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

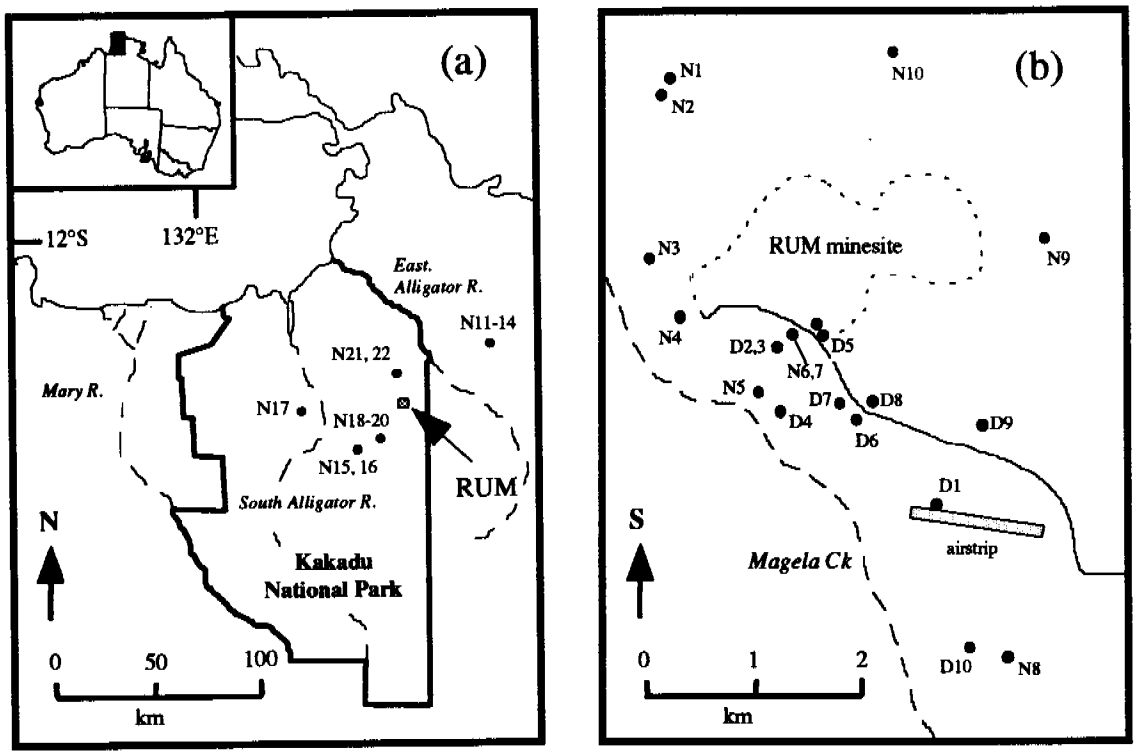


Figure 2.1 Location of study sites (a) outside and (b) inside the immediate area of Ranger uranium mine (RUM). The waste rock sites (W1–7) were all located on Ranger's northern waste rock dump, and are not indicated here.

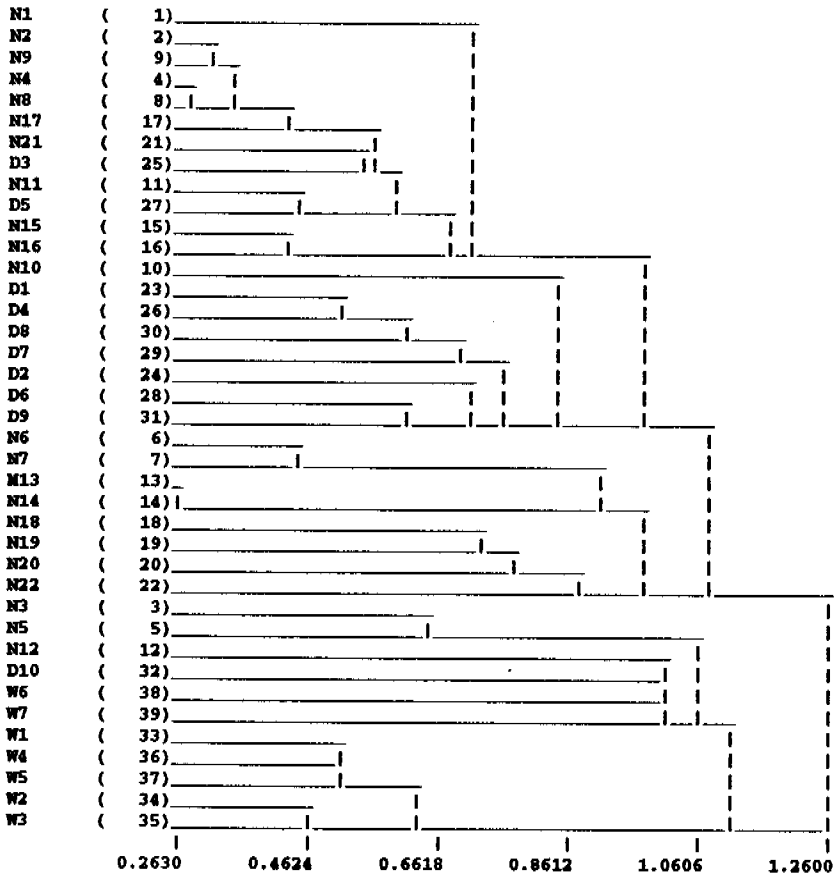


Figure 2.2 Dendrogram illustrating classification of study sites, using flexible UPMGA, based on woody plant composition

