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The role of ants in minesite restoration in the Kakadu region of Australia's Northern Territory, with particular reference to their use as bioindicators

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Executive summary

The goal of land rehabilitation following mining in environmentally sensitive areas is often ecosystem restoration, rather than simply revegetation. This is the case at Ranger uranium mine (RUM) in the Alligator Rivers Region of Australia's Northern Territory. Effective methods of monitoring ecological restoration are therefore required. Ants have frequently been used as indicators of restoration success following mining in northern Australia, but the extent to which ants actually provide a reliable indication of ecological change has been poorly documented. This study aimed, primarily, to investigate the degree to which ants provide an indication of the general status of ecosystems and, secondarily, to examine the direct role of ants in ecosystem restoration. The desired outcome was the development of procedures for using ants to assess restoration success following mining in the Ranger uranium mine region.

A total of 39 sites were selected to represent the full range of sclerophyll habitats and disturbance histories in the region. They comprised 22 natural (ie relatively undisturbed by human activity) sites, ten disturbed (representing a wide range of human disturbances) sites, and seven sites at various stages of rehabilitation on Ranger's main waste rock dump. All vascular plant species occurring at each site were surveyed during March 1994.

Ants were sampled on three occasions at each site using pitfall traps, recording a total of 162 species from 32 genera. Site species richness was highly correlated with plant species richness ($r = 0.695$ for all plant species; $r = 0.663$ for woody species only). Five measures of ant community composition were analysed, covering the species, genus and functional group levels. Bray-Curtis association matrices based on ant community composition were highly correlated (r ranging from 0.492 to 0.665) with association matrices based on plant species composition.

Data were obtained on the ordinal composition of invertebrate assemblages in the soil, on the ground and on ground vegetation, and on species composition of beetles, grasshoppers and termites. Correlation analyses were performed on site association matrices based on these data and site association matrices based on five measures of ant community composition. There was only a marginal correlation between ant community composition and soil invertebrate assemblages (r ranging from 0.194 to 0.282; only 10 sites sampled), but a good correlation with ground-foraging invertebrates (0.238–0.341; all 39 sites), and an even higher correlation with invertebrates on ground vegetation (0.471–0.675; 31 sites). Ant community composition was correlated with the species composition of all insect groups studied (beetles: 0.398–0.533, 31 sites; grasshoppers: 0.412–0.454, 27 sites; termites: 0.168–0.280, 39 sites).

A litter decomposition experiment was conducted during the 1993/94 Wet season, measuring biomass loss of leaves of *Eucalyptus tetrodonta* and *Acacia auriculiformis*. Eucalyptus leaves decomposed far more rapidly than those of Acacia, but rates of decomposition did not vary markedly across sites. Soil microbial biomass and respiration, on the other hand, did vary markedly across sites, and were correlated with ant species richness. This correlation was particularly high ($r = 0.638$) at disturbed and waste rock sites.

Studies were conducted on the potential influence of ants, through their interactions with seeds, on ecological restoration following disturbance. Elsewhere in Australia, it is common for sites severely disturbed by human activity to be colonised by high densities of harvester ants, resulting in unusually high rates of seed predation. This could have a serious impact on revegetation following disturbance. However, this is unlikely to be a problem in the Ranger uranium mine region, as disturbance does not appear to lead to increases in either harvester ant populations, or rates of seed harvesting (which, during 1992 and 1993 respectively, averaged 27% and 32% at natural sites, 26% and 28% at disturbed sites, and 6% and 14% at waste rock sites). Disturbance, on the other hand, has a major impact on seed dispersal by ants, primarily through its influence on the distribution and abundance of ant species. On waste rock sites, for example, no seeds were transported further than 50 cm (compared with up to 13 m at other sites). The influence of this on seedling establishment is unknown.

Two major conclusions can be drawn from this study. First, ant communities in the Ranger uranium mine region provide a very good general indication of the state of ecosystems in which they occur. 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. Given that ants need only be identified to genus to be assigned to functional groups, the use of functional groups instead of species is a legitimate, cost-effective measure for rapid assessment.

It is therefore recommended that ants be included in biological monitoring of restoration programs in the region. Ideally, ant communities should be analysed at both species and functional group levels, but the use of functional groups alone would be adequate. A specific sampling protocol is recommended.

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Preface

This is the final report as required under the consultancy agreement between the Environmental Research Institute of the Supervising Scientist (***eriss***) and CSIRO Division of Wildlife and Ecology (the consultant, Principal Investigator, Dr Alan N Andersen).

The *aims* of the consultancy were:

1. to assess the extent to which ants provide an indication of the general status of ecosystems (including those undergoing restoration) in which they occur,
2. to examine the influence of ants on ecosystem restoration dynamics, and
3. hence develop procedures for assessing restoration success, in the Ranger uranium mine region of the Top End of the Northern Territory.

Acknowledgments

We are grateful to a number of ***eriss*** officers, particularly Kym Brennan, for assistance with site selection, fieldwork, and administrative matters. We thank Ranger uranium mine for granting permission to work on their lease. All grasshopper fieldwork was conducted by L Lowe (CSIRO Division of Wildlife & Ecology), who also performed species identifications, with assistance from D Rentz (CSIRO Division of Entomology). Termite species were identified with the assistance of L Miller (CSIRO Division of Entomology), and C Reid (James Cook University) assisted with the identification of beetles. W Muller (CSIRO Biometrics Unit) performed the ANOVA on results from the litter decomposition experiment. Drs Jonathan Majer and Ian Oliver provided valuable comments on the draft report. Finally, we wish to thank W Waggitt and B McKaige for assistance with the layout and production of the report.

1 Introduction

1.1 Background

The goal of land rehabilitation following mining has recently shifted in emphasis from simple revegetation towards complete (as far as practicable) ecosystem restoration. This is particularly so when mining occurs in and around ecologically sensitive areas, such as national parks and sites of Aboriginal significance. A good example is provided by the Alligator Rivers Region of the Northern Territory, containing the prestigious Kakadu National Park, where the environmental performance of mining operations is strictly controlled, and the highest standards of rehabilitation are expected (Unger & Milnes 1992). Whereas the aim of revegetation is directed towards producing a stable site with a 'green' appearance, restoration aims at developing self-sustaining ecosystems comparable to those occurring prior to disturbance (Jordan et al 1987).

The goal of ecosystem restoration poses an important challenge to both the mining industry and its government regulators, as ecosystems are extremely complex and inadequately understood. The science of restoration ecology is still in its infancy. One of the challenges is to develop management practices which accelerate and direct ecological succession toward desired end-points (Bradshaw 1987, Luken 1990). Another challenge lies in assessing restoration success—such an assessment must consider the proper functioning of an ecosystem, rather than just its superficial appearance (Salwasser & Tappeiner 1981, van Horne 1983).

There has been a recent focus on the role of fauna, particularly invertebrates, in ecosystem restoration (Majer 1989). Invertebrates play many important roles in ecological succession, relating to soil development, nutrient cycling, plant growth and reproduction, and the establishment of appropriate food webs (Majer 1989). Invertebrates can often also provide a more sensitive indication than can plants of the overall state of the ecosystem in which they occur and therefore have great potential for use as indicators of restoration success (Greenslade & Greenslade 1984, Disney 1986, Rosenberg et al 1986).

1.2 Ants as bioindicators

Ants are arguably the dominant faunal group in the Australian environment. Globally, ants account for an estimated 30% of terrestrial animal biomass (Hölldobler & Wilson 1990), and they are particularly diverse and abundant in Australia compared with most other regions of the world (Greenslade 1979, Andersen 1991a). Ants play many important ecological roles, having direct interactions with the soil (de Bruyn & Conacher 1990), plants (Buckley 1982, Beattie 1985, Huxley & Cutler 1991), and animals at all trophic levels (Hölldobler & Wilson 1990). Many of these roles, particularly those relating to paedogenesis (Abbott 1989), nutrient cycling (Hutson 1989), seed predation (Andersen 1990a, Majer 1990) and seed dispersal (Beattie 1985, Majer 1990), have direct relevance to ecosystem restoration following disturbance. The many linkages ants have with other parts of the ecosystem, combined with their high abundance, diversity and ease of sampling, make ants ideal candidates for use as bioindicators in land assessment programs (Majer 1983, Greenslade & Greenslade 1984, Andersen 1990b).

Invertebrates have a long and successful history of use as bioindicators in aquatic systems (Hellawell 1978, James & Evison 1979). Such monitoring programs have progressed from relying on univariate indices of dubious ecological meaning, to using sophisticated multivariate analysis of community composition (Norris & Norris 1995). They are most effective as bioindicators when supported by a predictive understanding of community responses to stress and disturbance (Wright 1995, Reynoldson et al 1995), which provides a powerful means of distinguishing the effects of anthropogenic disturbance from inherent site variability. This is particularly true given the common difficulty of finding sufficient numbers of suitable control sites in monitoring programs (Underwood 1994).

The use of invertebrates as bioindicators is considerably less advanced in terrestrial systems. The use of multivariate techniques is becoming increasingly common (Kremen 1992), but species tend to be treated as anonymous entities, with attention usually focussed on detecting differences in ordination space, rather than on developing a predictive understanding of community composition. Ants are exceptional in this context. They have a long history of use as bioindicators in Australia (Greenslade & Greenslade 1984, Andersen 1990b), particularly in relation to minesite restoration (Majer 1984, Andersen 1994). Indeed, ants have already been used to assess preliminary revegetation trials at Ranger uranium mine (Andersen 1993a). Moreover, ant monitoring programs are supported by a predictive understanding of the responses of ant communities to stress and disturbance (Andersen 1990b, 1995a).

1.3 Responses of ants to stress and disturbance

Much of our understanding of ant community dynamics is based on the recognition of functional groups of species (table 1.1) which respond to stress and disturbance in predictable ways (Andersen 1995a). Ant communities of open habitats in central and northern Australia are extremely diverse (up to 100 or more species per hectare), are almost always dominated by highly aggressive species of *Iridomyrmex* (Dominant Dolichoderinae), and include numerous highly specialised, thermophilic species of *Melophorus* (Hot Climate Specialists) (Andersen 1992, 1993b, Andersen & Patel 1994). The diversity and abundance of *Iridomyrmex* and *Melophorus* decline with increasing stress (primarily related to lower soil-surface temperature, such as in heavily shaded habitats) and disturbance. At highly stressed or disturbed sites, ant diversity is low, and the most abundant species are often Opportunists such as species of *Paratrechina*, *Tetramorium* and *Rhytidoponera*, and other unspecialised ants, especially species of *Pheidole* and *Monomorium* (Generalised Myrmicinae). In northern Australia, many of the Opportunists which colonise disturbed sites are exotic species, such as *Paratrechina longicornis*, *Tetramorium simillimum*, and *Pheidole megacephala* (see Wilson & Taylor 1967, Williams 1994). The most abundant of these exotic ants in the Ranger uranium mine region is *Paratrechina longicornis*, which is often a numerically dominant species at sites undergoing rehabilitation (Andersen 1993a).

1.4 Rapid assessment techniques

A recent trend in biological monitoring programs is the use of rapid assessment techniques. When monitoring for ecological change, simplified methodologies involving sub-sampling and identification to family or 'recognisable taxonomic units' have been promoted as being both cost-effective and reliable (Resh & Jackson 1993, Beattie 1993, Chessman 1995). This is analogous to the use of target taxa (Kremen 1994, Andersen 1995b) or higher-taxon surrogacy (Gaston & Williams 1993, Williams & Gaston 1994) in biodiversity assessment. When using benthic macroinvertebrates to monitor sewerage effluent, for example, Wright et al (1995) found that community patterns at the species level were accurately reflected by patterns at familial and even ordinal levels. The identification of ant functional groups which respond predictably to environmental stress and disturbance, provides an opportunity for rapid assessment using ants in terrestrial systems.

Table 1.1 Summary of functional groups scheme for Australian ants (Andersen 1990b, 1995a, based on Greenslade 1978)*

Functional group	Major taxa in north-western Australia	Attributes
Dominant Dolichoderinae	*Iridomyrmex*, *Papyrius*	Highly abundant, active and aggressive, exerting a strong competitive influence on other ants
Subordinate Camponotini	*Camponotus*, *Polyrhachis*, *Opisthopsis*	Co-occurring with Dominant Dolichoderinae, but competitively subordinate to them
Hot Climate Specialists	*Melophorus*, *Meranoplus*, *Monomorium* (*rothsteini* gp)	Co-occurring with Dominant Dolichoderinae, and highly specialised morphologically, physiologically and/or behaviourally
Cold Climate Specialists	nil	Distribution centred on cool-temperate southern Australia, where Dominant Dolichoderinae are poorly represented
Tropical Climate Specialists	*Oecophylla*	Distribution centred on tropical rainforests, where Dominant Dolichoderinae are poorly represented
Cryptic Species	*Solenopsis*, *Hypoponera*	Occurring primarily within soil and litter, and therefore having limited interaction with other ants
Opportunists	*Rhytidoponera*, *Paratrechina*, *Tetramorium*, *Odontomachus*	Unspecialised and poorly competitive ants characteristic of disturbed habitats and other sites of low ant diversity
Generalised Myrmicinae	*Monomorium* (part), *Pheidole*, *Crematogaster*	Unspecialised but highly competitive due to rapid forager recruitment, and ability to defend food resources
Specialist Predators	*Leptogenys*, *Bothroponera*, *Cerapachys*	Low colony size and generally large body size; limited interaction with other ants

* A comprehensive classification of taxa into functional groups is given in Andersen (1995a)

1.5 Scope of study and structure of report

Despite the history of use of ants as bioindicators, the extent to which ants actually provide a reliable indication of ecological change has been poorly documented. This study aimed, primarily, to investigate the degree to which ants provide an indication of the general status of ecosystems, and, secondarily, to examine the direct role of ants in ecosystem restoration. The desired outcome was the development of procedures for using ants to assess restoration success following mining in the Ranger uranium mine region.

The report begins (part A) by documenting ant-habitat associations in the Ranger uranium mine area, before examining the reliability of ants as indicators of ecosystems in general (part B), and investigating selected ecological roles of ants (involving seed dynamics) in relation to ecosystem restoration (part C). Finally, this information is used to develop procedures for using ants as bioindicators of restoration success following mining.

PART A

ANT-HABITAT ASSOCIATIONS

2 Study sites

2.1 Introduction

A total of 39 sites were selected to represent the full range of sclerophyll habitats (ie excluding monsoon forest) and disturbance histories occurring in the Ranger uranium mine region (table 2.1 and fig 2.1). Of these sites, 22 were natural (ie relatively undisturbed by human activity; N1–22), ten were disturbed (but on natural substrates; D1–10), and seven occurred on the northern waste rock dump (W1–7). Of the natural sites, special emphasis was placed on sites with substrate and landform most likely to be comparable to the waste rock dump, namely rocky hills (7 sites) and the schists of Tin Camp Creek (3 sites). The level of habitat alteration at disturbed sites ranged from relatively slight (eg D5, a roadside strip with intact vegetation, but subject to edge effects) to severe (eg D2 and D10, where the vegetation had been completely cleared, and regrowth was unmanaged). The waste rock sites included the 1982 and 1984 revegetation trials.

A representative subset of sites, comprising four natural, four disturbed and two waste rock sites (denoted by an asterix in table 2.1), was selected for studies that were not able to be conducted at all sites.

2.2 Vegetation classification

2.2.1 Methods

The floristic composition of all sites was recorded by Kym Brennan of ***eriss*** during March 1994. The cover of all vascular plant species located inside a 50 × 50 m quadrat overlaying each site's pitfall trapping grid (see chapter 3) was recorded according to the following scale: +: present (<1%); 1: 1–5%; 2: 6–10%; 3: 11–20%; 4: 21–40%; 5: 41–60%; 6: 61–80%; 7: >80%.

Multivariate analysis was performed on floristic data (woody species only) using the pattern analysis package PATN (Belbin 1994). A Bray-Curtis site association matrix was constructed using non-transformed data, and sites were classified into ten groups using the agglomerative hierarchical fusion technique, flexible UPGMA (beta = –0.25).

2.2.2 Results

A total of 369 vascular plant species, including 110 woody species, was recorded at the study sites. Site species lists are already held by ***eriss***, and are therefore not included here.

The classification dendrogram is shown in figure 2.2, and site composition at the 10 group level is given in table 2.2. The two largest groups (group 1 with 12 sites, and group 2 with 8 sites) comprise natural and disturbed sites dominated by various species of Eucalyptus (table 2.1), and always including *Eucalyptus tetrodonta.* Such woodlands and open forests are the dominant vegetation types in the region. Sites from group 1 usually also include *E. miniata* (75% constancy), which was absent from all group 2 sites. Groups 3–6 contain all the remaining natural sites. Group 3 (4 sites) represents open woodlands with *E. tectifica,* and group 4 (4 sites), and group 5 contains the two billabong sites (N3, N5) dominated by *Melaleuca viridiflora.* All the waste rock sites that have been revegetated with shrubs (W1–5) are grouped together.

Most of the above groups correspond well to structural formations, but it should be noted that site classification based on floristic data has produced some incongruity. For example, although site D1 has been cleared of timber and is regularly slashed, the presence of *E. tetrodonta* coppice groups it with *E. tetrodonta* woodlands (group 2). The point to be made here is that floristic classification is not the same as structural classification, and that floristic groups are imperfect delineators of 'habitats' from a faunal perspective.

Table 2.1 Summary descriptions of study sites (sites included in the representative subset are denoted by an asterisk)

Code	Location	Vegetation
Natural sites		
N1	RUM – Kym's site 10	*Eucalyptus foelschiana* woodland
N2	RUM – Kym's site 9	mixed eucalypt open forest
N3	RUM – Georgetown	*Melaleuca viridiflora* shrubland
N4*	RUM – Kym's site 8	mixed eucalypt open forest
N5	RUM – Djakmara	riverine *M. viridiflora* open forest
N6*	RUM – rocky hill	*E. tectifica/E. clavigera* open woodland
N7	RUM – rocky hill	*E. tectifica/E. clavigera* open woodland
N8	RUM – Kym's site 1	*E. tetrodonta* woodland
N9	RUM – Kym's site 6	*E. tetrodonta/E. porrecta* open forest
N10	RUM – south of pit	*E. tectifica/ E. latifolia* open woodland
N11*	Tin Camp Ck – laterite	*E. tetrodonta /E. bleeseri* woodland
N12	Tin Camp Ck – calcite	*E. pruinosa* open woodland
N13	Tin Camp Ck – mica	*E. foelscheana* open woodland
N14*	Tin Camp Ck – quartz	*E. foelscheana/E. tectifica* open woodland
N15	Mirray Lookout – lower	*E. miniata* open forest
N16	Mirray Lookout – upper	*E. phoenecia* woodland
N17	Buk Buk	*E. tectifica/E. tetrodonta* woodland
N18	Nourlangie – carpark	*E. latifolia* woodland
N19	Nourlangie – sand	*Terminalia/Buchanania* low open woodland
N20	Nourlangie – Little N	*E. tectifica* woodland
N21	Jabiluka – radio tower	*E. tetrodonta/E. setosa* woodland
N22	Jabiluka – sand	*E. miniata* woodland
Disturbed sites (all located in the Ranger uranium mine lease)		
D1*	Airstrip	slashed perennial grassland
D2*	Pit 3 South – cleared	*Acacia dimidiata* shrubland
D3*	Pit 3 South – disturbed	*E. tetrodonta* woodland
D4	Pit 3 North	*E. tetrodonta/E. porrecta* open forest, partly cleared
D5	Roadside strip	*E. tetrodonta/E. porrecta* open forest
D6*	Industrial area – A	*E. tetrodonta* open forest , partly cleared
D7	Industrial area – B	*Acacia/Calytrix* open shrubland, cleared and compacted
D8	NE of RP1	*Acacia* open shrubland
D9	Gagadju campsite	*Sorghum* grassland, with sparse shrubs
D10	Borrow pit, nr airstrip	*Sorghum* grassland

Table 2.1 cont'd next page

Table 2.1 cont'd

Code	Location	Vegetation
Waste rock sites		
W1	1982 Revegetation	*Acacia* shrubland
W2	1984 untreated	*Acacia* open shrubland
W3*	1984 Reveg (unburnt)	*Acacia* shrubland
W4*	1984 Reveg (burnt)	mixed shrubland
W5	Batter slope (1984 reveg)	*Acacia* shrubland
W6	Batter slope (1984 reveg)	mixed grassland
W7	Batter slope	unvegetated

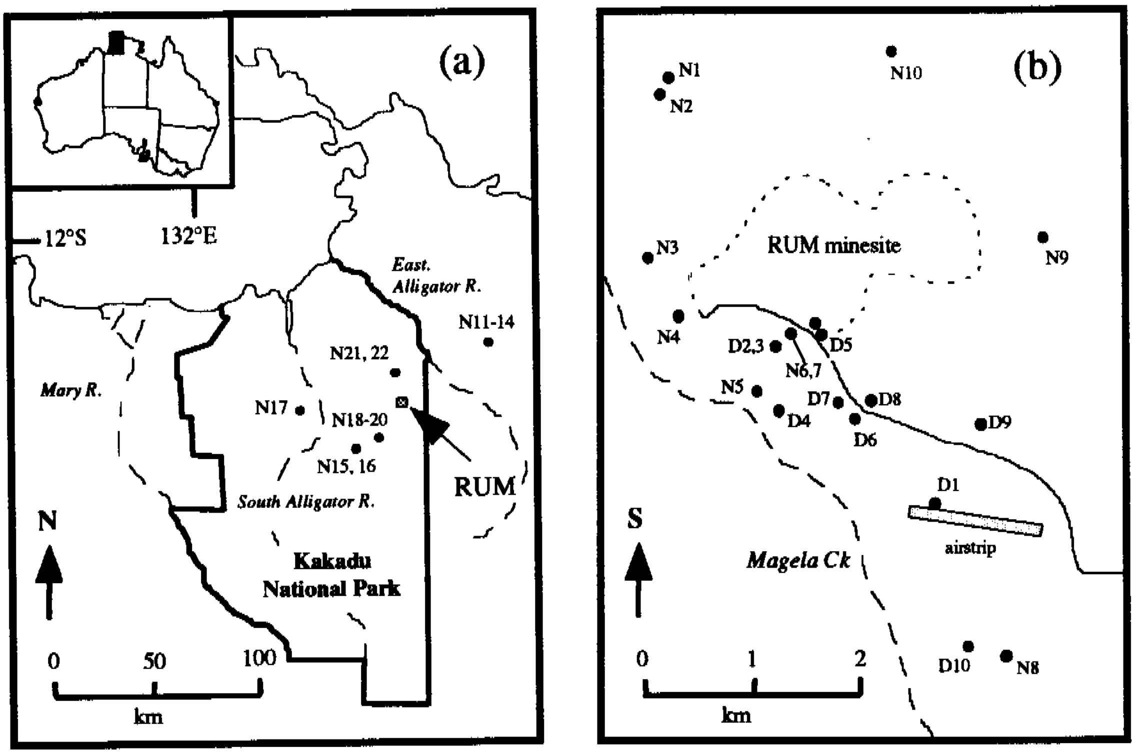


Figure 2.1 Location of study sites (a) outside and (b) inside the immediate area of Ranger uranium mine (RUM). The waste rock sites (W1–7) were all located on Ranger's northern waste rock dump, and are not indicated here.

