	306	584	417	303	617	632	314	1125	221	182	117	106	122	294	195	345	491	275	299	230	260	360

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Table 4.2 Cont'd

	Disturbed sites											Waste rock sites							
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	Mean	W1	W2	W3	W4	W5	W6	W7	Mean
Beetles	10	16	47	11	34	26	21	41	23	10	24	36	8	18	12	33	84	100	42
Spiders	40	8	19	20	23	17	19	47	19	12	22	57	23	46	57	61	31	27	43
Homopterans	19	20	18	16	4	16	13	8	11	12	14	3	5	3	6	2	26	1	7
Heteropterans	10	3	1	2	6	4	5	14	3	10	6	15	0	10	5	11	2	0	6
Flies	8	8	30	25	21	30	16	27	39	9	21	18	17	20	11	32	8	4	16
Wasps	9	2	8	14	21	35	14	21	13	40	18	5	3	16	17	28	21	9	14
Caterpillars	0	12	6	6	3	7	1	6	8	1	5	2	0	0	10	0	7	0	3
Springtails	40	63	83	38	483	223	122	163	47	68	133	76	89	69	120	110	168	209	120
Mites	44	63	34	57	57	33	44	43	43	29	45	51	121	11	13	16	76	32	46
Crickets	5	7	6	5	31	4	27	36	27	10	16	13	3	7	9	5	2	7	7
Termites	266	16	50	5	34	12	5	3	0	1	39	12	7	5	9	3	1	3	6
Silverfish	30	18	15	42	132	34	91	133	90	25	61	3	3	11	14	46	160	24	37
Others	15	17	16	17	43	14	39	14	17	14	21	51	65	11	18	79	39	12	39
TOTAL	496	253	333	258	892	455	417	556	340	241	424	342	344	227	301	426	625	428	385

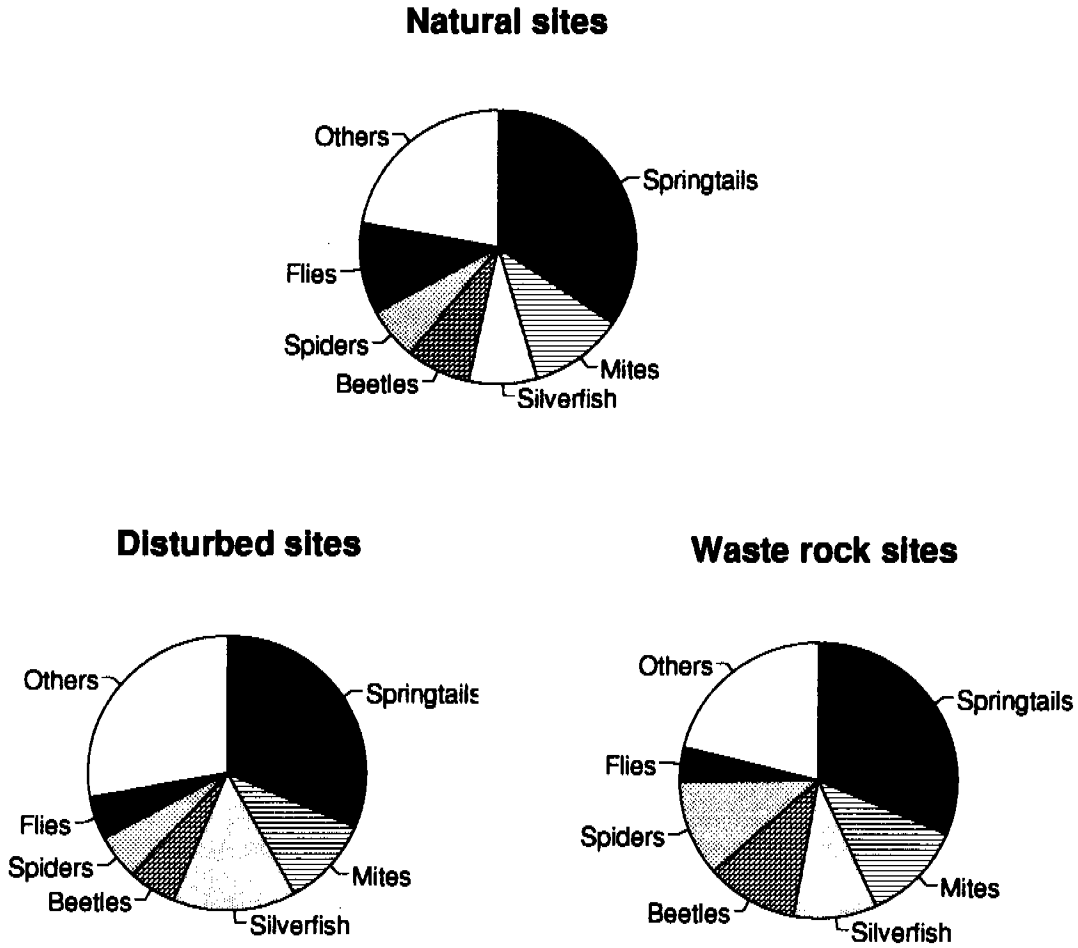

Figure 4.1 Summary composition of ground-foraging invertebrates (other than ants) recorded in pitfall traps at natural, disturbed and waste rock sites