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

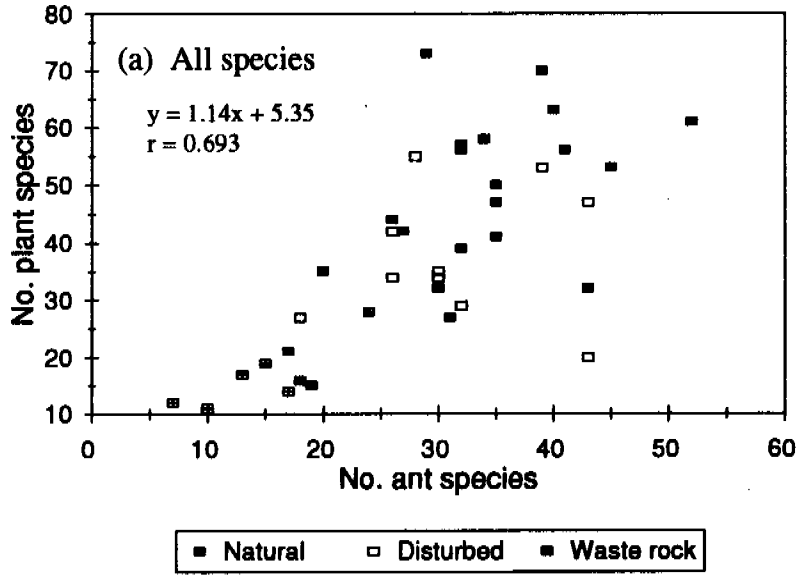
A total of 162 species of ants from 32 genera were recorded in pitfall traps (appendixes 1 and 2). The number of species ranged from 17 to 52 (mean of 33.1) at natural sites, from 18 to 43 (mean of 31.5) at disturbed sites, and 7 to 24 (mean of 14.9) at waste rock sites. Ant species richness was highly 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.



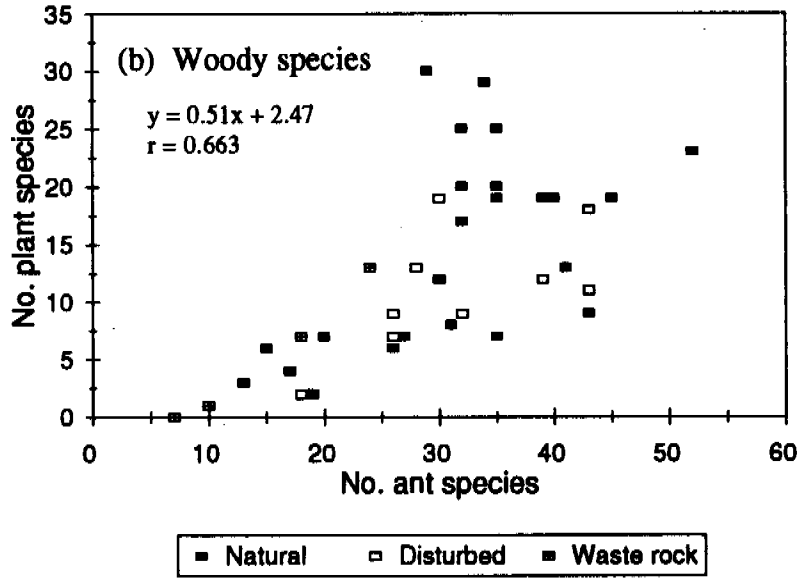


Figure 3.1 Relationships between ant and plant species richness, considering (a) all plant species, and (b) woody species only. Both correlation coefficients are highly significant ($p<0.001$).