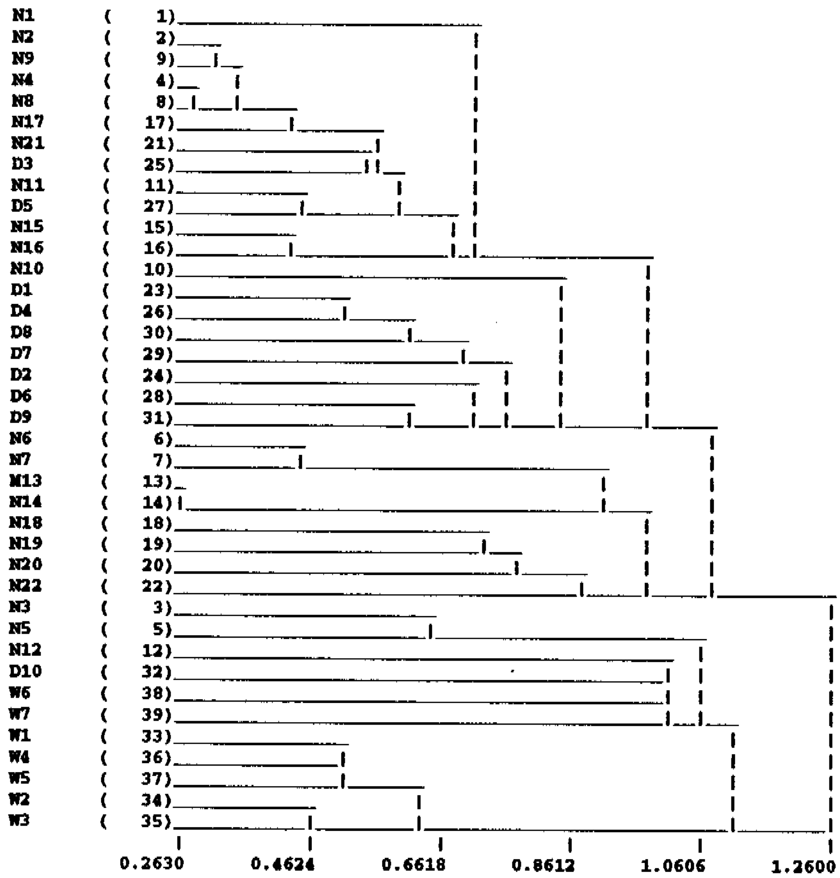


Figure 2.2 Dendrogram illustrating classification of study sites, using flexible UPMGA, based on woody plant composition

Table 2.2 Groups of sites identified by flexible UPGMA of woody species composition (fig 2.2)*

Group	Group members	Characteristic species
1	N1, N2, N4, N8, N9, N11, N15, N16, N17, N21, D3, D5	*Eucalyptus tetrodonta* (100), *Terminalia ferdinandiana* (100), *Petalostigma quadriloculare* (100)
2	N10, D1, D2, D4, D6, D7,	*E. tetrodonta* (88), *Wrightia saligna* (75)
3	N6, N7, N13, N14 D8, D9	*E. tectifica* (100), *Buchanania obovata* (100)
4	N18, N19, N20, N22	*Xanthostemon paradoxus* (100), *Gardenia megasperma*, *Persoonia falcata*, *Terminalia carpentariae* (all 75)
5	N3, N5	*Melaleuca viridiflora* (100)
6	N12	*E. pruinosa*, *E. foelscheana*
7	D10	*Acacia mimula*, *A. difficilis*
8	W6	*Pandanus spiralis* (only woody species present)
9	W7	no woody species present
10	W1, W2, W3, W4, W5	*Acacia holosericea* (100), *A. mountfordiae* (100)

* The constancy (% occurrence at sites within group) of each characteristic species is given in parentheses

3 Ant-habitat associations

3.1 Methods

3.1.1 Sampling

Ants were sampled by pitfall traps (4 cm diameter plastic specimen jars, partly filled with ethanol as a preservative). A 5 × 3 trapping grid with 10 m spacing was established at each site, and traps were operated for a 48 hour period at each site during three trapping sessions (July and November 1992 and November 1993). Pitfall traps have been widely used in quantitative studies of Australian ant communities and have been shown to provide a reliable estimate of species composition in the Kakadu region (Andersen 1991c). Sampling intensity was designed to provide comparative data on species richness and relative abundance (Palmer 1990), rather than to assemble complete species lists for each site.

Ants were identified to species, with unidentified taxa given code numbers following nomenclature established in the senior author's previous studies of Kakadu ants (Andersen 1991c, 1992, 1993a). The abundance of each species in each trap was scored according to a 6-point scale (where 1 = 1 ant; 2 = 2–5 ants; 3 = 6–10 ants; 4 = 11–20 ants; 5 = 21–50 ants; 6 = >50 ants), to avoid distortions caused by large numbers of individuals falling into a small number of traps (Andersen 1991c). A species' total abundance at a site was defined as the sum of its abundance scores, pooled over the three trapping sessions.

3.1.2 Analysis

The total number of ant species (species richness) for each site was determined, and the relationship between ant and plant species richness investigated.

Five data sets, portraying increasingly simplified representations of ant community composition, were considered for multivariate analysis:

1. The complete species x sites matrix of total abundance scores. This will be referred to as **species–abundance data**, and was used to compile the other four data sets.
2. A genus x sites matrix of abundance scores, with genus abundance being the sum of abundances of congeneric species. This will be referred to as **genus–abundance data**.
3. A genus x sites matrix of species richness, referred to as **genus–species data**.
4. A functional group (table 1.1) x sites matrix of abundance scores, with functional group abundance being the sum of abundances of constituent species. This will be referred to as **functional group–abundance data**.
5. A functional group x sites matrix of species richness, referred to as **functional group–species data**.

The five data sets were analysed using PATN. A Bray-Curtis site association matrix was constructed for each, after all abundance data (ie data sets 1, 2 and 4) had been cube-root transformed. The species-abundance matrix was used to classify sites into ten groups using flexible UPGMA (beta = –0.25). The Mantel test (Sokal & Rohlf 1995), using 1000 random permutations, was used to compare each of the five association matrices with each other, and with both the floristic association matrices (section 2.2.1). The test produces a correlation coefficient (r), with sample size defined by [n x (n-1)]/2, where n = number of sites.

3.2 Results

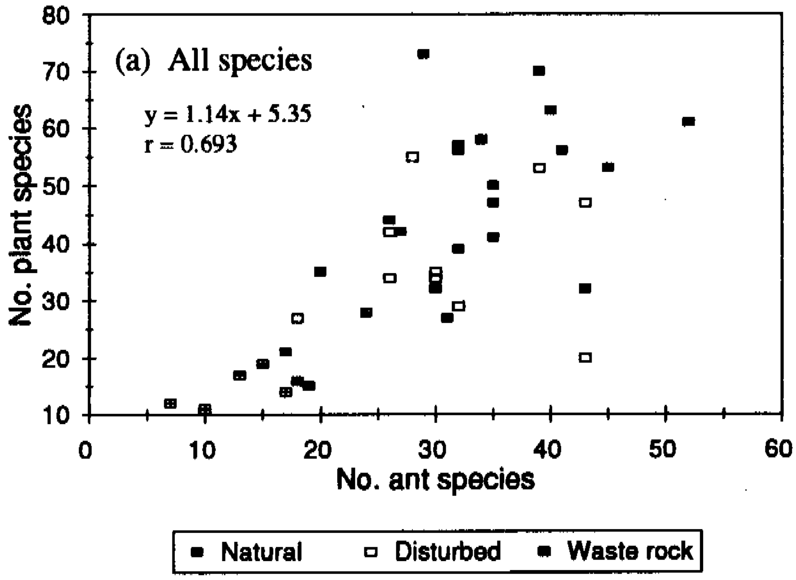
A total of 162 species of ants from 32 genera were recorded in pitfall traps (appendixes 1 and 2). The number of species ranged from 17 to 52 (mean of 33.1) at natural sites, from 18 to 43 (mean of 31.5) at disturbed sites, and 7 to 24 (mean of 14.9) at waste rock sites. Ant species richness was highly correlated with plant species richness, considering both total plant species, and woody species only (fig 3.1). There was a particularly strong correlation between ant species richness and woody species richness (fig 3.1b) at disturbed and waste rock sites ($r = 0.812$, $n = 17$, $p<0.001$).

The most abundant ants were Dominant Dolichoderinae (mostly species of *Iridomyrmex*), Hot Climate Specialists (mostly species of *Melophorus*), Opportunists (mostly species of *Rhytidoponera*, *Tetramorium* and *Paratrechina*) and Generalised Myrmicinae (mostly species of *Monomorium* and *Pheidole*) (appendixes 3–5). These four functional groups were abundant at virtually all natural and disturbed sites, but at waste rock sites Dominant Dolichoderinae were patchy and Hot Climate Specialists were mostly absent (fig 3.2).

The classification dendrogram based on ant species composition is shown in figure 3.3, and site composition at the ten group level is given in table 3.1. The groups are generally similar to those based on vegetation (table 2.2). Ant group 4 is almost identical to vegetation group 1 (woodlands and open forests with *Eucalyptus tetrodonta* and usually also *E. miniata*). The ant communities are dominated by species of *Iridomyrmex* (usually *I. sanguineus* and *Iridomyrmex* spp. 1 and 14; appendix 1), and include numerous widespread savanna species (table 3.1). Ant group 2 corresponds exactly to vegetation group 10 (W1–5), and ant group 3 corresponds to vegetation groups 8 (W6) plus 9 (W7). The ant communities of these groups all have low diversity and include the tramp species *Paratrechina longicornis*.

Association matrices based on the five ant community data sets were all highly correlated with each other (table 3.2). The highest correlation ($r = 0.901$) was between genus–species and functional group–species data. Interestingly, genus–species and functional group–species data were more highly correlated with species–abundance data ($r = 0.812$ and 0.715 respectively) than were genus–abundance and functional group–abundance data respectively ($r = 0.718$, 0.678).

The association matrix based on ant species–abundance was highly correlated with both plant species association matrices (table 3.3). The correlation coefficients were somewhat reduced for ant genus association matrices, and somewhat reduced again for ant functional group association matrices. However, it is noteworthy that ant functional group matrices, involving the collapsing of 162 species into only eight groups, are still very highly correlated (r values ranging from 0.492 to 0.536) with plant species matrices. Correlation coefficients were consistently higher for woody, compared with all plant species. This suggests that the ephemeral component of the vegetation is less important in determining ant community composition than are perennial, woody plants.



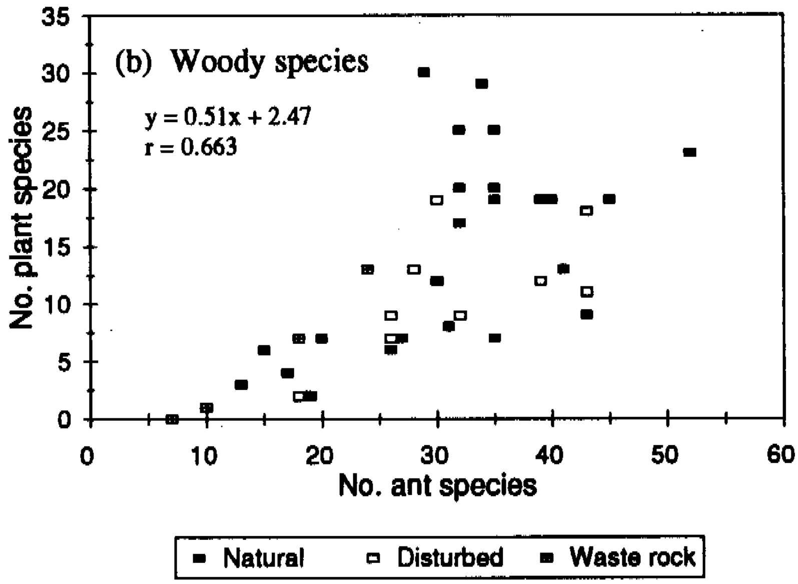


Figure 3.1 Relationships between ant and plant species richness, considering (a) all plant species, and (b) woody species only. Both correlation coefficients are highly significant ($p<0.001$).

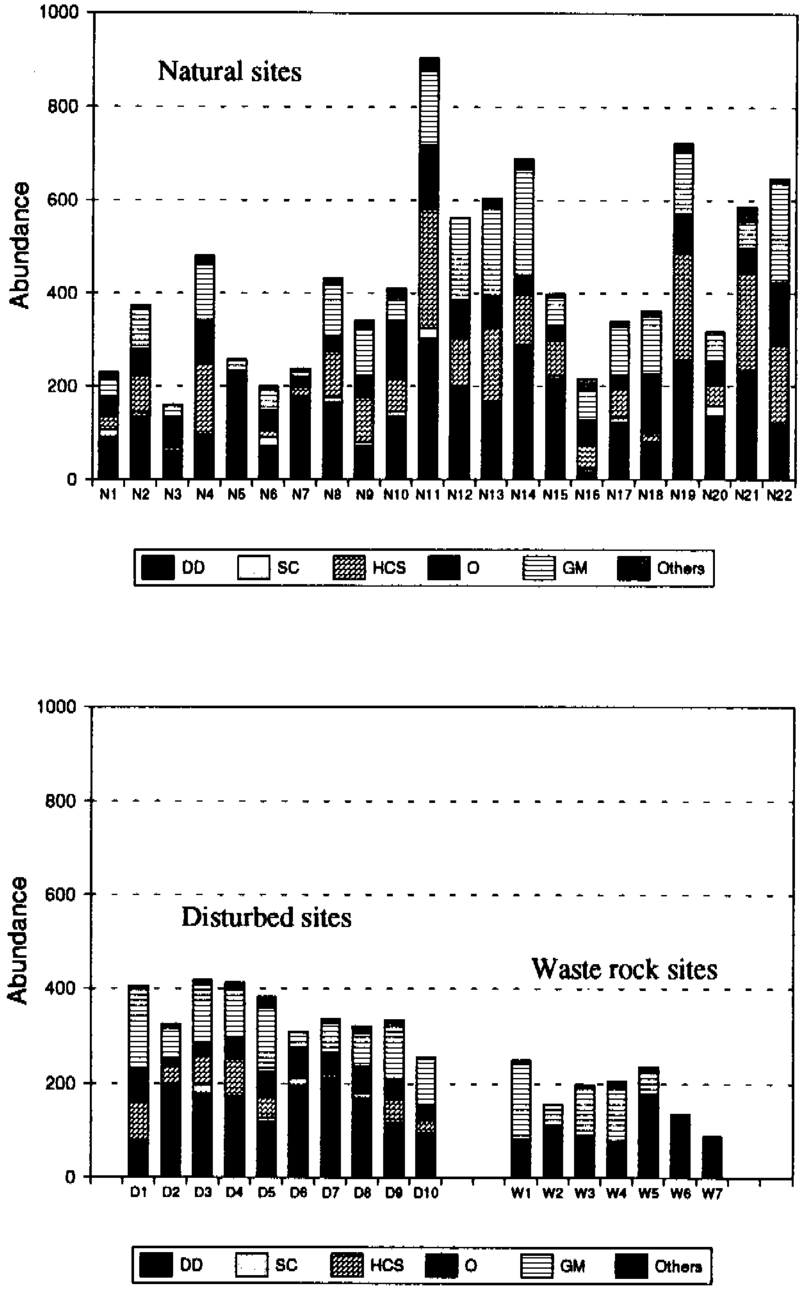


Figure 3.2 Abundances of major ant functional groups recorded in pitfall traps; DD = Dominant Dolichoderinae; SC = Subordinate Camponotinae; HCS = Hot Climate Specialists; O = -Opportunists; GM = Generalized Myrmicinae

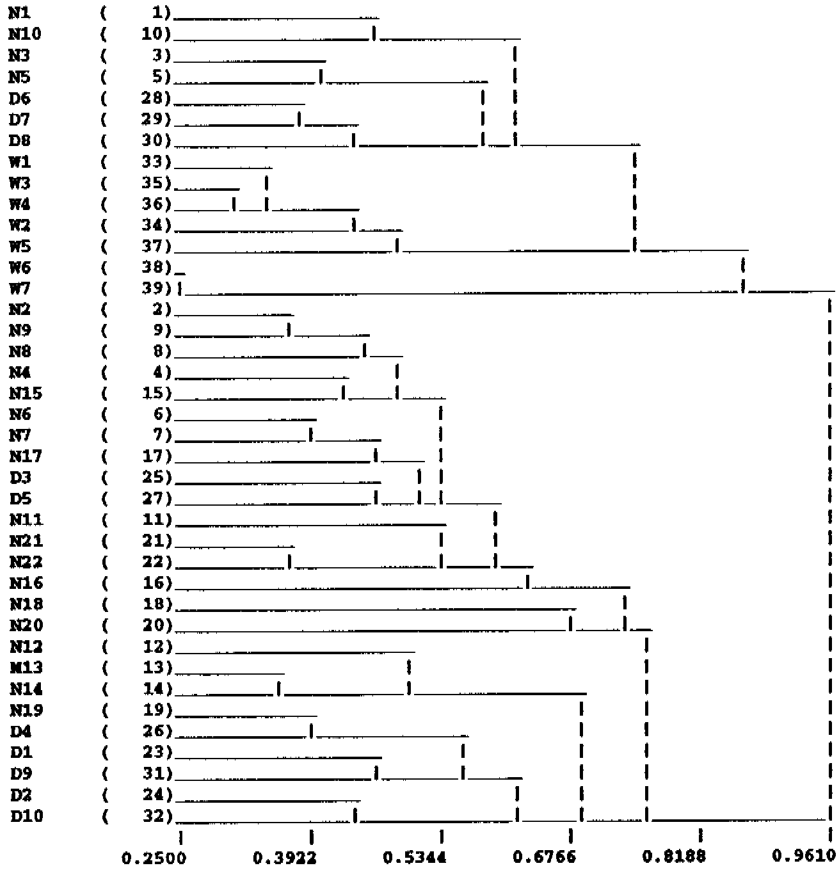


Figure 3.3 Dendrogram illustrating classification of study sites, using flexible UPMGA, based on ant species composition

Table 3.1 Groups of sites identified by flexible UPGMA of ant species composition (fig 3.3)*

Group	Group members	Characteristic species
1	N1, N3, N5, N10, D6, D7, D8	*Odontomachus* sp. nr. *turneri* (86), *Pheidole* sp. 3 (71), *Camponotus* sp. 13 (86)
2	W1, W2, W3, W4, W5	*Pheidole* sp. 3 (100), *Tetramorium lanuginosum* (100), *Camponotus* sp. 9 (100), *Paratrechina longicornis* (100)
3	W6, W7	*Paratrechina longicornis* (100) [Other characteristic species from group 3 absent]
4	N2, N4, N5, N7, N8, N9, N11, N15, N17, N21, N22, D3, D5	*Rhytidoponera aurata* (69), *Rhytidoponera* sp. 9, *Monomorium* sp. 24 (100), *Tetramorium* sp. sp. 1 (100), *Iridomyrmex* sp. 14 (100), *Melophorus* sp. 1 (100)
5	N16	*Rhytidoponera turneri*, *Monomorium* sp. 28
6	N18	*Odontomachus turneri*, *Rhytidoponera* sp. 10, *Monomorium* sp. 23, *Iridomyrmex* sp. 9
7	N20	*Monomorium* sp. 27, *Camponotus* sp. 8
8	N12, N13, N14	*R. aurata* (100), *Pheidole* sp. 5 (100), *Melophorus* sp. 20 (100)
9	N19, D1, D4, D9	*Pheidole* sp. 5 (100), *Melophorus* sp. 11 (100), *Polyrhachis* sp. 3 (100)
10	D2, D10	*Monomorium* spp. 1 & 5 (100), *Monomorium* sp. 18 (100), *Iridomyrmex* sp. 3

* The constancy (% occurrence at sites within group) of each characteristic species is given in parentheses. These 'characteristic' species do not include species occurring widely across groups, even if they have high constancy.