Table 4.3 Numbers of invertebrates other than ants collected in sweep samples (data pooled across two sampling periods)

	Natural sites														
	N4	**N6**	**N7**	**N8**	**N11**	**N12**	**N13**	**N14**	**N15**	**N16**	**N17**	**N18**	**N19**	**N20**	**Mean**
Spiders	36	76	110	30	50	46	45	48	65	54	17	61	68	50	54
Grasshoppers	20	29	31	29	9	46	49	57	13	11	31	1	4	13	25
Crickets	8	23	28	17	38	25	32	44	29	18	18	11	5	20	23
Homopterans	33	16	43	15	35	9	33	31	21	28	10	12	11	5	22
Heteropterans	3	4	11	11	52	15	5	14	3	2	3	2	26	3	11
Flies	51	119	180	42	27	7	14	9	92	70	19	105	100	112	68
Beetles	31	41	50	45	39	34	29	29	92	48	32	8	56	41	41
Caterpillars	13	7	21	18	5	9	4	6	15	3	2	22	4	1	9
Moths	2	4	19	10	1	1	1	6	7	7	8	0	3	2	5
Wasps	3	2	10	5	7	5	7	2	4	2	0	0	1	11	4
Others	12	12	9	7	36	32	33	33	9	4	5	21	9	11	17
TOTAL	212	333	512	229	299	229	252	279	350	247	145	243	287	269	278

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Table 4.3 Cont'd

	Disturbed sites											Waste rock sites							
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	Mean	W1	W2	W3	W4	W5	W6	W7	Mean
Spiders	53	18	48	38	57	42	26	45	19	12	36	98	120	158	78	33	51	52	84
Grasshoppers	8	4	31	16	26	3	3	3	9	15	12	7	8	11	5	17	3	1	7
Crickets	4	3	19	8	9	0	2	1	2	1	5	1	2	0	1	1	3	1	1
Homopterans	2	12	18	16	17	29	15	5	5	5	12	7	7	11	9	2	3	0	6
Heteropterans	89	3	5	5	17	16	23	5	6	6	18	15	34	20	49	13	9	2	20
Flies	39	62	50	50	144	83	87	161	21	45	74	444	529	163	316	128	288	93	280
Beetles	35	4	48	18	14	11	12	28	34	29	23	50	49	16	28	5	3	5	22
Caterpillars	7	6	17	8	19	1	2	0	3	4	7	7	7	9	4	2	17	0	7
Moths	1	1	21	6	9	2	0	1	1	0	4	2	2	9	18	2	1	0	5
Wasps	7	6	9	4	3	0	4	1	4	3	4	3	3	0	0	0	0	0	1
Others	19	6	14	11	22	3	12	20	14	12	13	6	26	10	17	4	11	5	11
TOTAL	264	125	280	180	337	190	186	270	118	132	208	640	787	407	525	207	389	159	445