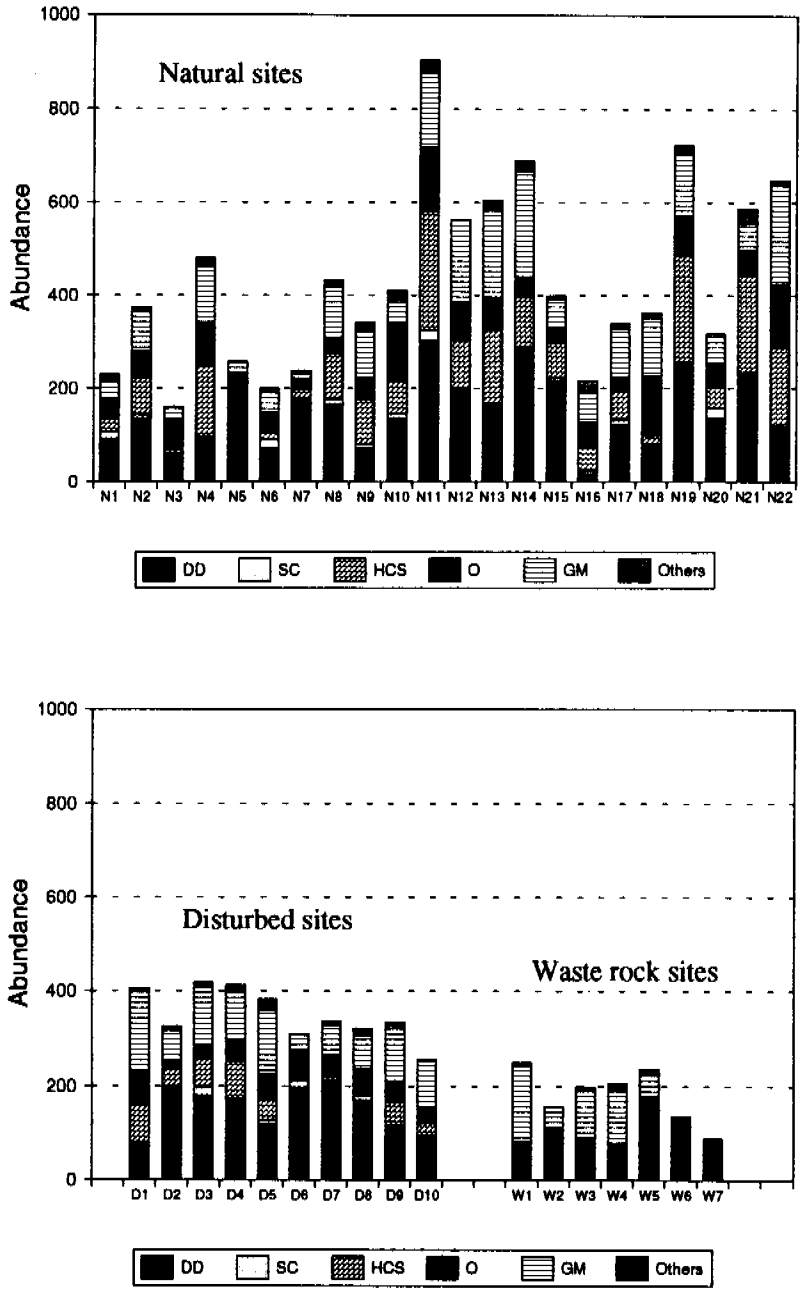


Figure 3.2 Abundances of major ant functional groups recorded in pitfall traps; DD = Dominant Dolichoderinae; SC = Subordinate Camponotinae; HCS = Hot Climate Specialists; O = -Opportunists; GM = Generalized Myrmicinae

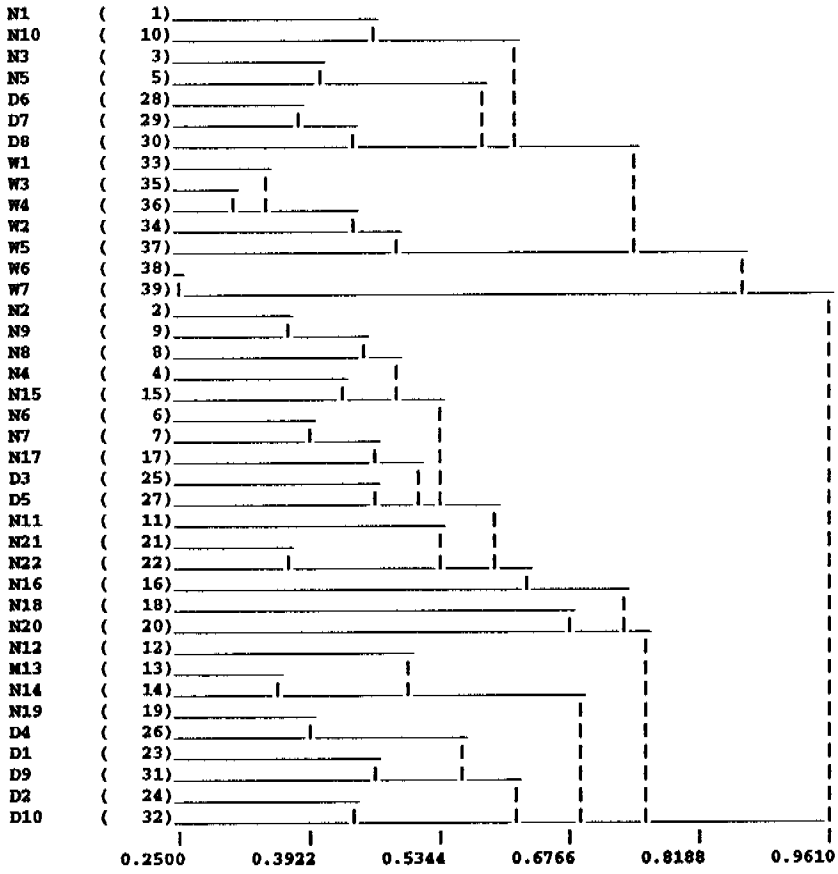


Figure 3.3 Dendrogram illustrating classification of study sites, using flexible UPMGA, based on ant species composition

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 ($p<0.001$)