Table 3.2 Correlation coefficients (r) comparing Bray-Curtis association matrices based on the five ant community data sets (section 3.1.2)*

	Species–abundance	Genus–abundance	Genus–species	Functional group–abundance
Genus–abundance	0.718			
Genus–species	0.812	0.860		
Functional group–abundance	0.678	0.865	0.811	
Functional group–species	0.715	0.759	0.901	0.827

* All are highly significant (p<0.001)

Table 3.3 Correlation coefficients (r) comparing ant and plant Bray-Curtis association matrices*

	Plant species (all)	Plant species (woody only)
Ant species–abundance	0.638	0.665
Ant genus–abundance	0.568	0.626
Ant genus–species	0.590	0.643
Ant functional group–abundance	0.495	0.539
Ant functional group–species	0.492	0.556

* All are highly significant (p<0.001)

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

Table 4.2 cont'd next page

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

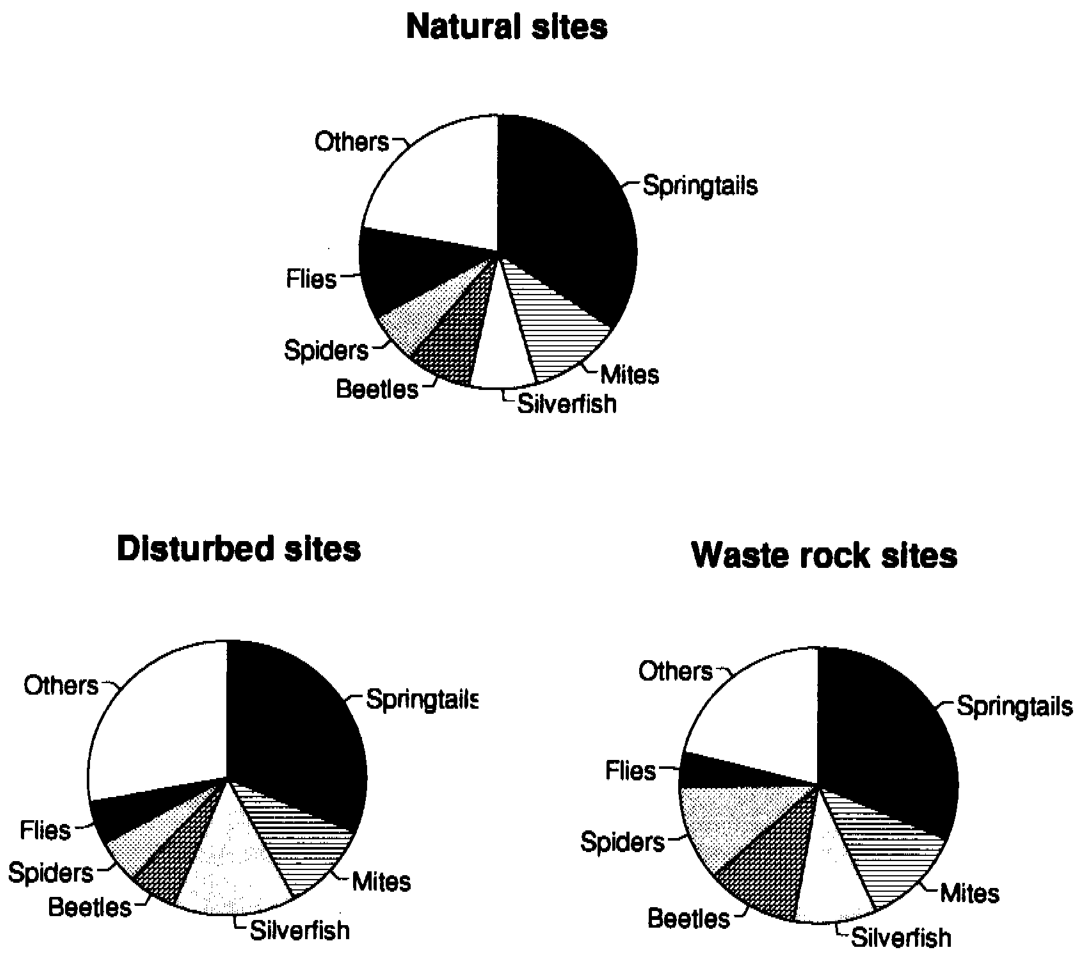


Figure 4.1 Summary composition of ground-foraging invertebrates (other than ants) recorded in pitfall traps at natural, disturbed and waste rock sites

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

Table 4.3 cont'd next page

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

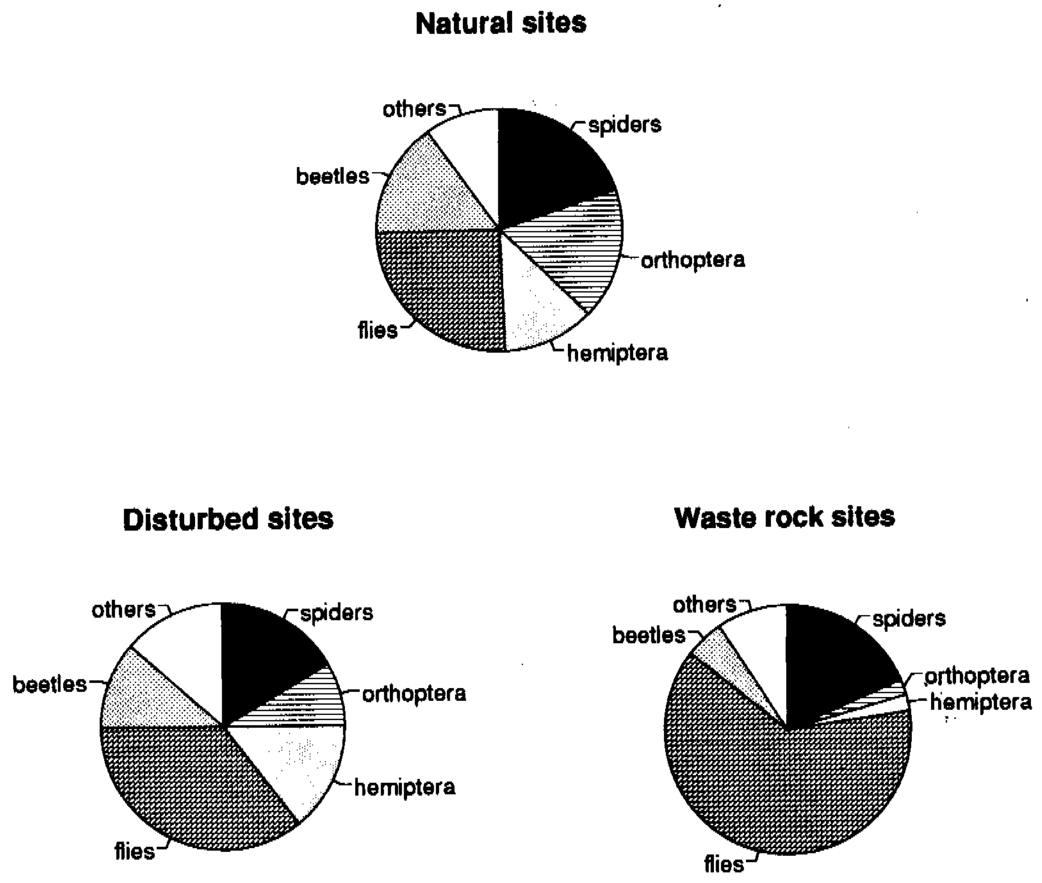


Figure 4.2 Summary composition of invertebrates (other than ants) recorded in sweep nets at natural, disturbed and waste rock sites

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

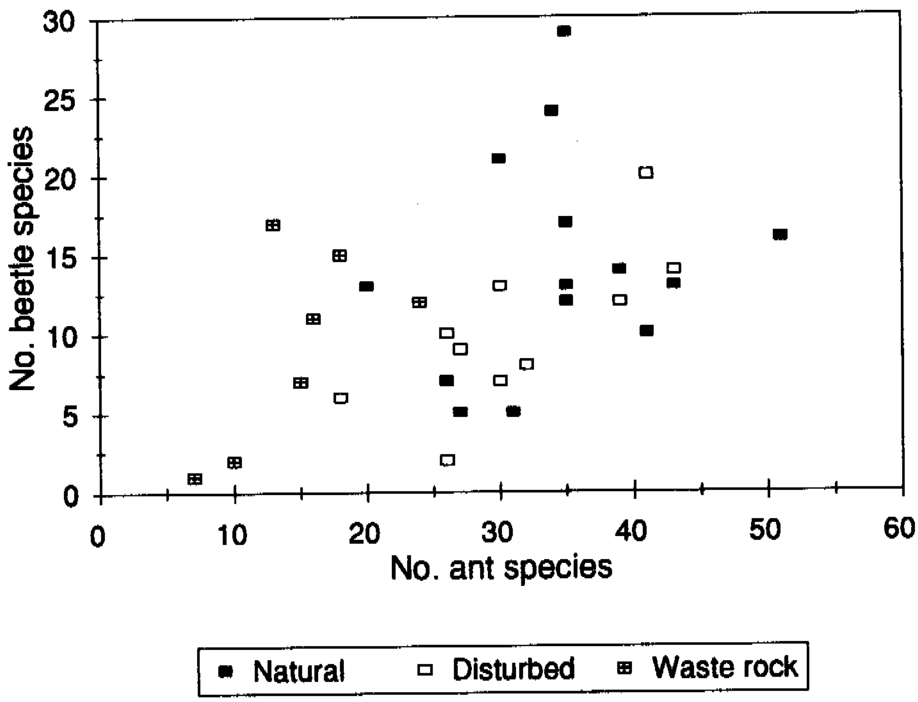


Figure 5.1 Relationship between number of ant species in pitfall traps and number of beetle species in sweep samples. The equation for the best fit linear regression is y = 0.273x + 3.867 (r = 0.455, p = 0.005).

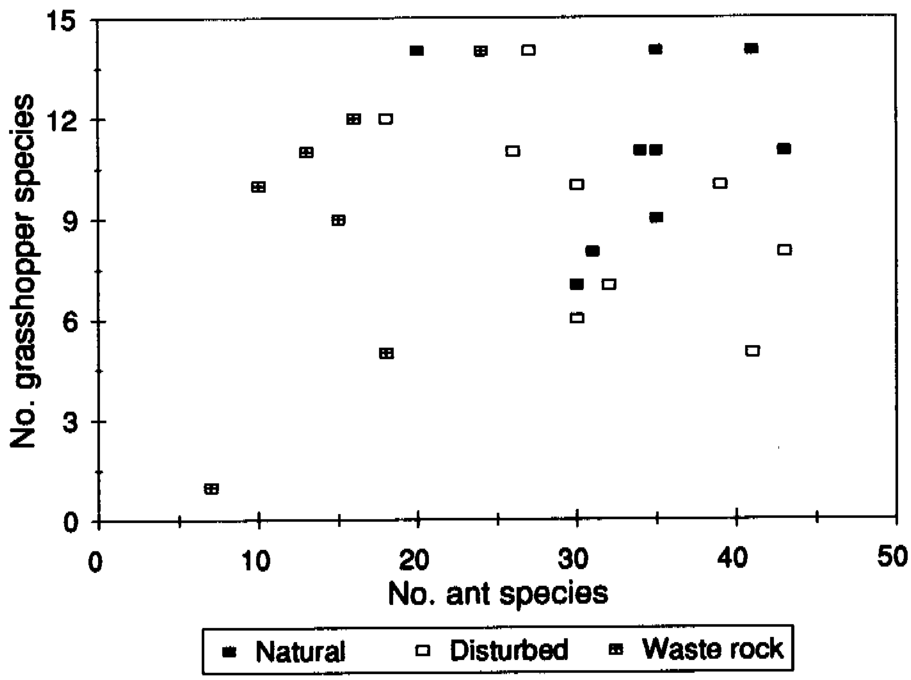


Figure 5.2 Relationship between number of ant species in pitfall traps and number of grasshopper species (r = 0.216, p > 0.05)

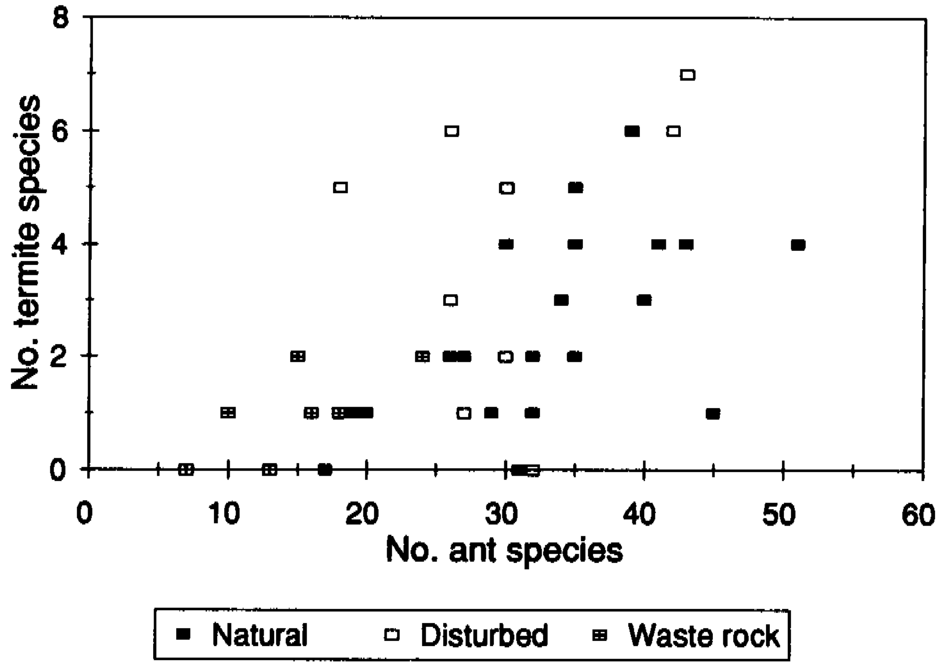


Figure 5.3 Relationship between number of ant species in pitfall traps and number of termite species at paper baits. The equation for the best fit linear regression is $y = 0.107x - 0.508$, $r = 0.546$, $p < 0.001$.

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.

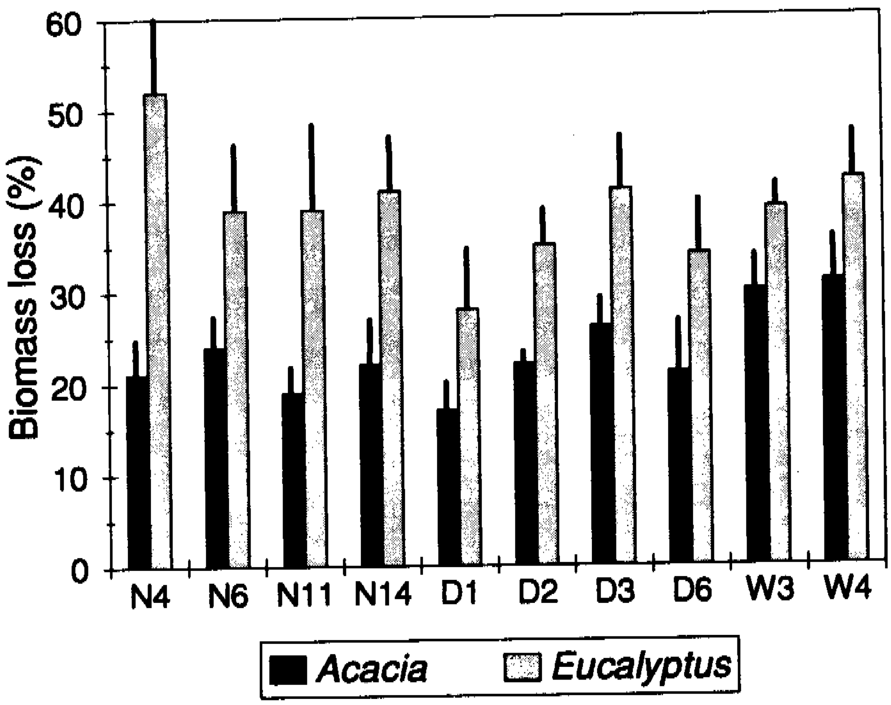


Figure 6.1 Loss of leaf biomass over a single Wet season at the ten representative sites

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**

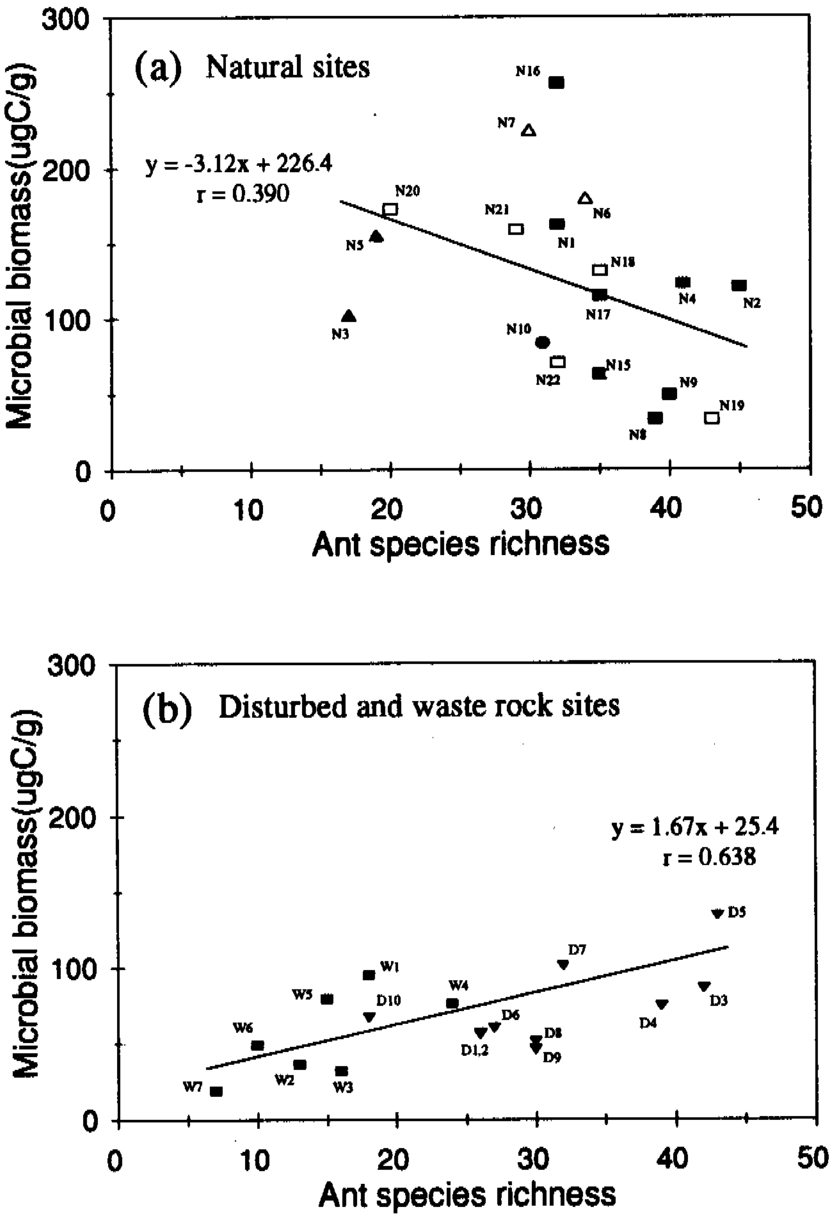


Figure 6.2 Relationships between ant species richness and soil microbial biomass at (a) natural and (b) disturbed (triangles) and waste rock (squares) sites. In (a), site groups based on woody species composition (table 2.2) are distinguished: group 1 (closed squares); group 2 (closed circles); group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

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

Table 7.1 cont'd next page

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.