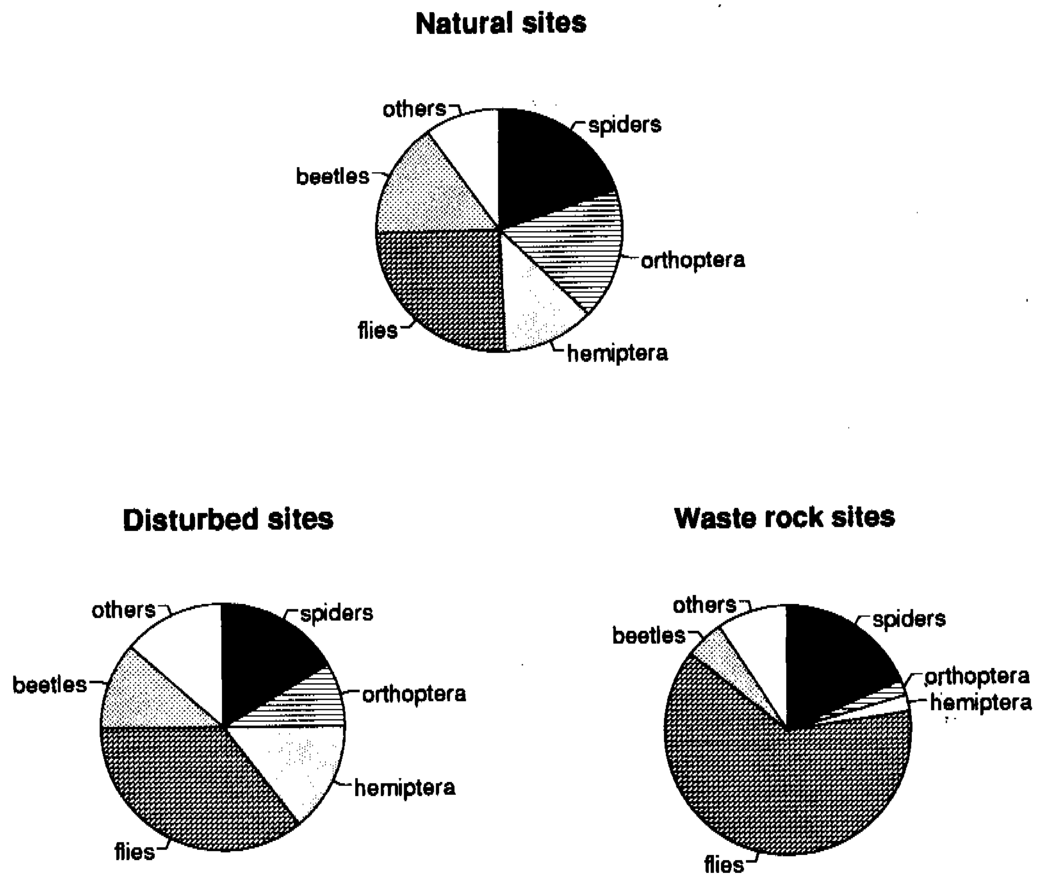


Figure 4.2 Summary composition of invertebrates (other than ants) recorded in sweep nets at natural, disturbed and waste rock sites

Table 4.4 Correlation coefficients (r) comparing site association matrices based on invertebrate assemblages (soil, ground and ground-layer vegetation) with those constructed from the five ant community data sets$^{\Psi}$

	Soil (10 sites)	Ground (39 sites)	Vegetation (31 sites)
Ant species–abundance	0.194^{ns}	0.341	0.471
Ant genus–abundance	0.282*	0.292	0.627
Ant genus–species	0.267*	0.269	0.562
Ant functional group–abundance	0.220^{ns}	0.323	0.675
Ant functional group–species	0.126^{ns}	0.238	0.561

Ψ Statistical significance is indicated as follows: ns = not significant; * = p<0.05; all others = p<0.001

5 Other insect species

This chapter examines the relationship between the five measures of ant community composition (recorded from pitfall traps) and the species composition of beetles, grasshoppers and termites.

5.1 Methods

5.1.1 Sampling

Beetles

All beetles recorded in sweep samples (section 4.1.1) were sorted to species.

Grasshoppers

Grasshoppers were surveyed at ten of the natural sites (N4, N6–8, N15–20), and at all disturbed and waste rock sites, during February 1993. At each site, a 50 × 50 m plot, with the pitfall trapping grid at its centre, was systematically searched for a two hour period. Species abundances were scored according to a five-point scale: 1 = 1; 2 = 2; 3 = 3–5; 4 = 6–10; 5 = >10. Species unable to be identified in the field were collected for laboratory identification. Many species and several genera are undescribed, and these were assigned code numbers from the Australian National Insect Collection (ANIC), CSIRO Division of Entomology, Canberra (appendix 8).

Termites

It is extremely difficult to obtain a comprehensive census of termite species at any site, due to their cryptic and varied habits. The approach adopted here was to obtain comparative information of termite activity at each site using a standardised sampling methodology, rather than to attempt any comprehensive census of termite species. The method involved the attraction of termites to moist paper baits. This records the activity of forager (litter-feeding) and, to a lesser extent, harvester (grass-eating) species, but is largely ineffectual for soil-feeding and wood-eating species.

Termites were sampled using paper baits on four occasions: during the Wet season of 1992/93 (sites N11–14 during April, remaining sites during February; sites N1, N2, N3, N5, N9, N10, N21 and N22 were not sampled at all because of their inaccessibility), the Dry season of 1993 (sites N11–14 during August, remaining sites during July), the Wet season of 1993/4 (sites N11–14 during March, remaining sites during January), and the Dry season of 1994 (sites N11–14 during June, remaining sites during May). Baits were wads of moist paper towelling, buried immediately beneath the soil surface for 24 hours. Thirty baits were located at each site, spaced equidistantly along each of the three pitfall trapping transects (10 baits per transect, each 3.3 m from nearest trap).

5.1.2 Analysis

Data were pooled across sampling periods for all analyses. The relationships between ant species richness and beetle, grasshopper and termite richness across sites were analysed using linear regression. Using PATN, a Bray-Curtis association matrix was constructed from each of the grasshopper, beetle and termite site x species abundance matrix and Mantel tests were used to determine the correlations between each association matrix and those of the five ant community data sets (section 3.1.2).

5.2 Results

5.2.1 The species

Beetles

A total of 147 beetle species from 21 families were recorded in sweeps, with site species richness ranging from 5–29 (mean of 14.2) at natural sites, 2–20 (mean of 10.1) at disturbed sites and 1–17 (mean of 9.3) at waste rock sites (appendix 7). The Chrysomelidae was a dominant family, with 70 (48%) species. Other major families were Curculionidae with 21 (14%) species, Rhipiphoridae with ten (7%) species, and Elateridae with nine (6%) species. Together, these four families accounted for three-quarters (75%) of all species recorded.

Species composition varied markedly across sites, and many taxa showed clear distributional patterns across natural, disturbed and waste rock sites. For example, many species were obviously affected adversely by disturbance (eg *Curculionidae* spp. A,B,C and E), but others apparently favoured disturbed habitats (eg *Galerucinae* sp. D, *Curculionidae* sp. D). Three of the four cryptocephaline species were most abundant (one exclusively so) at waste rock sites. Clear distributional patterns were also evident at higher taxonomic levels. Weevils (Curculionidae) were abundant at natural and disturbed sites, but, aside from one species (sp. D), were rarely recorded at waste rock sites. Within the Chrysomelidae, eumolpines were common at natural and disturbed sites, but largely absent from waste rock sites; galerucines were common across all groups of sites; and, as indicated above, cryptocephalines were most abundant at waste rock sites.