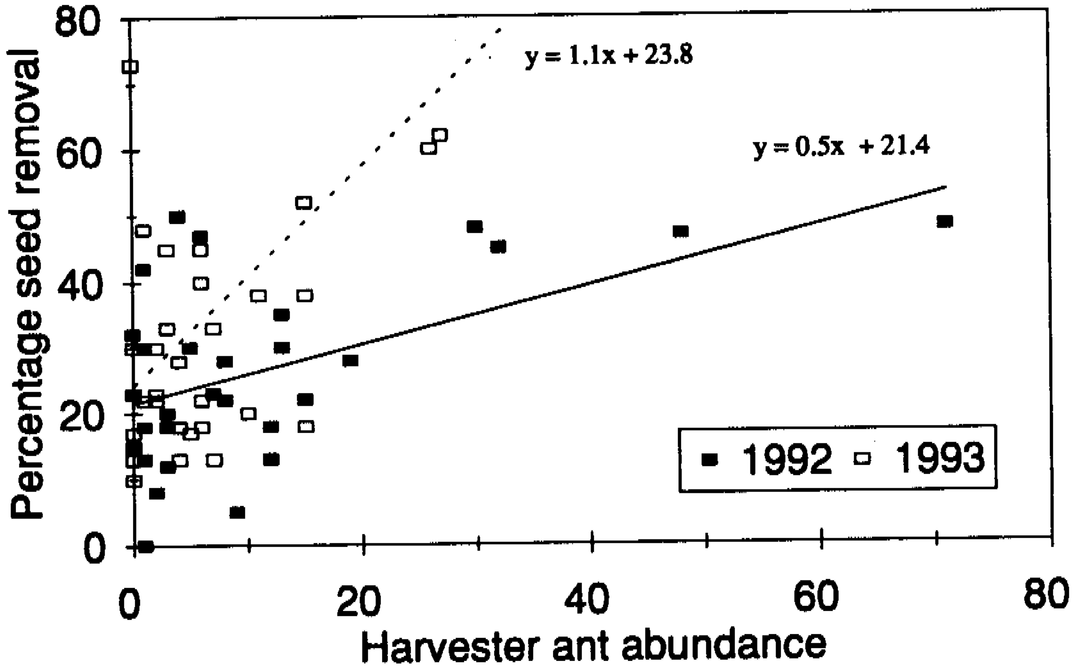


Figure 7.1 Relationships between harvester ant abundance and rates of seed removal during 1992 and 1993

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.

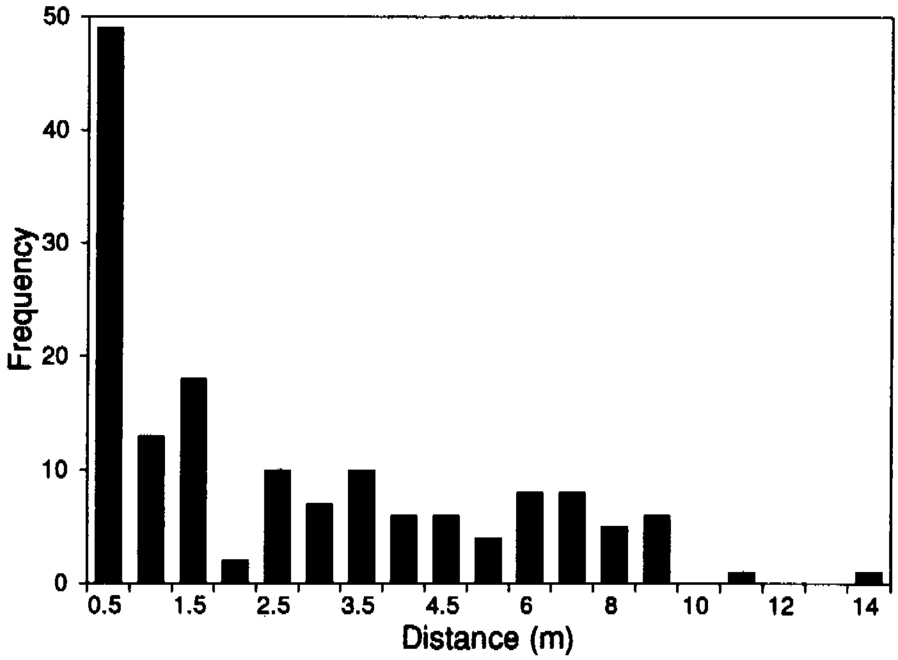


Figure 8.1 Overall dispersal curve generated by ants during myrmecochory trials (data pooled across all ant species and all sites)

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

Table 8.2 cont'd next page

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

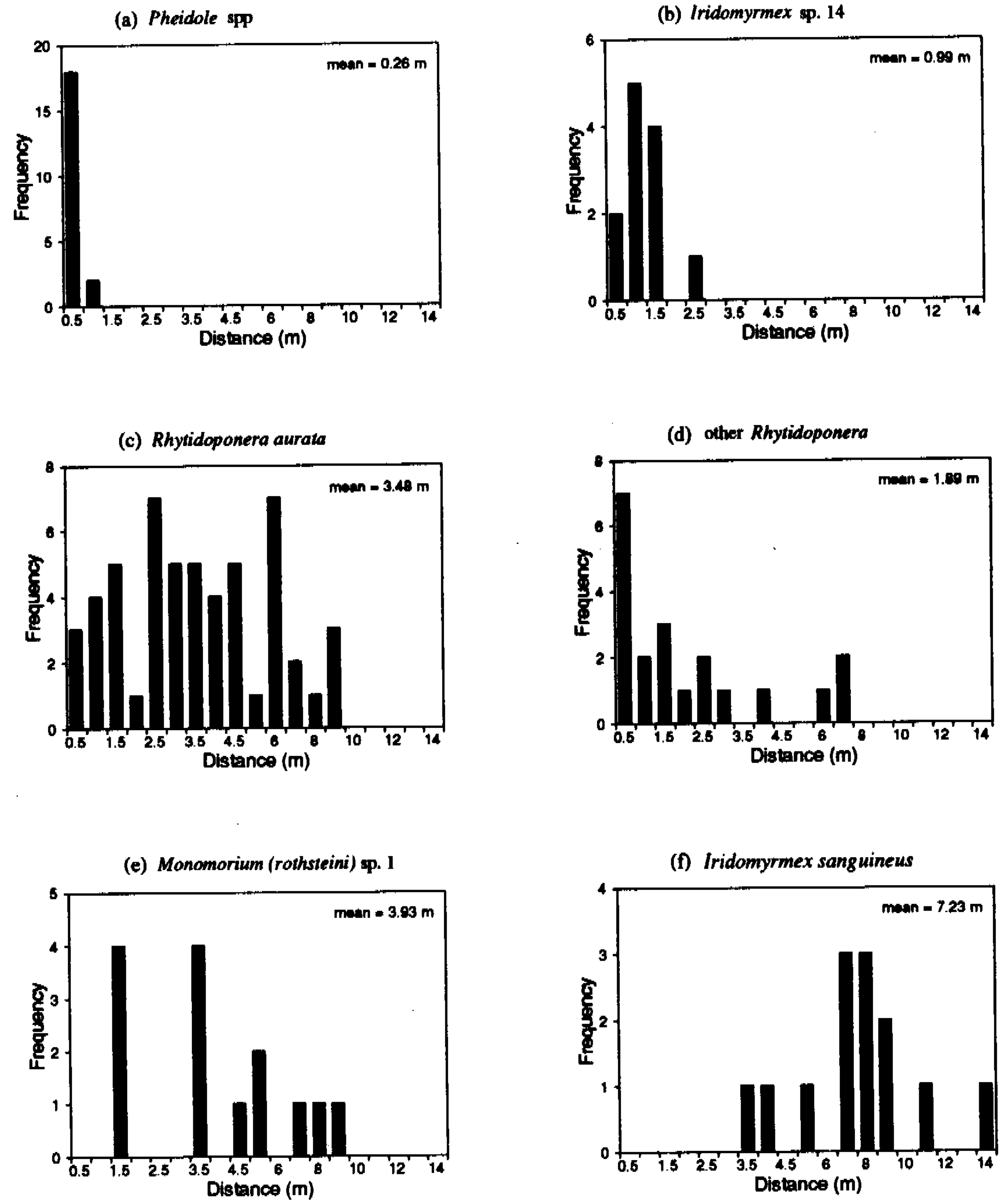
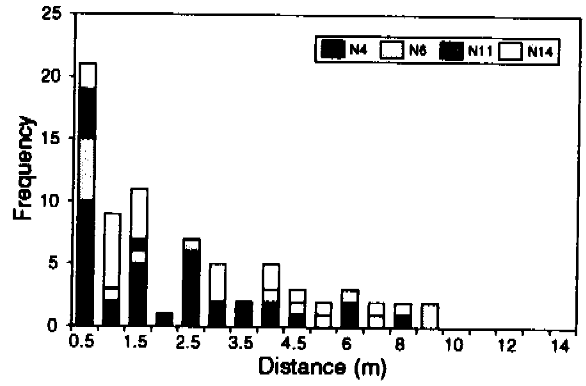
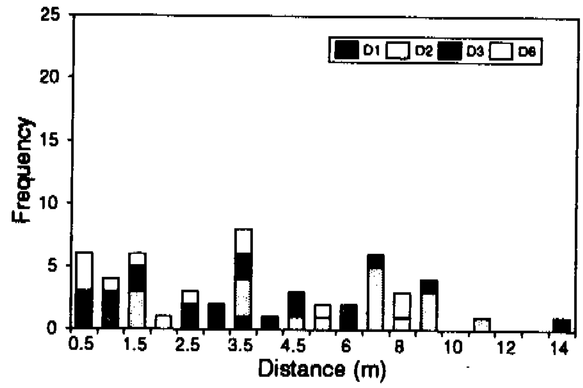


Figure 8.2 Dispersal curves generated by different ant taxa (data pooled across sites)

(a) Natural sites



(b) Disturbed sites



(c) Waste rock sites

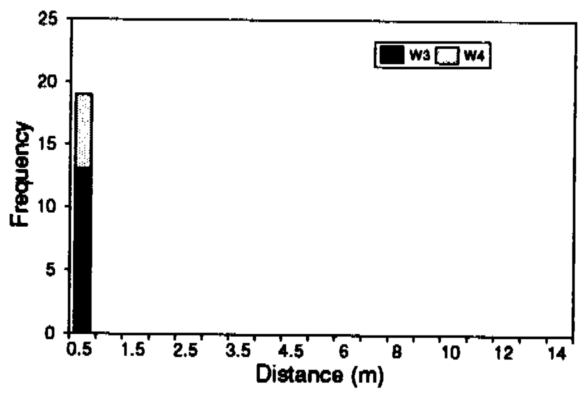


Figure 8.3 Dispersal curves generated by ants at different sites (data pooled across ant species)

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.

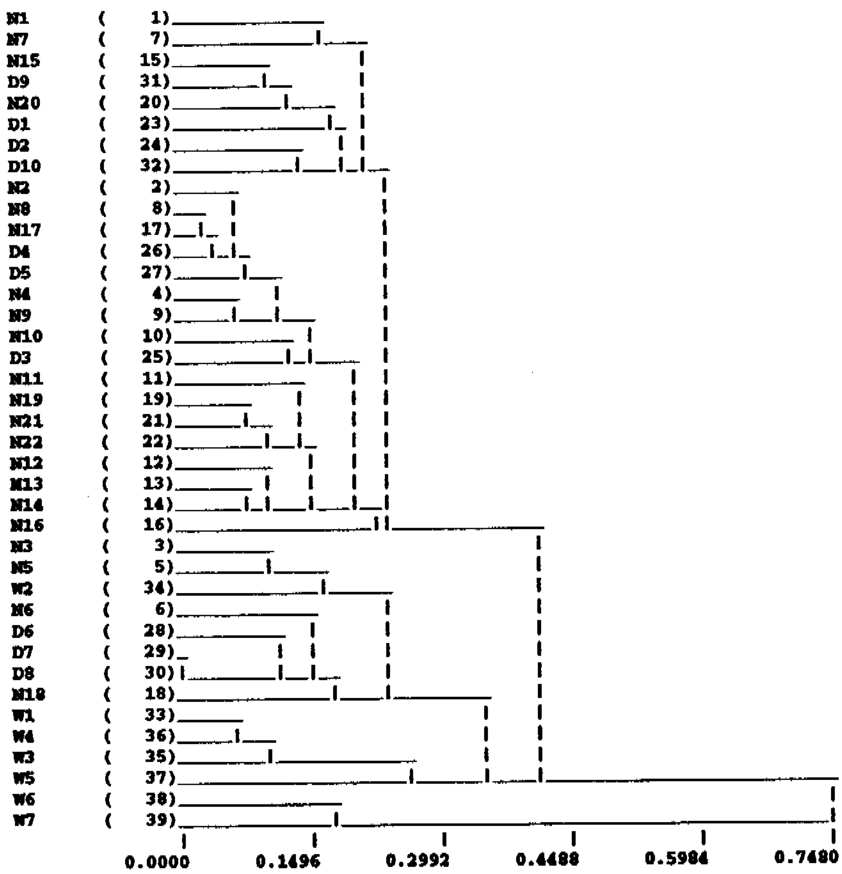


Figure 9.1 Dendrogram illustrating classification of study sites, using flexible UPMGA, based on the abundance of ant functional groups

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 × 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.

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APPENDICES

Appendix 1 Abundances of ant species in pitfall traps (species–abundance data). Introduced species are denoted by an asterisk.

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	N21	N22
Ochetellus sp.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Papyrius sp.1	.	.	.	.	.	.	.	.	.	.	.	.	.	13	.	.	.	.	.	.	.	.
Tapinoma melanocephalum*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tapinoma sp.1	.	1	.	.	.	1	.	.	.	.	.	2	.	.	.	.	1	.	.	1	.	.
Tap. sp.2	.	.	9	.	1	.	.	.	.	4	.	.	.	.	.	.	.	.	.	.	.	.
Tap. sp. 3	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.
FORMICINAE																						
Camponotus (nigroaeneus gp.) sp.4	.	.	.	.	.	.	.	.	.	.	2	.	.	.	2	.	.	1	.	.	.	.
Camp. sp. 6	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
C. (discors gp.) sp.8	.	2	.	1	.	.	.	.	.	.	.	1	.	1	1	2	.	.	.	22	2	.
C. (variegatus gp.) sp.9	4	.	3	.	2	.	.	.	.	3	.	4	.	1	.	.	.	.	.	.	.	.
C. (variegatus gp.) sp.11	.	.	.	.	.	.	.	6	2	.	1	.	.	1	.	.	.	.	.	.	.	.
C. (variegatus gp.) sp.12	.	.	.	2	.	.	2	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.
C. (variegatus gp.) sp.13	1	.	3	.	2	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.
C. (variegatus gp.) sp.14	4	1	.	.	1	.	1	.	.	1	6	.	.	.	3	1	1	.	.	.	.	.
C. (?ephippum gp.) sp.15	.	.	.	.	.	.	1	.	.	.	1	.	.	.	.	.	1	.	.	.	.	.
C. (rubiginosus gp.) sp.17	.	.	.	1	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
Camp. sp.18	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Melophorus (aeneovirens gp.) sp.1	6	10	2	14	.	2	2	4	4	.	50	.	.	8	12	13	18	5	1	.	33	64
M. (aeneovirens gp.) sp.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	59	.	.	.
M. (aeneovirens gp.) sp.4	.	.	.	.	.	.	.	2	.	.	13	1	.	.	.	.	1	.	4	.	.	.
Mel. sp.5	.	.	.	.	.	.	1	.	.	.	.	54	52	31	.	.	.	.	.	.	.	.
Mel. sp.6	.	4	.	4	.	2	7	24	13	.	1	.	.	.	6	.	34	2	1	36	8	.
Mel. sp. 9	.	12	.	2	.	.	.	1	.	.	.	1	35	39	2	.	.	.	7	.	26	.
M.el sp.10	7	43	.	115	.	1	.	23	47	65	101	.	.	1	9	1	1	4	22	.	72	23
Mel. sp.11	.	.	.	.	.	.	.	8	.	4	.	.	29	27	7	.	.	.	39	.	53	42
Mel. sp. 12	.	.	.	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Mel. sp.13	8	2	.	3	.	.	9	25	4	1	.	.	2	.	.	.	.	.	.	.	3	2
Mel. sp.15	.	.	.	.	.	.	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Mel. sp.16	.	.	.	.	.	.	.	.	.	.	74	.	.	.	36	36	.	4	.	.	15	.
Mel. sp.17	1	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	4	.	.	.	.
Mel. sp. 18	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.
Mel. sp.20	.	.	.	.	.	.	.	.	.	.	.	49	38	2	.	.	.	.	.	.	.	.
Oecophylla smaragdina	12	.	.	8	.	.	.	.	8	.	2	.	.	.	1	6	4	.	11	.	20	6
Opisthopsis haddoni	5	1	.	4	.	1	.	2	5	3	5	1	1	3	.	3	2	.	3	.	1	1
Paratrechina longicornis*	.	.	.	.	23	.	.	.	.	.	.	.	.	.	.	.	.	27	.	.	.	.
P. (obscura gp) sp.3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
P. (vaga gp) sp.4	8	1	1	7	7	3	.	.	1	16	.	.	.	2	.	.	.	.	.	.	.	.
P. (vaga gp) sp. 7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	.	.	.	.
P. (minutula gp.) sp.1	.	.	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
P. (minutula gp.) sp.2	3	5	.	16	.	.	.	9	5	1	55	.	.	.	4	1	.	1	20	2	.	.
P. (minutula gp.) sp.6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	.	.	19	62
Polyrhachis gab	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	.	.	.	.	.
P. inconspicua	.	.	.	.	.	.	.	.	1	.	.	.	.	.	1	.	.	.	.	.	.	.
P. pseudothrinax	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
P. (Hagiomyrma) sp.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
P. (Hagiomyrma) sp.3	.	.	.	.	.	16	1	.	1	.	3	.	.	.	.	1	.	4	.	1	.	.
P. (gab gp.) sp.16	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
P. (gab gp.) sp.17	1	2	.	.	1	3	1	3	2	.	2	.	.	.	1	.	1	.	.	.	.	.
Stigmacros (Stigmacros) sp.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.
Stigmacros (Campostigmacros) sp. 4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Total abundance	229	374	160	480	257	200	237	433	342	410	903	563	603	690	399	217	338	362	722	316	586	648
Number of species	32	45	17	41	19	34	30	39	40	31	52	26	27	35	35	32	35	35	43	20	29	32

Appendix 1 (cont'd)

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	N21	N22
PONERINAE																						
Anochetus rectangularis	.	1	.	.	.	.	.	.	1	.	.	.	.	.	.	3	1	.	.	.	.	.
A. sp. nr. armstrongi	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Anochetus sp.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cerapachys sp.3	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.
Cer. sp.4	.	.	1	.	.	.	1	.	2	1	.	.	.	.	.	.	.	3	.	.	.	.
Cer. sp.7	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.
C. (sp. nr. clarki) sp.8	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Discothyrea sp.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hypoponera sp.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Leptogenys exigua	.	.	.	.	.	.	.	.	.	.	1	.	.	2	.	.	.	.	2	.	.	.
Lept sp.2	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.
Odontomachus turneri	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	22	.	.	.	.
O. nr.turneri	3	.	19	.	19	.	.	.	.	10	.	1	.	.	.	.	.	.	.	.	.	.
O. (ruficeps gp) sp.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.
Bothroponera sp.3	.	.	.	.	.	1	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.
Both. sp. 6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.
Both. sp. 7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Platythyera parva	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
Rhytidoponera aurata	4	.	.	14	.	7	.	.	1	39	13	13	60	31	5	.	11	4	.	.	6	6
R. borealis	.	.	.	.	.	.	1	.	.	27	2	.	.	.	.	.	.	11	3	.	.	.
R. reticulata	.	17	31	.	6	1	.	18	3	11	10	64	.	.	.	.	8	.	17	32	.	.
R. trachypyx	.	17	.	10	.	7	6	.	5	.	15	.	.	.	3	20	2	13	.	.	13	25
R. (aurata gp.) sp.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	23	.	.	.
R. (aurata gp.) sp.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.
R. (aurata gp.) sp.10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	9	.	.	.	.
R. nr. rufithorax	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.
R. (reticulata gp.) sp.7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25
R. (tenuis gp.) sp.9	15	2	.	17	.	8	4	1	8	11	.	.	.	1	1	.	6	4	.	.	1	.
R. (tuneri gp.) sp.3	.	.	.	5	.	.	.	.	.	.	.	.	2	.	3	17	.	.	.	.	.	.
R. (tyloxys gp.) sp.8	.	.	.	7	.	2	.	.	.	.	.	.	1	.	.	.	.	4	.	.	.	.
R. (tyloxys gp.) sp.11	.	.	.	.	.	.	.	.	.	.	.	2	.	2	.	.	.	.	.	.	.	.
Sphinctomyrmex sp.2	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Sphinctomyrmex sp. 3	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.
DORYLINAE																						
Aenictus (ceylonicus group) sp.2	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
MYRMICINAE																						
Cardiocondyla ?nuda	2	.	4	.	21	1	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
Crematagaster sp.1	3	6	.	.	.	.	.	2	6	1	.	.	3	6	.	2	.	.	1	.	.	.
Crem. sp.2	.	.	17	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
Glamyromyrex sp.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
Meranoplus (diversus gp.) sp.1	2	.	.	.	.	.	.	4	.	1	.	.	.	.	.	.	.	.	14	.	3	.
M. (diversus gp.) sp.2	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	1	.	.	.
M. (diversus gp.) sp.3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
M. minimus	.	7	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
M. (mjobergi gp.) sp.4	.	.	.	2	.	1	.	.	25	.	.	.	.	.	1	.	.	.	.	.	.	.
M. (mjobergi gp.) sp.6	1	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	5	.	.
Mer sp.6	.	.	.	.	.	.	.	.	.	.	5	.	.	.	.	.	4	.	.	.	.	.
Mer. sp.8	2	2	.	.	.	1	1	.	.	.	.	.	.	.	.	.	1	.	4	.	.	.
Mer. sp.10	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	3
Mer. sp.14	.	.	.	4	.	7	.	.	2	.	.	.	.	.	.	.	1	.	.	3	.	5
Mer. sp.15	.	.	.	.	.	.	.	.	.	.	5	.	.	.	.	.	.	.	.	.	.	.
Mer. sp.16	.	.	.	.	.	.	.	1	.	.	2	.	.	.	.	.	.	.	.	.	.	.
Mer. sp. 17	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Appendix 1 (cont'd)

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	N21	N22
Monomorium (rothsteini gp.) sp.1																	4		76			29
M. ('Chelaner') sp.5								3	1													
M. ('Chelaner') sp.6		5						2			4		20	20							6	
M. ('Chelaner') sp.7	1	1				1	3		1		4				5	15				1	4	4
Mon. sp.8		2		10		2	6	13			2				2	9	2		9			7
Mon. sp. 9		2		4																		
Mon. sp.11		4	5	1		2	2			17	4	82	115	108	3	3	18		13	2	24	73
Mon. sp.13											7								1			2
Mon. sp.14				25	6	12		29			76	7	14	16	4	6	6	3	20	2	9	50
Mon. sp.17		4		3	9	18	1	7	7							2		27	1	0	11	18
Mon. sp.18		16							26													
Mon. sp.21	6	19		36	2	9	1	34	39		33	74	40	29	35	1	40	13	8	2		22
Mon. sp.22																1						
Mon. sp.23																5		10				
Mon. sp.24	20	14	2	5	3	1	1	11	15	12	12		3	10	6	9	19	49		17	11	8
Mon. sp.26															7	9						
Mon. sp.27																		9	36	37		
Mon. sp.28																7						
Mon. sp.29														1								
Mon. sp.30																						
Mon. sp. 31																			1			
Oligomyrmex sp.1						2										1						
Pheidole sp.1																			36			
Ph. sp.3			2	9					3	4				15								6
Ph. sp. 5		2						1				9	15	5			12		4		1	
Ph. sp.7																		4				
Ph. sp.8	6	5		3		3	3		2	1								11				2
Ph. sp.9											14											9
Ph. sp.13		1	1	25			1	8	1				1		3	10	7					15
Ph. sp.14										18				4								
Ph. sp.15																				2		
Ph. sp.17		1																				
Ph. sp.18																						
Ph. sp.19																						
Ph. sp.20		7						8														
Ph. sp.21												2		34								
Ph. sp.25																			4			
Ph. sp.26											11											
Quad. sp. 4				+																		
Solenopsis sp.1	3	3		7	1		1	4	3	17	14				1				4		1	2
Sol. sp.2	1	1		1		2	1	2	3		2			1			3	3				
Sol. sp.4				1																		
T. lanuginosum						3			9							4						
T. simillimum*																						
T. (striolatum gp) sp.1	6	7		13		10	7	1	14	4	10	2	3	6	7	13	1	18	5	16	9	6
T. (striolatum gp) sp.2	1	3		2				2	1		1				9				5			
T. (spininode gp.) sp.5		4									24								14		4	11
DOLICHODERINAE																						
Bothriomyrmex sp.1																						
I. rufoinclinus																						
I. sanguineus	39	15	29	20	122	28	128	115	15	87	145	181	85	28	149		44	37	153	103		
I. (anceps gp) sp.1	21	4	26		19	9	5		12	15	67	3	1	28			29		3	1	31	72
Irid. sp.2		31		36		9	9	10			1	1	40	109	30	11	5		21	22	52	9
Irid. sp.3																			33			
I. (bicknelli gp.) sp.8									7	16			4						10			
Irid. sp.9																		27	10	9		
Irid. sp. 11												1										
I. (hartmeyeri gp.) sp.12		5		7				12			4	5	6	1					1			3
I. (pallidus gp.) sp.14	30	80	3	26	10	24	27	28	36	16	81		30	103	36	4	43	9	20		147	34
Irid. sp.16	1										4		1									
Irid. sp.17																			2			
Irid. sp.18															1							
Irid. sp.20																						

Appendix 1 (cont'd)

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	W1	W2	W3	W4	W5	W6	W7	TOTAL
PONERINAE																		
Anochetus rectangularis				1				1			2	1		2				13
A. sp. nr. armstrongi																		1
Anochetus sp.1					1													1
Cerapachys sp.3																		3
Cer. sp.4					4			2										14
Cer. sp.7							1	3										6
C. (sp. nr. clarki) sp.8																		1
Discothyrea sp.1											1		+	2				3
Hypoponera sp.1		+									1							1
Leptogenys exigua			1				3											9
Lept sp.2																		1
Odontomachus turneri																		22
O. nr.turneri				3		5		16			6	6	28	22	6			144
O. (ruficeps gp) sp.																		2
Bothroponera sp.3																		2
Both. sp. 6																		3
Both. sp. 7										1								1
Platythyera parva																		1
Rhytidoponera aurata			6															220
R. borealis			9		7													60
R. reticulata	53	13	4	18	3	5	7	13	20	27	9				13	32	15	450
R. trachypyx			3	1		13	27	15	1									196
R. (aurata gp.) sp.1																		23
R. (aurata gp.) sp.2																		2
R. (aurata gp.) sp.10																		9
R. nr. rufithorax																		2
R. (reticulata gp.) sp.7																		25
R. (tenuis gp.) sp.9				4	11	20	2	5										121
R. (tuneri gp.) sp.3																		27
R. (tyloxys gp.) sp.8																		14
R. (tyloxys gp.) sp.11																		4
Sphinctomyrmex sp.2																		1
Sphinctomyrmex sp. 3																		2
DORYLINAE																		
Aenictus (ceylonicus group) sp.2																		1
MYRMICINAE																		
Cardiocondyla ?nuda						1	1			1			1	1	2			36
Crematagaster sp.1	2		3				1	1	7									44
Crem. sp.2		1		2									4					26
Glamyromyrex sp.2			1		2		4											8
Meranoplus (diversus gp.) sp.1									1									25
M. (diversus gp.) sp.2																		3
M. (diversus gp.) sp.3									4									4
M. minimus			2		3													15
M. (mjobergi gp.) sp.4			8															37
M. (mjobergi gp.) sp.6					5				4									16
Mer sp.6																		9
Mer. sp.8				17														28
Mer. sp.10																		4
Mer. sp.14																		22
Mer. sp.15																		5
Mer. sp.16																		3
Mer. sp. 17																		2

Appendix 1 (cont'd)

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	W1	W2	W3	W4	W5	W6	W7	TOTAL
Monomorium (rothsteini gp.) sp.1	.	5	6	13	.	.	.	.	.	26	.	.	.	.	.	.	.	159
M. ('Chelaner') sp.5	5	2	.	.	.	.	.	.	3	1	.	.	.	.	.	.	.	15
M. ('Chelaner') sp.6	.	.	.	.	.	.	.	.	5	1	.	.	.	.	.	.	.	63
M. ('Chelaner') sp.7	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	42
Mon. sp.8	.	1	10	25	3	2	1	.	.	5	.	.	.	1	.	.	.	112
Mon. sp. 9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6
Mon. sp.11	.	.	.	.	.	.	16	14	1	10	.	.	.	.	.	.	.	517
Mon. sp.13	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	11
Mon. sp.14	2	.	59	6	15	.	3	.	11	.	.	.	.	.	.	.	.	381
Mon. sp.17	.	.	3	25	8	1	3	9	53	.	.	7	.	4	.	.	.	221
Mon. sp.18	88	30	5	.	.	.	.	.	.	63	.	.	.	.	.	.	.	228
Mon. sp.21	4	10	15	18	69	1	6	2	13	12	23	3	3	18	19	.	.	661
Mon. sp.22	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Mon. sp.23	.	.	14	.	.	.	.	.	.	.	.	.	.	.	.	.	.	29
Mon. sp.24	31	9	9	6	24	27	25	31	19	7	95	31	66	88	25	1	.	722
Mon. sp.26	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	16
Mon. sp.27	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	82
Mon. sp.28	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8
Mon. sp.29	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3
Mon. sp.30	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Mon. sp. 31	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Oligomyrmex sp.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3
Pheidole sp.1	3	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	42
Ph. sp.3	.	.	.	.	.	1	3	7	.	.	43	5	28	8	6	.	.	140
Ph. sp. 5	26	.	.	5	3	2	1	2	8	.	.	.	.	.	.	.	.	96
Ph. sp.7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4
Ph. sp.8	.	.	4	10	8	.	.	.	.	.	.	.	.	.	.	.	.	58
Ph. sp.9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	23
Ph. sp.13	.	7	3	9	4	.	.	1	3	1	.	.	.	.	.	.	.	101
Ph. sp.14	1	4	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	28
Ph. sp.15	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
Ph. sp.17	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Ph. sp.18	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Ph. sp.19	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	2
Ph. sp.20	9	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25
Ph. sp.21	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	36
Ph. sp.25	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	6
Ph. sp.26	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	11
Quad. sp. 4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	
Solenopsis sp.1	1	4	3	7	.	1	.	1	.	.	.	.	+	.	.	.	.	78
Sol. sp.2	.	3	+	.	6	+	.	8	.	.	3	.	5	6	.	.	.	51
Sol. sp.4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
T. lanuginosum	.	.	.	.	4	.	2	.	.	.	22	1	8	3	22	.	.	78
T. simillimum'	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1
T. (striolatum gp) sp.1	5	.	2	6	11	9	.	.	8	1	.	.	.	.	.	.	.	202
T. (striolatum gp) sp.2	.	.	.	.	.	.	.	.	.	5	.	.	.	.	.	.	.	29
T. (spininode gp.) sp.5	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	58
DOLICHODERINAE																		
Bothriomyrmex sp.1	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1
I. rufoinclinus	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	1
I. sanguineus	11	70	53	103	88	101	102	123	71	68	6	87	.	1	.	26	32	2,465
I. (anceps gp) sp.1	2	.	1	1	9	42	45	45	5	.	10	6	8	5	2	3	2	534
Irid. sp.2	49	.	6	.	12	6	1	.	.	.	.	.	.	2	37	41	17	567
Irid. sp.3	.	55	.	13	.	.	.	.	13	18	.	.	.	.	.	.	.	132
I. (bicknelli gp.) sp.8	.	9	.	11	.	.	.	.	.	.	.	.	.	.	.	.	.	57
Irid. sp.9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	46
Irid. sp. 11	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
I. (hartmeyeri gp.) sp.12	2	21	1	.	4	3	.	.	9	9	.	.	.	.	.	.	1	94
I. (pallidus gp.) sp.14	16	44	117	40	4	45	57	.	3	.	.	3	1	1	.	1	.	1,119
Irid. sp.16	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6
Irid. sp.17	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
Irid. sp.18	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Irid. sp.20	.	.	.	.	.	.	.	.	14	.	.	.	.	.	.	.	.	14

Appendix 1 (cont'd)

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	W1	W2	W3	W4	W5	W6	W7	TOTAL
Ochetellus sp.2			1															1
Papyrius sp.1																		13
Tapinoma melanocephalum*					4													4
Tapinoma sp.1	4	3	1	1		2		1			7	1	6	7				39
Tap. sp.2							2								9			25
Tap. sp. 3																		3
FORMICINAE																		
Camponotus (nigroaeneus gp.) sp.4			3		1	1	1											11
Camp. sp. 6																		1
C. (discors gp.) sp.8			2		2			1										37
C. (variegatus gp.) sp.9								2			2	5	1	3	1			31
C. (variegatus gp.) sp.11																		10
C. (variegatus gp.) sp.12									1									7
C. (variegatus gp.) sp.13				3	4	1		5			4			1				26
C. (variegatus gp.) sp.14			4		1		1							1		1		27
C. (?ephippum gp.) sp.15																		3
C. (rubiginosus gp.) sp.17																		2
Camp. sp.18																		1
Melophorus (aeneovirens gp.) sp.1	11	2	10	5	2				3									281
M. (aeneovirens gp.) sp.2				3														62
M. (aeneovirens gp.) sp.4				1														22
Mel. sp.5	17	6		3	1				6									171
Mel. sp.6			2	2	7													153
Mel. sp. 9	33	2	3	5	4			3	11									186
M.el sp.10			12	7	4	6	9	3										576
Mel. sp.11	21	9		23	1	1			20	1								285
Mel. sp. 12																		5
Mel. sp.13		12	17		15													103
Mel. sp.15																		4
Mel. sp.16				1														166
Mel. sp.17																		7
Mel. sp. 18																		1
Mel. sp.20																		89
Oecophylla smaragdina				4	9								1	3	9			104
Opisthopsis haddoni			1	1		1		1			1			1				47
Paratrechina longicornis*					13		2				7	1	24	15	77	28	20	237
P. (obscura gp) sp.3							1				8		13			1		23
P. (vaga gp) sp.4				2		2		3					1	10	7	1		72
P. (vaga gp) sp. 7																		7
P. (minutula gp.) sp.1			5		2										1		1	13
P. (minutula gp.) sp.2	7			6					13									148
P. (minutula gp.) sp.6																		88
Polyrhachis gab																		5
P. inconspicua					1													3
P. pseudothrinax																		1
P. (Hagiomyrma) sp.2																		1
P. (Hagiomyrma) sp.3			3		1	2	2											35
P. (gab gp.) sp.16							2											2
P. (gab gp.) sp.17			5			8		1						1				32
Stigmacros (Stigmacros) sp.2																		1
Stigmacros (Campostigmacros) sp. 4			2															2
Total abundance	405	325	420	412	383	309	336	321	334	257	250	157	198	206	236	135	88	14,241
Number of species	26	26	43	39	43	28	32	30	30	18	18	13	17	24	15	10	7	162

Appendix 2 Abundances of ant genera in pitfall traps (genus–abundance data)

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	N21	N22
Anochetus	.	1	.	.	.	.	.	.	1	.	.	1	.	.	.	3	1	.	.	.	.	.
Bothroponera	.	.	.	.	.	1	.	.	.	.	.	.	1	.	.	.	.	3	.	.	.	.
Discothyrea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hypoponera	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Leptogenys	.	.	.	.	.	.	.	.	.	.	1	.	.	3	.	.	.	.	2	.	.	.
Odontomachus	3	.	19	.	19	.	.	.	.	10	1	2	.	.	.	.	.	22	.	.	.	.
Platythyrea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
Rhytidoponera	19	36	31	53	6	25	11	19	17	88	42	79	63	34	14	37	27	45	43	32	20	56
Cerapachys	.	.	1	.	1	.	1	2	3	1	.	.	.	.	.	.	.	5	.	.	.	.
Sphinctomyrmex	.	.	.	.	.	.	.	2	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Aenictus	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cardiocondyla	2	.	4	.	21	1	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
Crematogaster	3	6	17	.	1	.	.	2	6	1	.	.	3	6	.	2	.	.	1	.	1	.
Glamyromyrmex	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
Meranoplus	5	9	.	6	.	9	4	7	27	2	15	.	.	.	1	.	6	.	19	8	3	8
Monomorium	29	67	7	84	20	45	14	99	89	29	142	163	192	184	62	67	89	111	165	61	65	213
Oligomyrmex	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.
Pheidole	6	16	3	37	.	3	4	17	6	23	25	11	16	58	3	10	19	15	44	2	1	32
Solenopsis	4	4	.	9	1	2	2	6	6	17	16	.	.	1	1	.	3	3	4	.	1	2
Tetramorium	7	14	.	15	.	13	7	3	24	4	35	2	3	6	16	17	1	18	24	16	13	19
Bothriomyrmex	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Iridomyrmex	91	135	60	89	151	70	169	165	70	134	302	191	167	269	216	15	121	73	253	135	230	118
Ochetellus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Papyrius	.	.	.	.	.	.	.	.	.	.	.	.	.	13	.	.	.	.	.	.	.	.
Tapinoma	.	1	9	.	1	1	.	.	.	4	3	2	.	.	.	.	1	.	.	1	.	.
Camponotus	9	4	6	4	5	.	4	6	2	7	13	5	.	3	6	3	2	1	.	22	2	.
Melophorus	22	71	2	143	.	5	19	91	68	70	241	105	157	108	72	50	54	19	133	36	210	131
Oecophylla	12	.	.	8	.	.	.	.	8	.	2	.	.	.	1	6	4	.	11	.	20	6
Opisthopsis	5	1	.	4	.	1	.	2	5	3	5	1	1	3	.	3	2	.	3	.	1	1
Paratrechina	11	6	1	27	30	3	.	9	6	17	55	.	.	2	4	1	.	42	20	2	19	62
Polyrhachis	1	3	.	.	1	19	2	3	4	.	5	.	.	.	2	1	6	5	.	1	.	.
Stigmacros	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.
Total abundance	229	374	160	480	257	200	237	433	342	410	903	563	603	690	399	217	338	362	722	316	586	648

Appendix 2 (cont'd)

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	W1	W2	W3	W4	W5	W6	W7	TOTAL
Anochetus	.	.	.	1	1	.	.	1	.	.	2	1	.	2	.	.	.	15
Bothroponera	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	6
Discothyrea	.	.	.	.	.	.	.	.	.	.	1	.	.	2	.	.	.	3
Hypoponera	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	1
Leptogenys	.	.	1	.	.	.	3	.	.	.	.	.	.	.	.	.	.	10
Odontomachus	.	.	.	3	.	5	.	16	.	.	6	6	28	22	6	.	.	168
Platythyrea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Rhytidoponera	53	13	22	23	21	38	36	33	21	27	9	.	.	.	13	32	15	1,153
Cerapachys	.	.	.	.	4	.	1	5	.	.	.	.	.	.	.	.	.	24
Sphinctomyrmex	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3
Aenictus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Cardiocondyla	.	.	.	.	.	1	1	.	.	1	.	.	1	1	2	.	.	36
Crematogaster	2	1	3	2	.	.	1	1	7	.	.	.	4	.	.	.	.	70
Glamyromyrmex	.	.	1	.	2	.	4	.	.	.	.	.	.	.	.	.	.	8
Meranoplus	.	.	10	17	8	.	.	.	9	.	.	.	.	.	.	.	.	173
Monomorium	131	59	122	93	122	31	54	56	105	125	118	41	69	111	44	1	0	3,279
Oligomyrmex	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3
Pheidole	40	12	7	24	15	3	7	11	15	1	43	5	28	8	6	.	.	576
Solenopsis	1	7	3	7	6	1	.	9	.	.	3	.	5	6	.	.	.	130
Tetramorium	5	.	2	7	15	9	3	.	8	6	22	1	8	3	22	.	.	368
Bothriomyrmex	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1
Iridomyrmex	80	199	178	168	117	197	205	169	115	95	16	96	9	9	39	71	52	5,039
Ochetellus	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Papyrius	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	13
Tapinoma	4	3	1	1	4	2	2	1	.	.	7	1	6	7	9	.	.	71
Camponotus	.	.	9	3	8	2	2	8	1	.	6	5	1	5	1	1	.	156
Melophorus	82	31	44	50	34	7	9	6	40	1	.	.	.	.	.	.	.	2,111
Oecophylla	.	.	.	4	9	.	.	.	.	.	.	.	1	3	9	.	.	104
Opisthopsis	.	.	1	1	.	1	.	1	.	.	1	.	.	1	.	.	.	47
Paratrechina	7	.	5	8	15	2	3	3	13	.	15	1	38	25	85	30	21	588
Polyrhachis	.	.	8	.	2	10	4	1	.	.	.	.	.	1	.	.	.	79
Stigmacros	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3
Total abundance	405	325	420	412	383	309	336	321	334	257	250	157	198	206	236	135	88	14,241