Grasshoppers

A total of 58 grasshopper species were recorded, belonging to the families Acrididae (40 species), Tettigoniidae (10 species), Eumastacidae (6 species), Pyrgomorphidae (1 species) and Tetrigidae (1 species) (appendix 8). The number of species ranged from 7–20 (mean of 11.9) at natural sites, 5–12 (mean of 9.4) at disturbed sites, and 1–12 (mean of 8.9) at waste rock sites.

As for beetles, there were clear distributional patterns across natural, disturbed and waste rock sites at both species and higher taxonomic levels. Locally common species which appear to be adversely affected by disturbance include *Caloptilla australis*, *Goniaea vocans*, *Xanterriaria mediocris*, *Zebratula flavonigra* and *Tolgadia infirma* (appendix 8). On the other hand, *Acrida conica*, *Gastrimargus musicus*, *Hetropternis obscurella* and *Bermiella acuta* were all most common at, or exclusive to, disturbed or waste rock sites. Within the Acrididae, catantopines were widespread, acridines occurred almost exclusively at disturbed and waste rock sites, and virtually all cyrtacanthacridines occurred at waste rock sites. Most Tettigoniidae, on the other hand, were found only at natural sites.

Termites

A total of 22 termite species from nine genera were recorded at paper baits, with the most common being *Amitermes* sp. 3, *Tumulitermes* sp. 1 and sp. 3, *Heterotermes venustus*, and *Drepanotermes rubriceps* (table 5.1). Total records of termites were similar across sampling periods (allowing for the fewer sites sampled during the 1992/93 Wet season), but more species were recorded during the Dry season than the Wet (table 5.1)

Overall rates of termite occurrence were low, averaging 6.3% (range 0–19.2%) at natural sites, 9.4% (0–22%) at disturbed sites, and only 2.0% (0–4.2%) at waste rock sites (appendix 9). There were consistently few termite records at waste rock sites. The notorious pest species *Mastotermes darwiniensis* was recorded at disturbed and waste rock sites, but not at any natural sites and *Schedorhinitermes actuosus* was recorded at four of the seven waste rock sites but at no others.

5.2.2 Ants as indicators

Site species richness of ants showed a strong positive relationship with the richness of beetles (fig 5.1) and termites (fig 5.3), but not grasshoppers (fig 5.2). All ant community association matrices were highly correlated with association matrices based on beetle, grasshopper and, to a lesser extent, termite species composition (table 5.2). The ant community data set producing the highest correlation varied between the three insect groups. For example, ant species-abundance was clearly the best for beetles, but was among the worst for grasshoppers and termites. Ant functional group-abundance performed best for grasshoppers, whereas ant genus-abundance performed best for termites.

Table 5.1 Termite species recorded during each sampling period. Data are total number of records (pooled across sites) at paper baits*

	Wet 1992/93	Dry 1993	Wet 1993/94	Dry 1994	TOTAL
Mastotermitidae					
Mastotermes darwiniensis Froggatt			4	3	7
Rhinotermitidae					
Heterotermes venustus (Hill)	4		13	15	32
Schedorhinotermes actuosus (Hill)		1	4	1	6
S. ?breinli (Hill)		1		1	2
Termitidae					
Amitermes sp. 1	6	2		1	9
Amitermes sp. 3	11	6	10	11	38
Amitermes sp. 4	4			2	6
Amitermes sp. 5	1			1	2
Drepanotermes septentrionalis Hill	3	3	11		17
Microcerotermes boreus Hill		6		2	8
M. nanus (Hill)				1	1
M. nervosus Hill	1	1	3	1	6
M. serratus (Froggatt)	1	2		3	6
Microcerotermes sp. 4		1			1
Microcerotermes sp. 5		1			1
Nasutitermes sp. 1		1			1
Nasutitermes sp. 2		1			1
'*Termes*' sp.				1	1
Tumulitermes sp. 1	8	11	11	6	36
Tumulitermes sp. 2	1				1
Tumulitermes sp. 3	1	15		4	20
Tumulitermes sp. 4	1	4	2		7
Tumulitermes sp. 7		7	2	3	12
Unidentified workers	12	16	23	25	76
Total species records	54	79	83	81	297
Number of species	12	17	9	16	22

* Eight natural sites were unable to be sampled during the 1992/93 Wet season due to their inaccessibility