Appendix 3 Numbers of ant species per genus in pitfall traps (genus–species data)

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	N21	N22
Anochetus	.	1	.	.	.	.	.	.	1	.	.	1	.	.	.	1	1	.	.	.	.	.
Bothroponera	.	.	.	.	.	1	.	.	.	.	.	.	1	.	.	.	.	1	.	.	.	.
Discothyrea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hypoponera	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Leptogenys	.	.	.	.	.	.	.	.	.	.	1	.	.	2	.	.	.	.	1	.	.	.
Odontomachus	1	.	1	.	.	.	.	.	.	1	1	2	.	.	.	.	.	1	.	.	.	.
Platythyrea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
Rhytidoponera	2	3	1	5	1	5	3	2	4	4	5	3	3	3	5	2	4	6	3	1	3	3
Cerapachys	.	.	1	.	1	.	1	2	2	1	.	.	.	.	.	.	.	2	.	.	.	.
Sphinctomyrmex	.	.	.	.	.	.	.	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Aenictus	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cardiocondyla	1	.	1	.	1	1	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
Crematogaster	1	1	1	.	1	.	.	1	1	1	.	.	1	1	.	1	.	.	1	.	1	.
Glamyromyrmex	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
Meranoplus	3	2	.	2	.	3	2	3	2	2	5	.	.	.	1	.	3	.	3	2	1	2
Monomorium	3	9	2	7	4	7	6	7	6	2	8	3	5	6	7	11	6	6	9	6	6	9
Oligomyrmex	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.
Pheidole	1	5	2	3	.	1	2	3	3	3	2	2	2	4	1	1	2	2	3	1	1	4
Solenopsis	2	2	.	3	1	1	2	2	2	1	2	.	.	1	1	.	1	1	1	.	1	1
Tetramorium	2	3	.	2	.	2	1	2	3	1	3	1	1	1	2	3	1	1	3	1	2	2
Bothriomyrmex	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Iridomyrmex	4	5	3	4	3	4	4	4	4	4	6	5	7	5	4	2	4	3	9	4	3	4
Ochetellus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Papyrius	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.
Tapinoma	.	1	1	.	1	1	.	.	.	1	1	1	.	.	.	.	1	.	.	1	.	.
Camponotus	3	3	2	3	3	.	3	1	1	4	6	2	.	3	3	2	2	1	.	1	1	.
Melophorus	4	5	1	6	.	3	4	8	4	3	6	4	6	6	6	3	4	5	7	1	7	4
Oecophylla	1	.	.	1	.	.	.	.	1	.	1	.	.	.	1	1	1	.	1	.	1	1
Opisthopsis	1	1	.	1	.	1	.	1	1	1	1	1	1	1	.	1	1	.	1	.	1	1
Paratrechina	2	2	1	3	2	1	.	1	2	2	1	.	.	1	1	1	.	4	1	1	1	1
Polyrhachis	1	2	.	.	1	2	2	1	3	.	2	.	.	.	2	1	2	2	.	1	.	.
Stigmacros	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.
TOTAL	32	45	17	42	19	34	30	39	40	31	52	26	27	35	35	32	35	35	43	20	29	32

Appendix 3 (cont'd)

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	W1	W2	W3	W4	W5	W6	W7	TOTAL
Anochetus	.	.	.	1	1	.	.	1	.	.	1	1	.	1	.	.	.	3
Bothroponera	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	3
Discothyrea	.	.	.	.	.	.	.	.	.	.	1	.	.	1	.	.	.	1
Hypoponera	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	1
Leptogenys	.	.	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	2
Odontomachus	.	.	.	1	.	1	.	1	.	.	1	1	1	1	1	.	.	3
Platythyrea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Rhytidoponera	1	1	4	3	3	3	3	3	2	1	1	.	.	.	1	1	1	13
Cerapachys	.	.	.	.	1	.	1	2	.	.	.	.	.	.	.	.	.	4
Sphinctomyrmex	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
Aenictus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Cardiocondyla	.	.	.	.	.	1	1	.	.	1	.	.	1	1	1	.	.	1
Crematogaster	1	1	1	1	.	.	1	1	1	.	.	.	1	.	.	.	.	2
Glamyromyrmex	.	.	1	.	1	.	1	.	.	.	.	.	.	.	.	.	.	1
Meranoplus	.	.	2	1	2	.	.	.	3	.	.	.	.	.	.	.	.	13
Monomorium	6	7	9	6	7	4	6	4	7	8	2	3	2	4	2	1	.	21
Oligomyrmex	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Pheidole	5	3	2	3	3	2	3	4	4	1	1	1	1	1	1	.	.	16
Solenopsis	1	2	2	1	1	2	.	2	.	.	1	.	2	1	.	.	.	3
Tetramorium	1	1	1	2	2	1	2	.	1	2	1	1	1	1	1	.	.	5
Bothriomyrmex	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1
Iridomyrmex	5	5	5	5	5	5	4	3	6	3	2	3	2	4	2	4	4	14
Ochetellus	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Papyrius	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Tapinoma	1	1	1	1	1	1	1	1	.	.	1	1	1	1	1	.	.	4
Camponotus	.	.	3	1	4	2	2	3	1	.	2	1	1	3	1	1	.	11
Melophorus	4	5	5	9	7	2	1	2	4	1	.	.	.	.	.	.	.	15
Oecophylla	.	.	.	1	1	.	.	.	.	.	.	.	1	1	1	.	.	1
Opisthopsis	.	.	1	1	.	1	.	1	.	.	1	.	.	1	.	.	.	1
Paratrechina	1	.	1	2	2	1	2	1	1	.	2	1	3	2	3	3	2	7
Polyrhachis	.	.	2	.	2	2	2	1	.	.	.	.	.	1	.	.	.	7
Stigmacros	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
TOTAL	26	27	43	39	43	28	32	30	30	18	18	13	19	24	15	10	7	163

Appendix 4 Abundance of ant functional groups in pitfall traps (functional group–abundance data). The two species of *Stigmacros* (Cold Climate Specialists) are not included.

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	N21	N22
Dominant Dolichoderinae	91	135	60	89	151	70	169	165	70	134	302	191	167	282	216	15	121	73	253	135	230	118
Subordinant Camponotini	15	8	6	8	6	20	6	11	11	10	23	6	1	6	8	7	10	6	3	23	3	1
Hot climate specialists	27	80	2	149	0	14	23	98	95	72	256	105	157	108	73	50	64	19	228	44	213	168
Tropical climate specialists	13	6	0	8	0	1	3	5	10	0	10	0	20	20	6	21	4	0	11	1	30	10
Cryptic species	4	4	0	10	1	4	2	8	6	17	16	1	0	1	1	1	4	3	4	0	1	2
Opportunists	42	57	64	95	77	43	18	31	47	123	136	85	66	42	35	55	29	127	87	51	52	137
Generalized Myrmicinae	37	83	27	121	21	47	15	113	99	53	159	174	191	228	60	64	104	126	134	62	57	212
Specialist Predators	0	1	1	0	1	1	1	2	4	1	1	1	1	3	0	3	2	8	2	0	0	0
TOTAL	229	374	160	480	257	200	237	433	342	410	903	563	603	690	399	216	338	362	722	316	586	648

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	W1	W2	W3	W4	W5	W6	W7	TOTAL
Dominant Dolichoderinae	80	199	178	168	117	197	205	169	115	95	16	96	9	9	39	71	52	5,052
Subordinant Camponotini	0	0	18	4	10	13	6	10	1	0	7	5	1	7	1	1	0	282
Hot climate specialists	82	36	60	80	42	7	9	6	49	27	0	0	0	0	0	0	0	2,443
Tropical climate specialists	5	2	0	4	11	0	0	0	8	2	0	0	1	3	9	0	0	224
Cryptic species	1	7	4	7	8	1	5	9	0	0	5	0	5	8	0	0	0	150
Opportunists	69	16	31	42	55	57	45	53	42	34	59	9	81	58	137	62	36	2,385
Generalized Myrmicinae	168	65	126	106	135	34	62	68	119	98	161	46	101	119	50	1	0	3,646
Specialist Predators	0	0	1	1	5	0	4	6	0	1	2	1	0	2	0	0	0	56
TOTAL	405	325	418	412	383	309	336	321	334	257	250	157	198	206	236	135	88	14,238

Appendix 5 Number of ant species per functional group in pitfall traps (functional group–species data). The two species of *Stigmacros* (Cold Climate Specialists) are not included.

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	N21	N22
Dominant Dolichoderinae	4	5	3	4	3	4	4	4	4	4	6	5	7	6	4	2	4	3	9	4	3	4
Subordinant Camponotini	5	6	2	4	4	3	5	3	5	5	9	3	1	4	5	4	5	3	1	2	2	1
Hot climate specialists	7	7	1	8	0	6	6	11	6	5	11	4	6	6	7	3	8	5	11	3	8	7
Tropical climate specialists	2	2	0	1	0	1	1	2	3	0	3	0	1	1	2	2	1	0	1	1	3	2
Cryptic species	2	2	0	4	1	2	2	3	2	1	2	1	0	1	1	1	2	1	1	0	1	1
Opportunists	8	9	5	10	5	10	4	5	9	9	11	7	4	5	9	6	6	12	7	4	6	6
Generalized Myrmicinae	4	13	5	10	5	7	7	9	8	6	8	5	7	10	7	12	7	8	12	6	6	11
Specialist Predators	0	1	1	0	1	1	1	2	3	1	1	1	1	2	0	1	2	3	1	0	0	0
TOTAL	32	45	17	41	19	34	30	39	40	31	51	26	27	35	35	31	35	35	43	20	29	32

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	W1	W2	W3	W4	W5	W6	W7	TOTAL
Dominant Dolichoderinae	5	5	5	5	5	5	4	3	6	3	2	3	2	4	2	4	4	15
Subordinant Camponotini	0	0	6	2	6	5	4	5	1	0	3	1	1	5	1	1	0	19
Hot climate specialists	4	6	8	11	9	2	1	2	7	2	0	0	0	0	0	0	0	28
Tropical climate specialists	1	1	0	1	2	0	0	0	2	2	0	0	1	1	1	0	0	1
Cryptic species	1	2	2	1	2	1	2	2	0	0	3	0	1	2	0	0	0	11
Opportunists	4	3	8	9	8	8	9	6	4	4	6	4	7	6	8	4	3	34
Generalized Myrmicinae	11	9	11	9	9	6	10	9	10	6	3	4	4	5	3	1	0	39
Specialist Predators	0	0	1	1	2	0	2	3	0	1	1	1	0	1	0	0	0	13
TOTAL	26	26	41	39	43	27	32	30	30	18	18	13	16	24	15	10	7	160

Appendix 6 Ants recorded in sweep samples. Data for each site are pooled across sampling periods.

	N4	N6	N7	N8	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20
Ponerinae														
Odontomachus sp. nr *turneri*												2		
Rhytidoponera aurata							1							
R. (*tyloxys* gp) sp. 8	1	3	1		1		9		1			17		
R. (*tyloxys* gp) sp. 11						3	3	5						
Pseudomyrmecinae														
Tetraponera punctulata	1													
Myrmicinae														
Crematogaster sp. 1							2							
Crematogaster sp. 2														
Crematogaster sp. 5		1												
Meranoplus sp. 2					1									
Meranoplus sp. 16														1
Monomorium sp. 11														
Monomorium sp. 17					1									
Monomorium sp. 18								1						
Pheidole sp. 21				1										
Tetramorium bicarinatum														
Dolichoderinae					1									
Iridomyrmex rufoinclinus	6		5	1	1	2	2		2		6		9	25
I. sanguineus					5		2				2			
I. (*anceps* gp) sp. 1									3		1			
I. (*anceps* gp) sp. 2												4		5
I. (*anceps* gp) sp. 9	1					5	3	6						
I. (*anceps* gp) sp. 11							1	1						
I. (*pallidus* gp) sp. 14												24		
Ochetellus sp. 2														
Formicinae	1	1	6						4					
Camponotus sp. 4		4												
C. (*variegatus* gp) sp. 9														
C. (*variegatus* gp) sp. 13	4													
C. (*rubiginosus* gp) sp. 17								1						
Camponotus sp. 18	1													
Melophorus sp. 1	5	4								4	1			
Oecophylla smaragdina	17	1	10	4	3	7	16	7	17	20	7	2	14	
Opisthopsis haddoni							1							
Paratrechina longicornis												1		
Plagiolepis sp. 1											7			
Polyrhachis gab	1		1		1									
P. inconspicua												1		
P. schenkii										3		2		
P. (*ammon* gp) sp. 2		4		1	8				3		1	1		
P. (*ammon* gp) sp. 3														
P. (*obtusa* gp) sp. 9		7	9		3		1		11		6			
P. (gab gp) sp. 17														
TOTAL	38	25	32	7	25	17	41	21	41	27	31	54	23	31
NO. SPECIES	10	8	6	4	10	4	11	6	7	3	8	9	2	3

Appendix 6 (cont'd)

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Ponerinae										
Odontomachus sp. nr *turneri*										
Rhytidoponera aurata										
R. (*tyloxys* gp) sp. 8										
R. (*tyloxys* gp) sp. 11										
Pseudomyrmecinae										
Tetraponera punctulata										
Myrmicinae										
Crematogaster sp. 1										
Crematogaster sp. 2										
Crematogaster sp. 5			1							
Meranoplus sp. 2		1								
Meranoplus sp. 16										
Monomorium sp. 11										
Monomorium sp. 17										1
Monomorium sp. 18										
Pheidole sp. 21										
Tetramorium bicarinatum										
Dolichoderinae										
Iridomyrmex rufoinclinus		1								
I. sanguineus		2	2	1	1	1	7	1	2	12
I. (*anceps* gp) sp. 1							3	8		
I. (*anceps* gp) sp. 2										
I. (*anceps* gp) sp. 9										
I. (*anceps* gp) sp. 11										
I. (*pallidus* gp) sp. 14						3	1			
Ochetellus sp. 2										
Formicinae										
Camponotus sp. 4			6		3		2			
C. (*variegatus* gp) sp. 9					1					
C. (*variegatus* gp) sp. 13										
C. (*rubiginosus* gp) sp. 17										
Camponotus sp. 18										
Melophorus sp. 1								1		
Oecophylla smaragdina		4	5	2	4	2	4	5		
Opisthopsis haddoni					2					
Paratrechina longicornis										
Plagiolepis sp. 1										
Polyrhachis gab										
P. inconspicua										
P. schenkii										
P. (*ammon* gp) sp. 2					4	1				
P. (*ammon* gp) sp. 3										
P. (*obtusa* gp) sp. 9	1		10		8	2		1		
P. (gab gp) sp. 17										
TOTAL	1	8	24	3	23	9	17	16	2	13
NO. SPECIES	1	4	5	2	7	5	5	5	1	2

Appendix 6 (cont'd)

	W1	W2	W3	W4	W5	W6	W7	TOTAL N	TOTAL D	TOTAL W	GRAND TOTAL
Ponerinae											
Odontomachus sp. nr *turneri*								2			2
Rhytidoponera aurata								1			1
R. (*tyloxys* gp) sp. 8								33			33
R. (*tyloxys* gp) sp. 11								11			11
Pseudomyrmecinae											
Tetraponera punctulata								1			1
Myrmicinae											
Crematogaster sp. 1								2			2
Crematogaster sp. 2				1						1	1
Crematogaster sp. 5								1	1		2
Meranoplus sp. 2									1		1
Meranoplus sp. 16								1			1
Monomorium sp. 11								1			1
Monomorium sp. 17									1		1
Monomorium sp. 18								1			1
Pheidole sp. 21								1			1
Tetramorium bicarinatum								1			1
Dolichoderinae											
Iridomyrmex rufoinclinus								1	1		2
I. sanguineus								59	29		88
I. (*anceps* gp) sp. 1	3						1	9	11	4	24
I. (*anceps* gp) sp. 2								4			4
I. (*anceps* gp) sp. 9								9			9
I. (*anceps* gp) sp. 11								15			15
I. (*pallidus* gp) sp. 14				3				2	4	3	9
Ochetellus sp. 2								24			24
Formicinae											
Camponotus sp. 4								12	11		23
C. (*variegatus* gp) sp. 9	7	1	8	6				4	1	22	29
C. (*variegatus* gp) sp. 13	6									6	6
C. (*rubiginosus* gp) sp. 17								4			4
Camponotus sp. 18								1			1
Melophorus sp. 1								1			1
Oecophylla smaragdina	1	1	10	6	21			14	1	39	54
Opisthopsis haddoni			1	6	1			125	26	7	158
Paratrechina longicornis			2					1	2	3	6
Plagiolepis sp. 1								1			1
Polyrhachis gab								7			7
P. inconspicua								3			3
P. schenkii								1			1
P. (*ammon* gp) sp. 2								5			5
P. (*ammon* gp) sp. 3				1				18	5	1	24
P. (*obtusa* gp) sp. 9	1	1	2	2						6	6
P. (gab gp) sp. 17		3						37	22	3	62
TOTAL	18	6	23	25	22	0	1	413	116	95	624
NO. SPECIES	5	4	5	7	2	0	1	35	15	11	40

Appendix 7 Beetles collected in Wet season sweep samples (pooled 1993 and 1994 data)

	N4	N6	N7	N8	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	W1	W2	W3	W4	W5	W6	W7	TOTAL N	TOTAL D	TOTAL W	GRAND TOTAL
ADERIDAE																																			
sp A																												1						1	1
ALLECULIDAE																																			
sp A			1	1																												2			2
sp B		3	6						4								1															13	1		14
ANTHRIBIDAE																																			
sp A			1					1			1								1						2							3	1	2	6
sp B																												1						1	1
BUPRESTIDAE																																			
sp A									3					2																		5			5
sp B														1																		1			1
sp C									1																							1			1
BRENTIDAE																																			
sp A		1			8				6			1		11																		27			27
sp B								1																								1			1
sp C		6	4																													10			10
sp E						1		1																								2			2
CARABIDAE																																			
Cicindelina sp A											1																					1			1
CERAMBYCIDAE																																			
sp A			1		4				3						1																	8	1		9
sp B													1																			1			1
CHRYSOMELIDAE																																			
Eumolpinae																																			
Eumolpinae sp D												1	1																			2			2
Eumolpinae sp F		1																										1				1		1	2
Eboo sp	6			1	8				1								2															16	2		18
Agetinus sp A				1									2	1	1			4							1							4	5	1	10
Agetinus sp B													1																			1			1
Agetinus sp C									2			1		5																		8			8
Agetinus sp D									8									1								1						8	1	1	10
Scelodonta sp					1			1																								2			2
Galopiera sp	1			5					3	2	1	2							1													14	1		15
Galopiera sp E					1																											1			1
Rhyparida sp A						2	7	3							2			1														12	3		15
Rhyparida sp B																		1					1										2		2
Rhyparida sp C	1		1		1						1										1	7	2	3								4	13		17
Rhyparida sp D					3												2		7													3	9		12
Rhyparida sp E								1																								1			1
Rhyparida sp F		1											1									1										2	1		3
Rhyparida sp G											1																					1			1
Rhyparida sp H																													1					1	1
Rhyparida sp I				1																												1			1
sp A																															1			1	1
sp C																													1					1	1

continued ....

Appendix 7 (cont'd)

	N4	N6	N7	N8	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	W1	W2	W3	W4	W5	W6	W7	TOTAL N	TOTAL D	TOTAL W	GRAND TOTAL
Hispinae																																			
Eurispa sp													6																			6			6
Hispellinus sp					1		1						1					2	3			3		1	3							3	9	3	15
Hispinae sp A		2																														2			2
Hispinae sp E											1																					1			1
Alticinae																																			
Arsipoda sp															1																		1		1
Alticinae sp A												1																				1			1
Alticinae sp B																				1						1							1	1	2
Alticinae sp C																1									1	1							1	2	3
Alticinae sp D						1																										1			1
Clytrinae																																			
Ditropidus sp A	1			8					1								1								2			4				10	1	6	17
Ditropidus sp B				2				2	2				11			2		2														17	4		21
Ditropidus sp C		1			2						1			1															2			5		2	7
Ditropidus sp D									1								1															1	1		2
Ditropidus sp E						25	17	9																3								51	3		54
Galerucinae																																			
sp A																								1									1		1
sp B																										1	1	1						3	3
sp D			2								1		1		18			1		2	2			19		23	1	2		3		4	40	29	73
sp E		1	1		1				4	7	5	2		3			1								14				1			24	1	15	40
sp F									1																							1			1
sp G													5	1																		6			6
sp H					4																											4			4
sp I		2																									1					2		1	3
sp J									9		2																					11			11
sp K																	1																1		1
sp L																								1									1		1
sp M											1																					1			1
sp N																										1								1	1
sp O	1																															1			1
sp P																											1							1	1
sp Q																													1					1	1
sp S																			1														1		1
sp R						1																										1			1
Monolepta sp.																				1													1		1
Chrysomelinae																																			
Chrysomelinae sp K			1																													1			1
Chrysomelinae sp L			1																													1			1
Calomela sp																		1										1					1	1	2
sp A																										1								1	1
sp B																				1													1		1
sp C									1																							1			1
sp D			1						1																							2			2
sp E																										1				1				2	2
sp F																										1								1	1
sp G															1					1													2		2
sp J												1																				1			1
sp K														1																		1			1

continued ....

Appendix 7 (cont'd)

	N4	N6	N7	N8	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	W1	W2	W3	W4	W5	W6	W7	TOTAL N	TOTAL D	TOTAL W	GRAND TOTAL
Cryptocephalinae																																			
Cryptocephalinae sp A																									3	2	3	1	1					10	10
Cryptocephalus sp			1											3			1		4	1		2			9	7	2	7				4	8	25	37
sp A																						5			5	1		4	1				5	11	16
sp B								1											1								1					1	1	1	3
CLERIDAE																																			
sp A														1																		1			1
sp B																						1											1		1
sp C						1																										1			1
COCCINELLIDAE																																			
sp A									1																1							1		1	2
sp B																										1								1	1
sp C			1														1					1										1	2		3
sp D																					2												2		2
sp E		1															1									1						1	1	1	3
sp F		1	1					5																								7			7
sp G																						1											1		1
CRYPTOPHAGIDAE																																			
sp A																		1															1		1
CURCULIONIDAE																																			
sp A				3							3	2		8			1					1										16	2		18
sp B	10			2	2				1	1	8																					22			22
sp C	1	1		4	3	4	3		7		2		22				8			2			1									47	8		56
sp D	1	3	3								4	1	1	4	2		7	1	1		2		25		4	4		3				17	38	11	66
sp E	3	33	7	6					15	13	1				2		10		1		1											80	14		94
sp F		3							3	2							1		1													8	2		10
sp G																				1													1		1
sp H																					1												1		1
sp I																									1									1	1
sp J			3						1																							4			4
sp K									1									3	1													1	4		5
sp L													1																			1			1
sp M									1																							1			1
sp N	1								1																							2			2
sp O																		1															1		1
sp P																						1											1		1
sp Q											1																					1			1
sp R		1																														1			1
sp S		1																														1			1
sp T																							1										1		1
Scolytinae sp A																						1											1		1
ELATERIDAE																																			
sp A				1																						1						1		1	2
sp B																					1												1		1
sp C									2																							2			2
sp D												2																				2			2
sp E												2																				2			2
sp F		2	2	1															1													5	1		6
sp G									2																							2			2
sp H					1																											1			1
sp I					1																											1			1

continued .....

Appendix 7 (cont'd)

	N4	N6	N7	N8	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	W1	W2	W3	W4	W5	W6	W7	TOTAL N	TOTAL D	TOTAL W	GRAND TOTAL
LAMPYRIDAE																																			
sp A		1																														1			1
LYCIDAE																																			
sp A												1																				1			1
sp B																					1				1	1	1						1	3	4
MELOIDAE																																			
sp A																							1										1		1
MELYRIDAE																																			
Malachinae																																			
sp A					1																											1			1
sp B							1	1																								2			2
RHIPIPHORIDAE																																			
sp A		1	3	3													1						3									7	4		11
sp B									1											1												1	1		2
sp C		1																														1			1
sp D		8	2														1															10	1		11
sp E												1			1		1											1				1	2	1	4
sp F		1																														1			1
sp G			4														1									1						4	1	1	6
sp H															1							2											3		3
sp I								1														1										1	1		2
sp J																									1		1							2	2
SCAPHIDIIDAE																																			
sp A																			1							1							1	1	2
SCIRTIDAE																																			
sp A																											2							2	2
sp B																	2								1		1						2	2	4
sp C																			1														1		1
SILVANIDAE																																			
sp A		1																														1			1
NO BEETLES	26	77	47	41	40	35	29	27	69	26	33	18	54	42	28	3	43	19	25	11	11	27	34	28	49	49	15	27	8	4	1	583	229	153	965
NO SPECIES	10	24	21	14	16	7	5	12	29	5	17	13	13	13	10	2	20	12	14	9	8	13	7	6	15	17	11	12	7	2	1	100	65	45	147

Appendix 8 Grasshoppers collected during February 1993. Unidentified species have been assigned ANIC code numbers. Data are abundances scored according to a five-point scale (see section 5.1.1 in text).

	Natural sites										Disturbed sites						
	N4	N6	N7	N8	N15	N16	N17	N18	N19	N20	D1	D2	D3	D4	D5	D6	D7
ACRIDIDAE																	
Acridinae																	
Acrida conica																2	1
Aiolopus thalassinus																1	
Caledia captiva									1					1			
Froggattina australis																	3
Gastrimargus musicus											3	1					4
Heteropternis obscurella											1	3				1	
Locusta migratoria																	
Pycnostictus seriatus	1															1	1
Catantopinae																	
Adlappa erythroptera				3	1					1	1			2			
Aretza sp. 1	2				1				2								
Aretzina sp.								2									
Caloptilia australis	2	3	3	3	4		3	1	3	4	3	2		3	2	1	
Coryphistes sp. 4																	
Curpilladia flavocarinata	1			3	2	1	3			3	3		1	1	3	1	
Erythropomala amaena																	
Goniaea furcifera	3	3		1		2						2	1		3	1	
G. vocans	5	4	3	3	3	1	3	3	3	1	1		1	2	4	1	
Goniaeoidea sp. 3		3	2	3	1		1						1	2		1	
Happarana pallida								3		5							
Macrazelota sp. 3										1		1					
Macrocara conglobata				2			1					2		3			
Macrocara sp. 1		1															
Macrotona sp. 17				3					2								
Rectitrophis australis	1					1									3		
Stenocatantops augustifrons			1														
S. vitripennis			1	4	3		3		3	1	3	2			1	3	2
Xanterriaria mediocris	1	4	3	4	4	2	4	3	2	1					3	1	1
Xypachtia sp. 1				3	1				3		1	4		2			
Zebratula flavonigra		3		4		3		4		3							
Gen. nov. 61, sp. 2	3	2		1			1				1	1					
Gen. nov. 70, sp. 1.	4	2		3			3		3		2	1		4			
Gen. nov. 98 sp. 1.																	2
Gen. nov. 105, sp. 1	1			1				1	4								
Cyrtacanthacridinae																	
Nomadacris basalis																1	
N. guttulosa																	
Valanga irregularis																	
V. meleager																	
Oxyinae																	
Bermiella acuta																	
Daperria accola																2	
Tolgadia infirma	2	1	4		1	3	2	1		2			1	3			
EUMASTACIDAE																	
Gackomima sp.						1											
Kakadu sp. 1							1			3							
Kakadu sp. 2				2			1		4		1						
Kakadu sp. 4															1		
Kakadu sp. 9												1					
Kakadu sp. 10																	
unidentified																	
PYRGOMORPHIDAE																	
Attractomorpha similis																1	
TETRIGIDAE																	
Kakadu sp. 3										1							
TETTIGONIIDAE																	
Conocephalinae																	
Conocephalus Kakadu sp. 2				1													
Conocephalus Kakadu sp. 4				2													
Decticinae																	
Chlorobalius sp.																	
Listroscelinae																	
Gen . nov. 12	1																
Meconemitinae																	
Gen. M.E.1		1		1			1										
Phaneropterinae																	
Caedicia Kakadu sp. 5				2				1									
Caedicia Kakadu sp. 7					3												
Caedicia Kakadu sp. 9										1							
Polichne parvicauda	1						1										
Polichne sp. 6										1							
unidentified	1	1							3	1		1			2		
TOTAL	29	28	17	49	24	14	28	19	33	29	20	21	5	23	22	18	14
NO. SPECIES	14	11	7	20	11	8	14	9	11	14	11	11	5	10	8	14	7

continued .....

Appendix 8 (cont'd)

	D8	D9	D10	W1	W2	W3	W4	W5	W6	W7	N	D	W	TOTAL
				Waste Rock sites							Totals			TOTAL
ACRIDIDAE														
Acridinae														
Acrida conica		2	1		4	2	3		3			6	12	18
Aiolopus thalassinus					2							1	2	3
Caledia captiva				1							1	1	1	3
Froggattina australis					3			1				3	4	7
Gastrimargus musicus	1		2						1	1		11	2	13
Heteropternis obscurella		2	1		3				1			8	4	12
Locusta migratoria								1					1	1
Pycnostictus seriatus											1	2		3
Catantopinae														
Adiappa erythroptera											5	3		8
Aretza sp. 1											5			5
Aretzina sp.											2			2
Caloptilla australis		3	4		2	1	2	1	1		26	18	7	51
Coryphistes sp. 4	1					1	2					1	3	4
Curpilladia flavocarinata	1	2	1	1			3	2	1		13	13	7	33
Erythropomala amaena		1				1						1	1	2
Goniaea furcifera	1						3	1			9	8	4	21
G. vocans		1					1				29	10	1	40
Goniaeoidea sp. 3			1		1	1	3				10	5	5	20
Happarana pallida											8			8
Macrazelota sp. 3			3								1	4		5
Macrocara conglobata											3	5		8
Macrocara sp. 1											1			1
Macrotona sp. 17		1									5	1		6
Rectitrophis australis				3		1	1				2	3	5	10
Stenocatantops augustifrons											1			1
S. vitripennis	2			1	1		4	3	3		15	13	12	40
Xanterriaria mediocris	2	2	4	2		1	3	4	2		28	13	12	53
Xypechtia sp. 1		1	4					1	2		7	12	3	22
Zebratula flavonigra											17			17
Gen. nov. 61, sp. 2			1								7	3		10
Gen. nov. 70, sp. 1.							1				15	7	1	23
Gen. nov. 98 sp. 1.												2		2
Gen. nov. 105, sp. 1											7			7
Cyrtacanthacridinae														
Nomadacris basalis						4	2					1	6	7
N. guttulosa						2	3						5	5
Valanga irregularis					3								3	3
V. meleager						1							1	1
Oxyinae														
Bermiella acuta					4	4	2						10	10
Dapernia accola					1	2						2	3	5
Tolgadia infirma		1	2								16	7		23
EUMASTACIDAE														
Geckomima sp.								1			1		1	2
Kakadu sp. 1									1		4		1	5
Kakadu sp. 2											7	1		8
Kakadu sp. 4												1		1
Kakadu sp. 9												1		1
Kakadu sp. 10			3									3		3
unidentified		1			4							1	4	5
PYRGOMORPHIDAE														
Attractomorpha similis												1		1
TETRIGIDAE														
Kakadu sp. 3											1			1
TETTIGONIIDAE														
Conocephalinae														
Conocephalus Kakadu sp. 2											1			1
Conocephalus Kakadu sp. 4											2			2
Decticinae														
Chlorobalius sp.					3				1				4	4
Listroscelinae														
Gen . nov. 12											1			1
Meconemitinae														
Gen. M.E.1											3			3
Phaneropterinae														
Caedicia Kakadu sp. 5											3			3
Caedicia Kakadu sp. 7											3			3
Caedicia Kakadu sp. 9											1			1
Polichne parvicauda											2			2
Polichne sp. 6											1			1
unidentified											6	3		9
TOTAL	8	17	27	8	31	21	33	15	16	1	270	175	125	570
NO. SPECIES	6	10	12	5	11	12	14	9	10	1	38	33	28	58

Appendix 9 Records of termite species at paper baits (data pooled across 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
MASTOTERMITIDAE																						
Mastotermes darwiniensis																						
RHINOTERMITIDAE																						
Heterotermes venustus				5		1	2	1			2	1							1		2	3
Schedorhinotermes actuosus																						
S. ?breinli															1							
TERMITIDAE																						
Amitermes sp. 1					2			1			3											
Amitermes sp. 3						2	1	1									2	6		2		
Amitermes sp. 4																						
Amitermes sp. 5																	1					
Drepanotermes rubriceps											3	4		3			1	1				
Microcerotermes boreus															3	5						
M. nanus																						
M. nervosus							1								2							
M. serratus								1					1	1			1					
Microcerotermes sp. 4																		1				
Microcerotermes sp. 5									1													
Nasutitermes sp. 1																			1			
Nasutitermes sp. 2		1																				
"Termes"															1							
Tumulitermes sp. 1				2			1	8	4				1									
Tumulitermes sp. 2																						
Tumulitermes sp. 3				3												5		11	1			
Tumulitermes sp. 4				1											6							
Tumulitermes sp. 7	1					2		1	2		2								1			
unidentified workers		2		7			4	1			1	2		2	6	2	4	4	3	2	2	1
TOTAL	1	3	0	18	2	5	9	14	7	0	11	7	2	6	19	12	9	23	7	4	4	4
NO. SPECIES	1	1	0	4	1	3	4	6	3	0	4	2	2	2	5	2	4	4	4	1	1	1

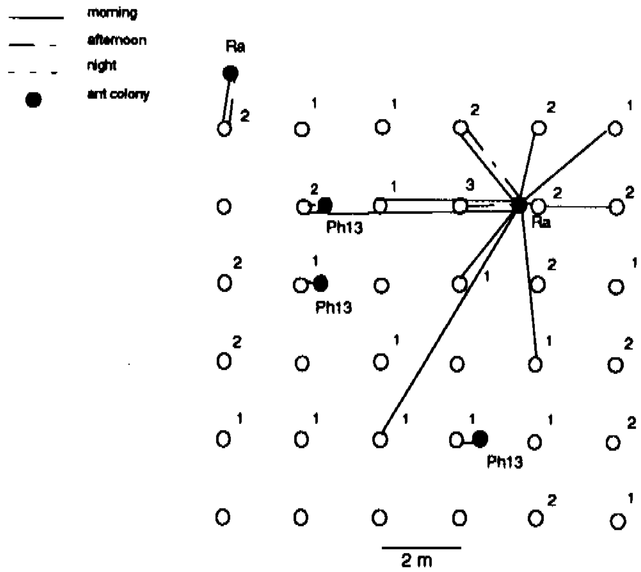
continued ....

Appendix 9 (cont'd)

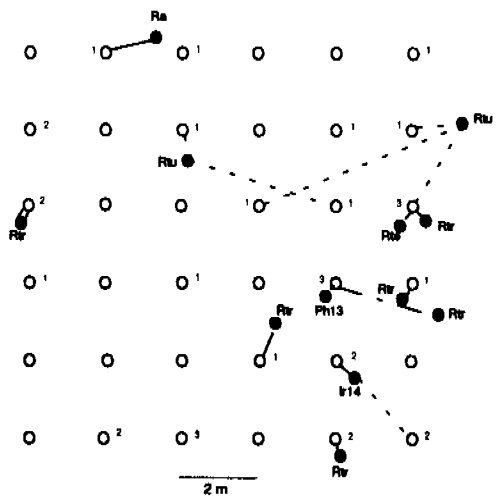
	Disturbed sites										Waste rock sites							Totals			
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	W1	W2	W3	W4	W5	W6	W7	N	D	W	TOTAL
MASTOTERMITIDAE																					
Mastotermes darwiniensis			1	1	1					2					2				5	2	7
RHINOTERMITIDAE																					
Heterotermes venustus	1		3	5	1	1		1		1				1				18	13	1	32
Schedorhinotermes actuosus											1		2	2	1					6	6
S. ?breinli								1										1	1		
TERMITIDAE																					
Amitermes sp. 1	2							1										6	3		9
Amitermes sp. 3	8	2		1				3	6	3						1		14	23	1	38
Amitermes sp. 4	1		1		2					2									6		6
Amitermes sp. 5										1								1	1		2
Drepanotermes rubriceps	4	1																12	5		17
Microcerotermes boreus																		8			8
M. nanus				1															1		1
M. nervosus			1					1	1									3	3		6
M. serratus			1		1													4	2		6
Microcerotermes sp. 4																		1			1
Microcerotermes sp. 5																		1			1
Nasutitermes sp. 1																		1			1
Nasutitermes sp. 2																		1			1
"Termes"																		1			1
Tumulitermes sp. 1	3	4	3	1	9													16	20		36
Tumulitermes sp. 2					1														1		1
Tumulitermes sp. 3																		20			20
Tumulitermes sp. 4																		7			7
Tumulitermes sp. 7				1	2													9	3		12
unidentified workers	7	2	1	4	4			1	4	3	2	2	1		2			43	26	7	76
TOTAL	26	9	11	14	21	1	0	8	11	12	3	2	3	3	5	1	0	167	113	17	295
NO. SPECIES	6	3	6	6	7	1	0	5	2	5	1	0	1	2	2	1	0	18	14	4	22

Appendix 10 Maps illustrating seed transport by ants from baiting stations (open circles) to nests during myrmecochory trials

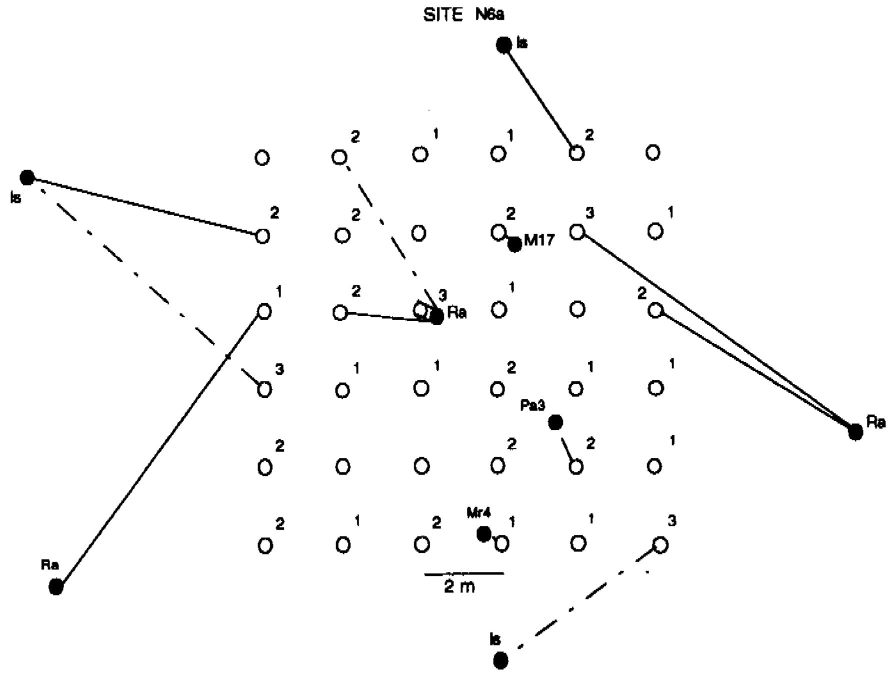
SITE N4a

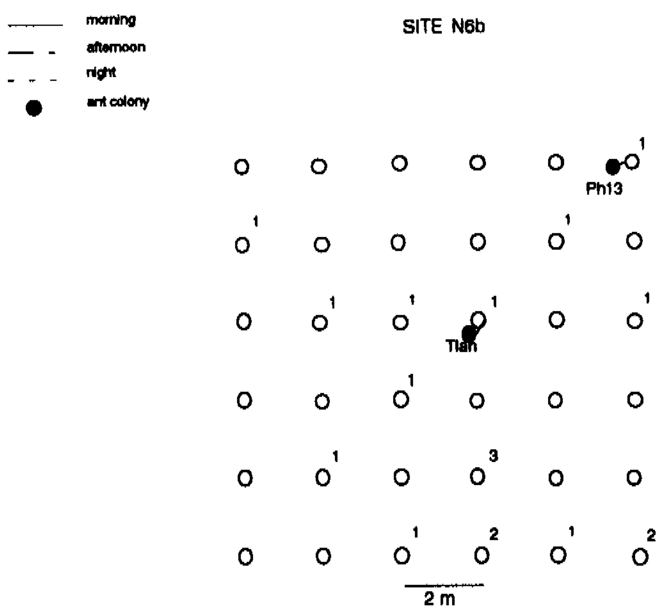


SITE N4b



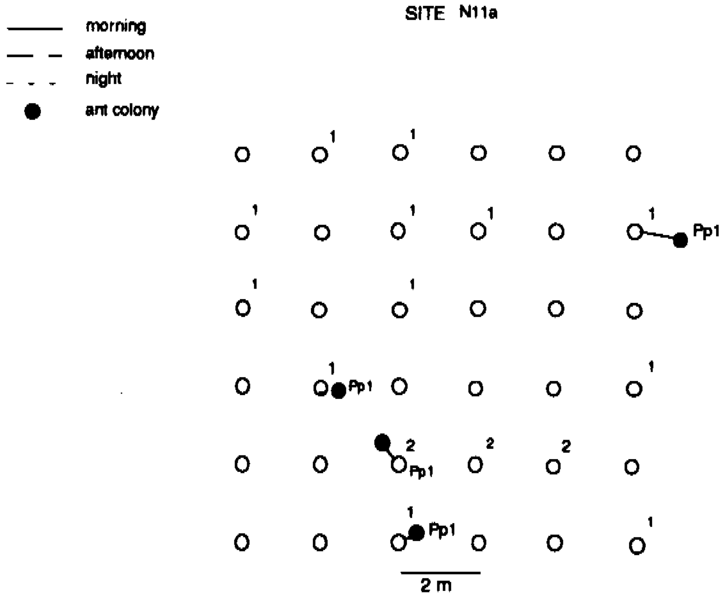
Appendix 10 (cont'd)