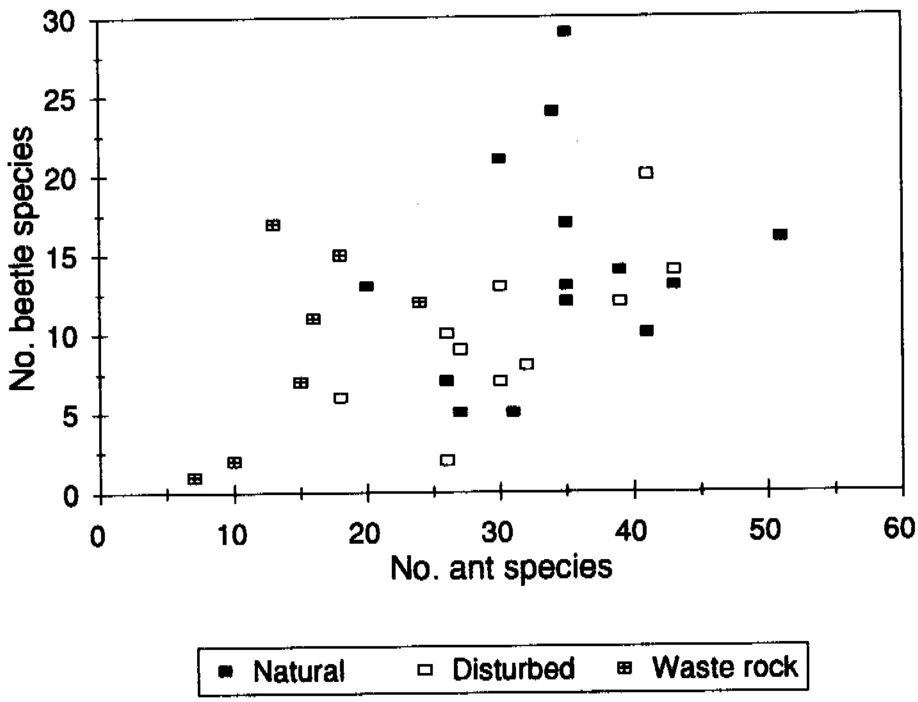


Figure 5.1 Relationship between number of ant species in pitfall traps and number of beetle species in sweep samples. The equation for the best fit linear regression is $y = 0.273x + 3.867$ ($r = 0.455$, $p = 0.005$).

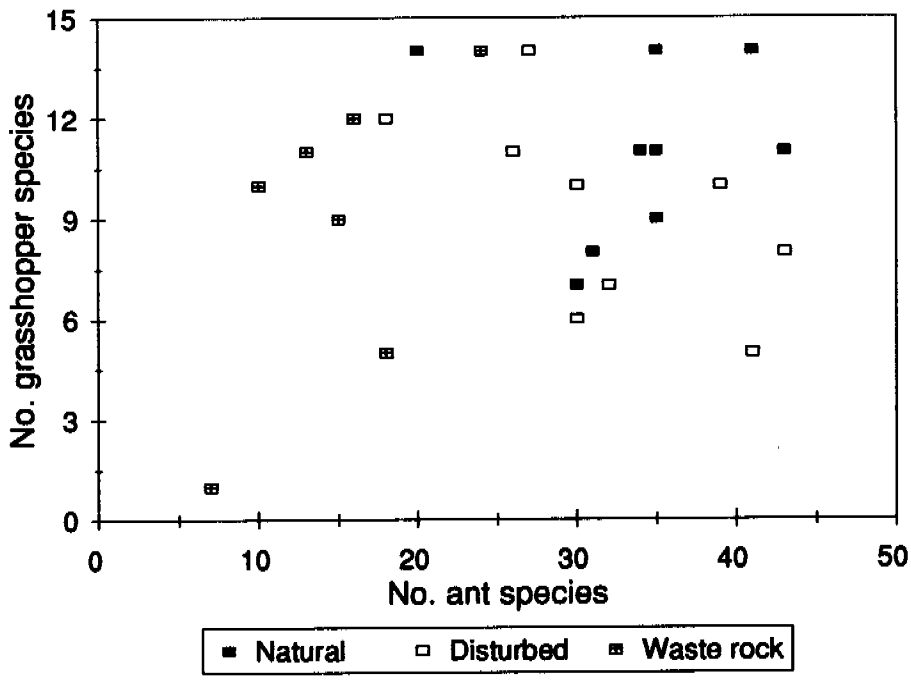


Figure 5.2 Relationship between number of ant species in pitfall traps and number of grasshopper species ($r = 0.216$, $p > 0.05$)

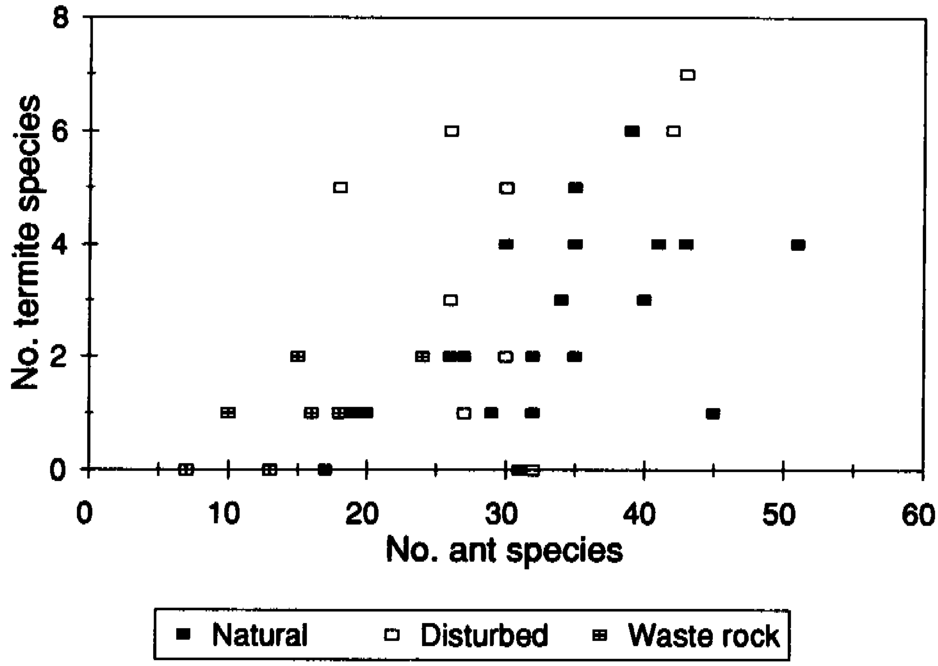


Figure 5.3 Relationship between number of ant species in pitfall traps and number of termite species at paper baits. The equation for the best fit linear regression is $y = 0.107x - 0.508$, $r = 0.546$, $p < 0.001$.

Table 5.2 Correlation coefficients (r) comparing association matrices based on beetle, grasshopper and termite species composition with those constructed from the five ant community data sets*

	Beetles (31 sites)	**Grasshoppers (27 sites)**	**Termites (39 sites)**
Ant species–abundance	0.533	0.412	0.185
Ant genus–abundance	0.428	0.429	0.280
Ant genus–species	0.435	0.451	0.247
Ant functional group–abundance	0.426	0.454	0.233
Ant functional group–species	0.398	0.451	0.168

* All correlations are highly significant ($p<0.001$)

6 Soil microbial activity

6.1 Methods

6.1.1 Litter decomposition

Rates of microbial decomposition were assessed at the ten representative sites by measuring biomass loss of dead leaves over the 1993/94 Wet season. The leaves of two very common and widespread species, *Eucalyptus tetrodonta* and *Acacia auriculiformis* were used. Leaves were collected fresh, oven-dried for 48 hours, and divided into three gram samples (approximately 5–6 leaves). Samples were placed inside 80% cover shadecloth bags to allow access by microorganisms, but to exclude larger decomposer insects such as termites and cockroaches. Access was also likely for some micro-invertebrates, such as springtails. A pair of samples (one sample of each species) was placed on the ground at ten locations at each site during early December (beginning of Wet season) 1993. At each site, samples were spaced by 10 m along each of two 40 m transects separated by 20 m. Samples were collected during early May (end of Wet season) 1994, oven-dried for 48 hours, re-weighed and biomass loss calculated.

Some samples were lost to fire and unknown causes, particularly at D2, resulting in variable sample sizes across sites (table 6.1). An ANOVA was performed on biomass (g) lost using the statistical software package Genstat, after excluding all missing data from D2, excluding the two missing Acacia samples from D6, and using the program to estimate all remaining missing values. The factors in the analysis were: Site type (2 df; comparison of natural, disturbed and waste rock sites); Site type.site (7 df; comparisons between sites within each site type); Species (1 df; comparison of Acacia with Eucalyptus); Site type.species (2 df; interaction between site type and species); Site type.site.species (7df; interaction between sites within site type and species) (table 6.2). No attempt was made to relate rates of litter decomposition with ant community composition, as the former did not vary systematically across sites.

Table 6.1 Sample sizes in litter decomposition experiment, after losses due to fire and other causes

	N4	N6	N11	N14	D1	D2	D3	D6	W3	W4
Acacia	10	10	10	10	6	2	10	8	10	5
Eucalyptus	10	10	10	10	10	2	10	9	9	10

6.1.2 Microbial biomass and respiration

Measurements of soil microbial biomass and respiration were conducted by Dr Graham Sparling (University of Western Australia) on soil samples collected by ***eriss*** from all sites except N11–14 during April 1994. Two soil samples (0–10 cm depth), each consisting of ten bulked sub-samples, were analysed from each site. Relationships between ant species richness and soil microbial biomass and respiration were analysed using linear regression.

6.2 Results

6.2.1 Litter decomposition

Rates of loss of leaf biomass varied markedly between the two species, averaging 23.2% for Acacia and 39.0% for Eucalyptus, but did not vary consistently between sites (fig 6.1).

Rates of decomposition of the two taxa were not significantly correlated across sites (r^2 = 0.11, n=10, p>0.05). Analysis of variance revealed a complex series of interactions between factors (table 6.2). For each species, there were significant differences between site types, and there was a significant site type x species interaction. For Acacia, biomass loss at waste rock sites (mean of 30.2%) was higher than at natural (mean of 21.7%) and disturbed (mean of 21.2%) sites. For Eucalyptus, biomass loss at natural (mean of 42.8%) and waste rock (mean of 40.43%) sites was higher than at disturbed (mean of 34.6%) sites.

There was a significant site type x site x species interaction for natural sites, but not for disturbed and waste rock sites (table 6.2). Among natural sites there were no significant differences for Acacia (19.3–24.3%), but for Eucalyptus biomass loss at N4 (51.2%) was higher than at the other three sites (38.8–41.2%).