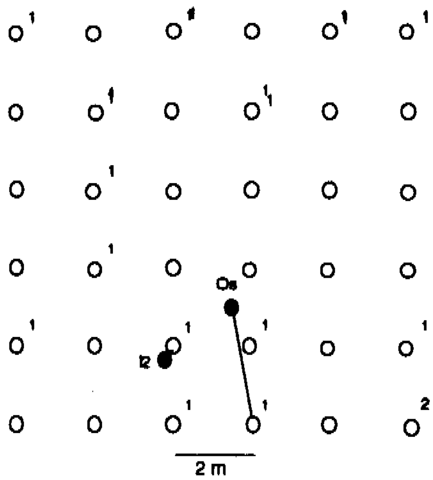


Appendix 10 (cont'd)

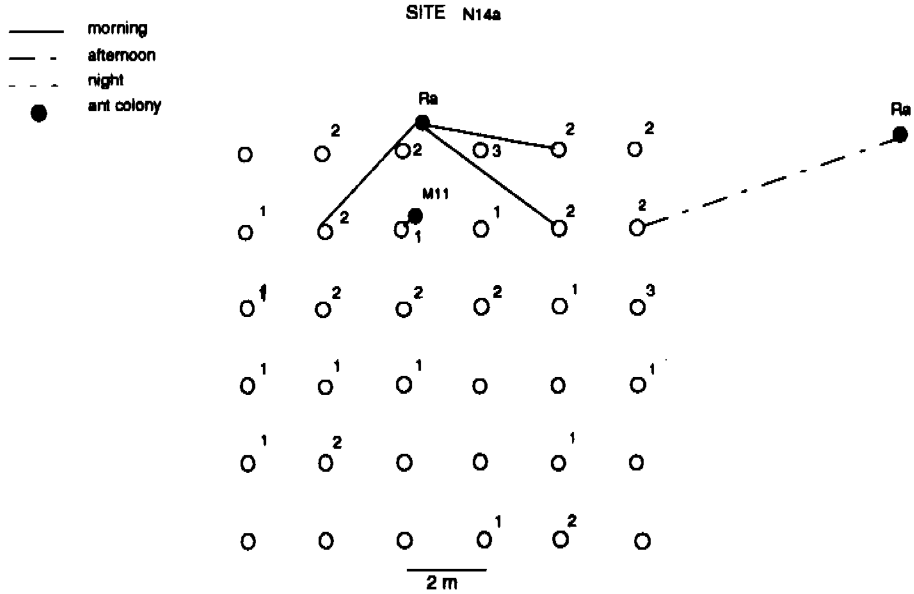
SITE N11a

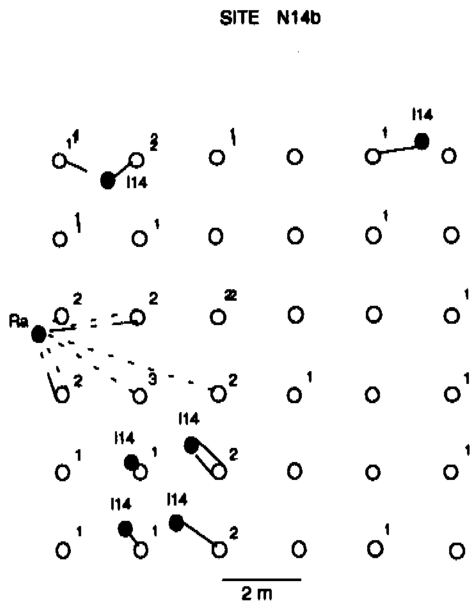


SITE N11b



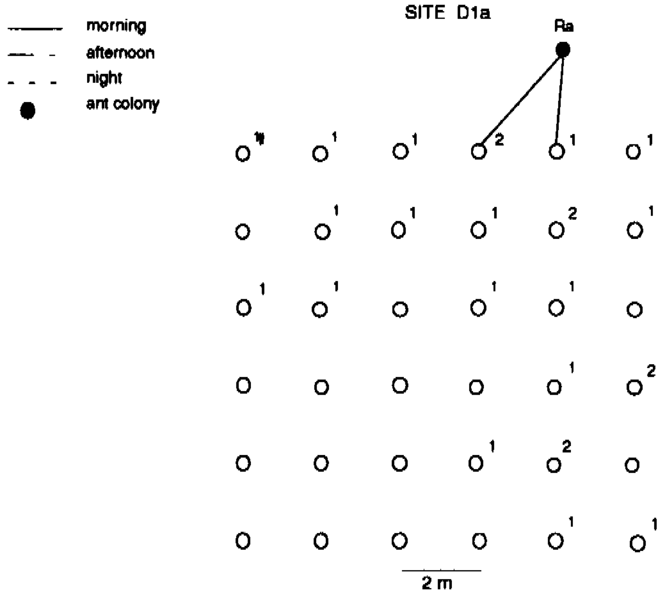
Appendix 10 (cont'd)



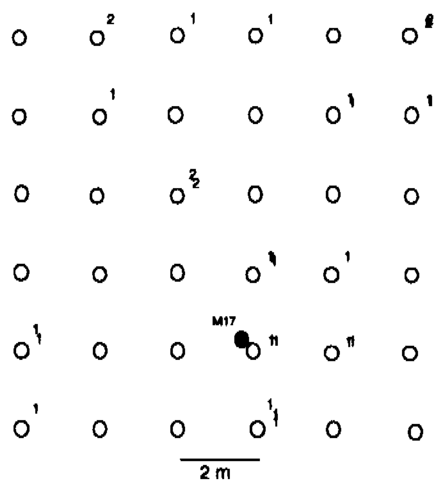


Appendix 10 (cont'd)

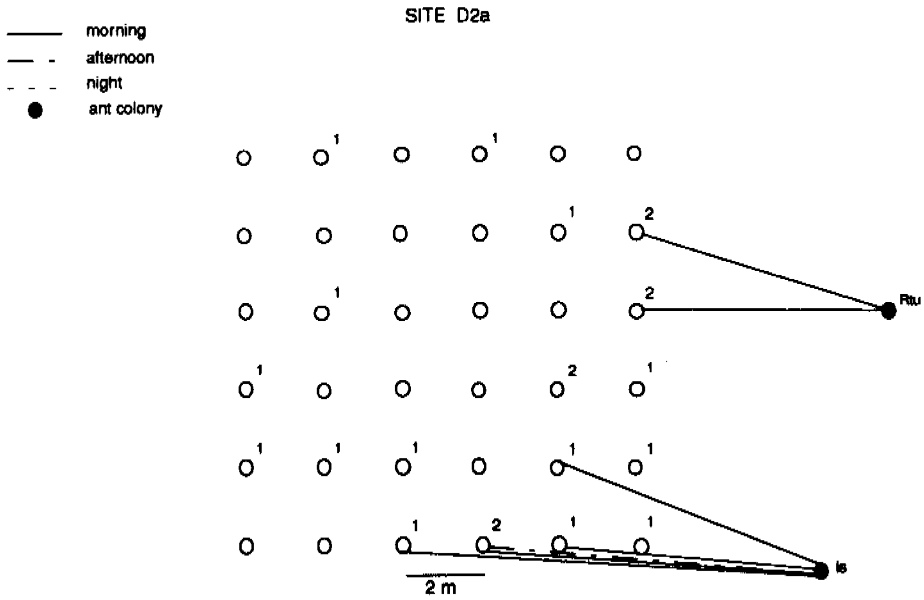
SITE D1a

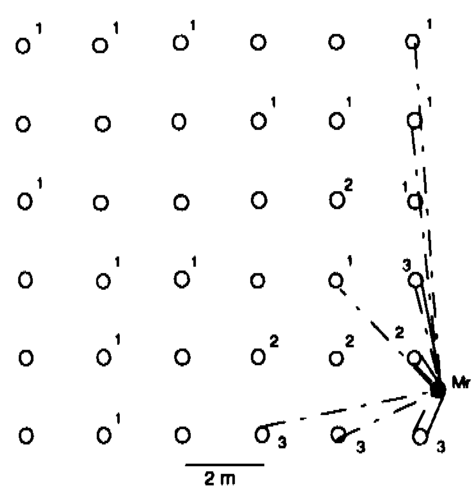


SITE D1b

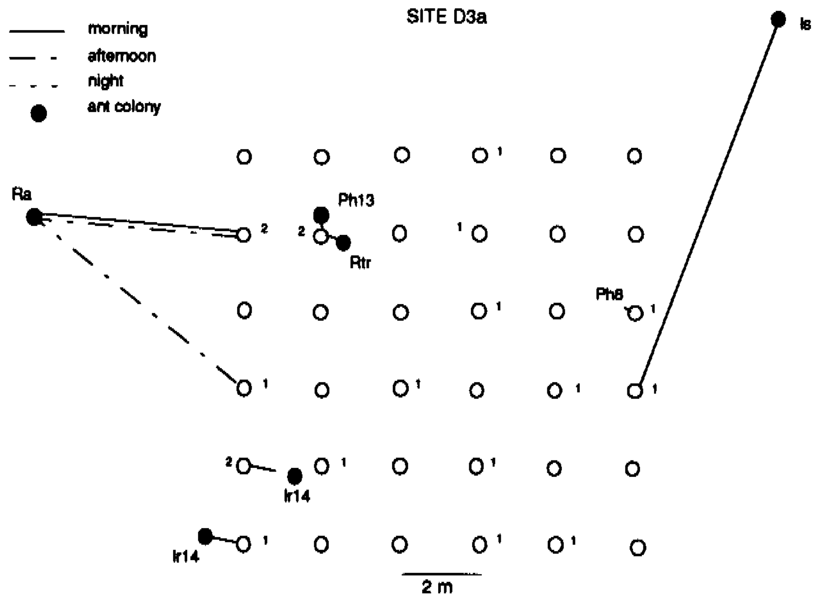


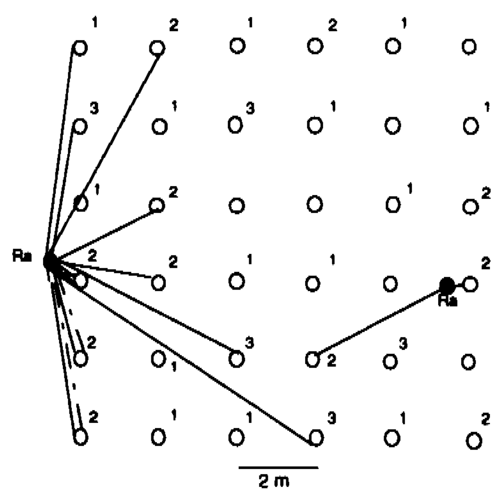
Appendix 10 (cont'd)





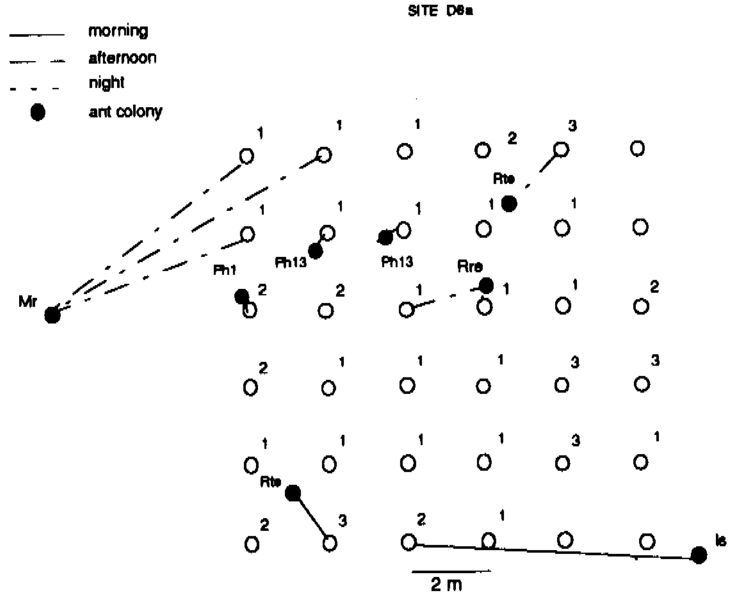
Appendix 10 (cont'd)



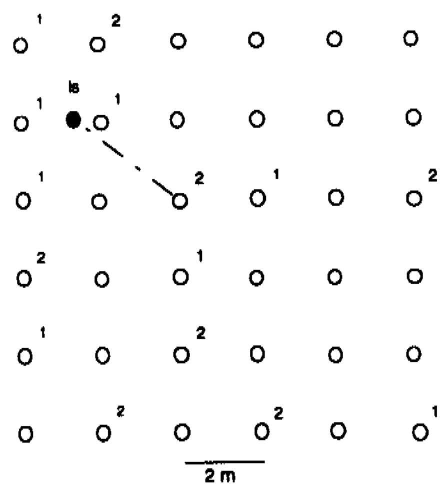


Appendix 10 (cont'd)

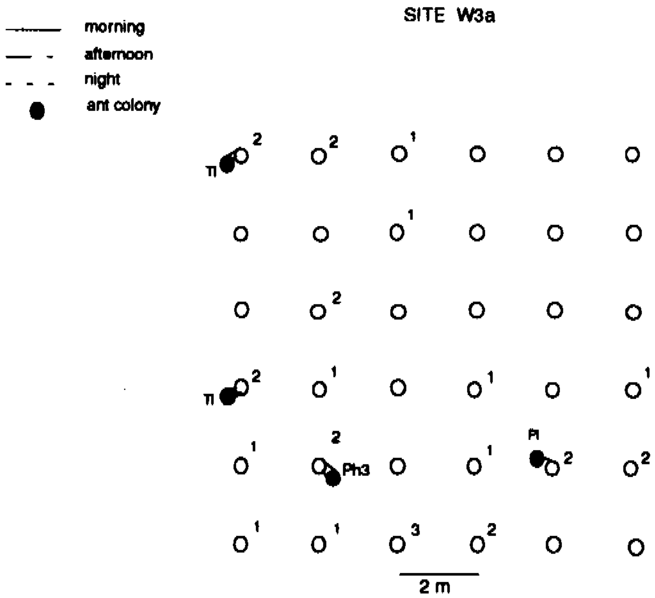
SITE D6a

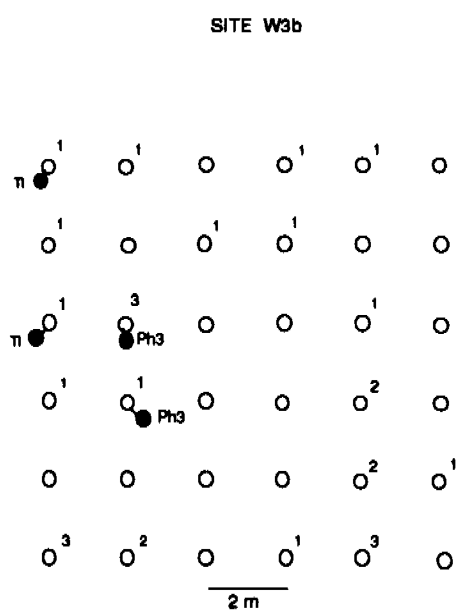


SITE D6b

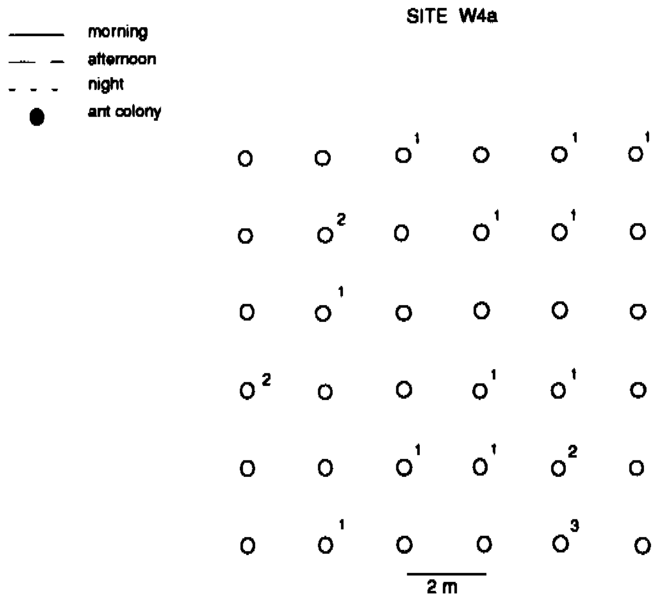


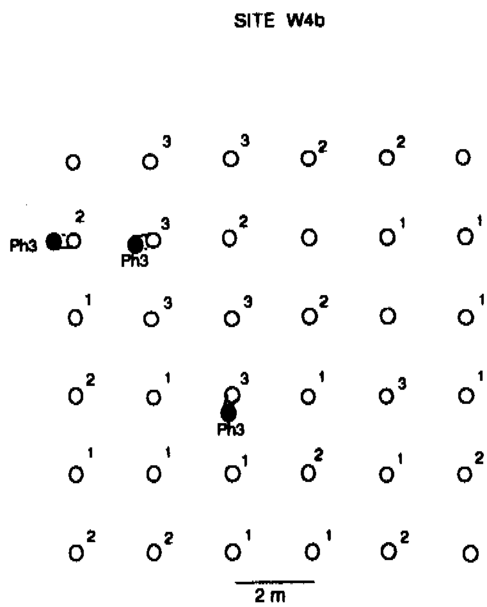
Appendix 10 (cont'd)





Appendix 10 (cont'd)





Appendix 11 Numbers of seed depots (n = 36 each plot) at which ants were observed feeding on arils *in situ*

	N4		N6		N11		N14		D1		D2		D3		D6		W3		W4		TOTAL
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	
MYRMICINAE																					
Crematogaster sp. 1							3	5													8
Crematogaster sp. 2													1								1
Meranoplus sp. 4	1	1																			2
Monomorium sp. 5										1	1	1									3
Monomorium sp. 6						1	5														6
Monomorium sp. 8		1																			1
Monomorium sp. 11				1	5	11	8	10	12		10	6	11	12	11						97
Monomorium sp. 14		5			5								4								14
Monomorium sp. 17	5		6	15		2			31	34			4								97
Monomorium sp. 21				2			2														4
Monomorium sp. 23													10								10
Monomorium sp. 24			3	7	8	17	8	5	7	22			3	15	4	3	13	24	35	26	200
Monomorium sp. 28		3																			3
Pheidole sp. 3													2						2		4
Pheidole sp. 8		3											3								6
Pheidole sp. 13	8								1												9
Solenopsis sp. 1											9	8	2								19
Tetramorium sp. 1		1																			1
Tetramorium sp. 2																1					1
Tetramorium sp. 5						1															1
T. lanuginosum				7													5	2		1	15
DOLICHODERINAE																					
Iridomyrmex sp. 2		1									1	5									7
FORMICINAE																					
Camponotus sp. 17	4																				4
Paratrechina sp. 2					1											28					29
TOTAL (%depots)	44	39	22	75	42	67	61	44	100	100	53	47	69	69	39	81	50	69	97	75	62