Table 6.2 Summary ANOVA table for results of litter decomposition experiment

Source of variation	df	Sums of squares	Mean squares	Variance ratio	F test
Site type	2	1.300	0.650		
Site type.Nsite	3	0.464	0.155		
Site type.Dsite	3	1.108	0.369		
Site type.Wsite	1	0.022	0.022		
Species	1	10.608	10.608	350.07	p<0.001
Site type.species	2	0.862	0.431	14.22	p<0.001
Site type.Nsite.species	3	0.633	0.211	6.96	p<0.001
Site type.Dsite.species	3	0.040	0.013	0.244	p=0.724
Site type.Wsite.species	1	0.008	0.008	0.27	p=0.603
Residual	151	4.576	0.030		
TOTAL	170	18.676			

6.2.2 Microbial biomass and respiration

Microbial respiration and microbial biomass varied markedly across sites, with waste rock sites averaging less than half the values of natural sites, and disturbed sites having intermediate values (table 6.3). Considering all sites together, microbial respiration and biomass were extremely highly correlated with each other (r^2 = 0.9999, n=70). However, neither were correlated with leaf biomass lost from either Acacia (r^2 = 0.004, n=8, p>0.05 in both cases) or Eucalyptus (r^2 = 0.18, n=8, p>0.05 in both cases). It is not at all clear why rates of decomposition were unrelated to microbial biomass and respiration, but the access to litter bags by microinvertebrates is a possible contributing factor.

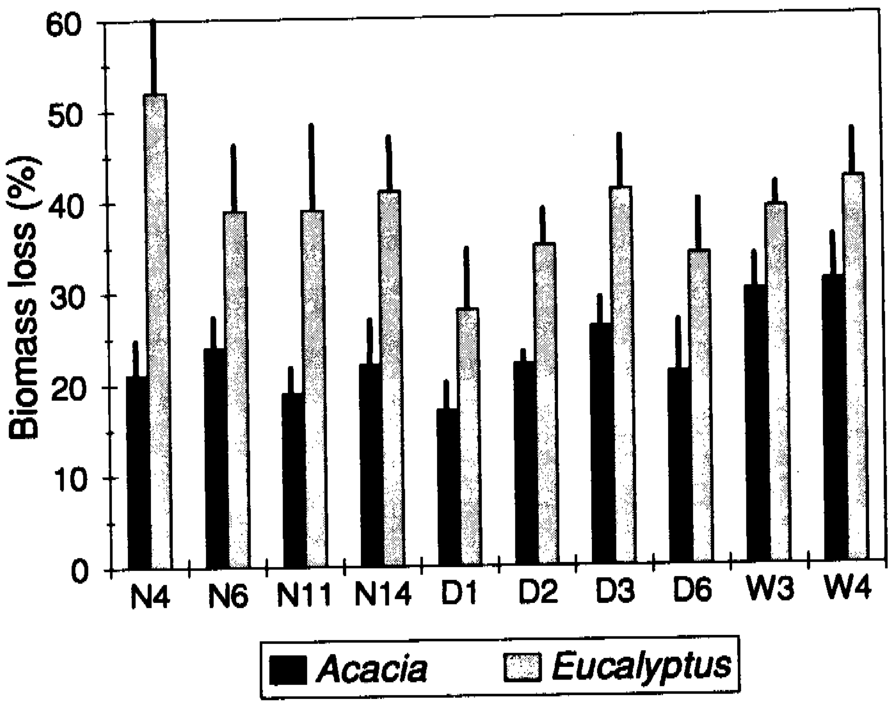


Figure 6.1 Loss of leaf biomass over a single Wet season at the ten representative sites

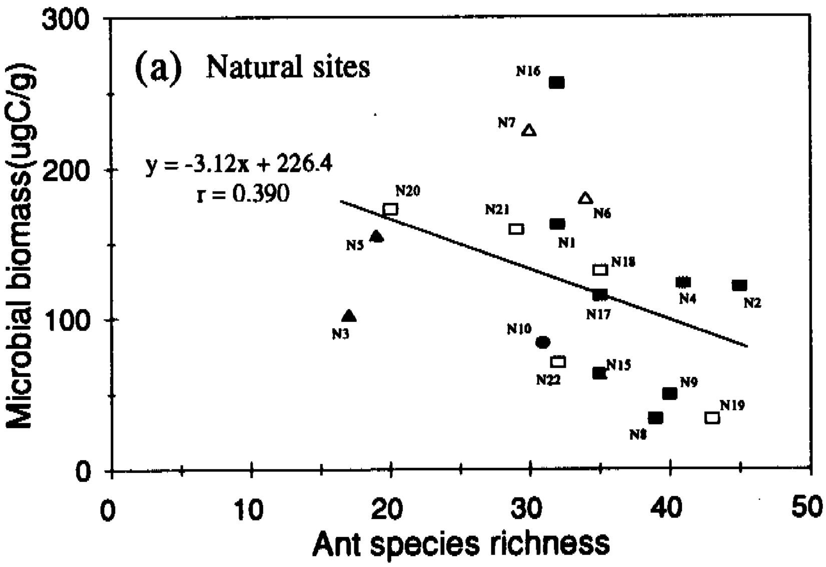
Considering only natural sites, there was a weak but significant negative correlation between microbial biomass (and therefore respiration) and ant species richness (fig 6.2a). A marked habitat effect on this relationship was evident. For example, sites from group 1 (various *Eucalyptus tetrodonta* open forests and woodlands) of the vegetation classification based on woody species (table 2.2) tended to have high ant species richness and low to moderate soil microbial biomass, sites dominated by *Melaleuca viridiflora* (group 5) had low ant richness and moderate microbial biomass and sites within group 4 (various woodlands on sandy soils) varied considerably, but following the overall regression line.

For disturbed and waste rock sites, on the other hand, there was a very strong, positive correlation between the same variables (fig 6.2b). There was continuous variation along the regression line from the least vegetated waste rock sites (W6, W7), through the best vegetated waste rock sites (W1, W4) and cleared disturbed sites (D1, D2, D6, D10), to the least impacted of the disturbed sites (D3–5). Interestingly, the burnt waste rock site (W4) was markedly different from adjacent unburnt W3 and in fact grouped more with disturbed sites than it did with other waste rock sites (fig 6.2b).

The high correlation between ant species richness and microbial biomass and respiration at disturbed and waste rock sites has important implications for the use of ants as bioindicators. In the context of ecosystem restoration following disturbance in the Alligator Rivers region, ant species richness is a very good indicator of microbial biomass and respiration.

Table 6.3 Microbial respiration (uL $g^{-1}h^{-1}$) and microbial biomass (ugC g^{-1}) of soil samples (two per site) from all sites except N11–14

	Resp'n	Biomass		Resp'n	Biomass
N1	3.2	160.1	D1	0.9	44.8
	3.3	165.0		1.4	69.9
N2	1.77	88.7	D2	1.22	60.9
	3.05	152.6		1.04	51.9
N3	2.33	116.7	D3	1.04	51.9
	1.75	87.5		2.43	121.3
N4	2.74	137.1	D4	1.35	67.4
	2.17	108.7		1.65	82.3
N5	2.98	148.9	D5	2.89	144.7
	3.24	162.1		2.48	123.9
N6	2.2	110.2	D6	1.43	71.5
	5.0	250		1.0	49.8
N7	5.12	255.8	D7	3.4	170
	3.89	194.5		0.67	33.5
N8	0.79	39.5	D8	0.67	33.7
	0.54	27.1		1.39	69.6
N9	1.5	75.0	D9	0.5	26.4
	0.47	23.7		1.32	66
N10	0.94	47	D10	1.14	56.9
	2.38	119.1		1.56	78.2
N15	1.39	69.5	**Dmean**	**1.47**	**73.73**
	1.13	56.3			
N16	4.87	243.3			
	5.37	268.6			
N17	1.67	83.6	W1	2.46	123.1
	2.93	146.3		1.34	67.2
N18	4.1	205	W2	0.88	44.2
	1.17	58.5		0.58	29
N19	0.25	12.7	W3	0.65	32.5
	1.08	53.8		0.64	32.2
N20	3.76	187.9	W4	0.83	41.4
	3.17	158.8		2.24	112
N21	3.91	195.6	W5	1.55	77.4
	2.46	122.8		1.65	82.6
N22	1.64	82.1	W6	0.82	41
	1.18	59		1.15	57.6
Nmean	**2.48**	**124.25**	W7	0.12	6
				0.65	32.6
			Wmean	**1.11**	**55.63**



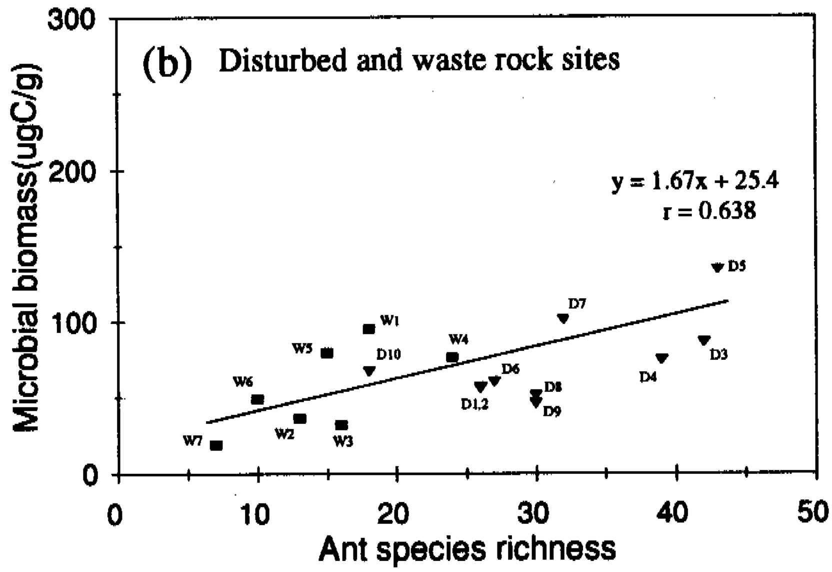


Figure 6.2 Relationships between ant species richness and soil microbial biomass at (a) natural and (b) disturbed (triangles) and waste rock (squares) sites. In (a), site groups based on woody species composition (table 2.2) are distinguished: group 1 (closed squares); group 2 (closed circles); group 3 (open triangles); group 4 (open squares); and group 5 (closed triangles).