

## Community Organisation, Biogeography and Seasonality of Ants in an Open Forest of South-eastern Queensland

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### Abstract

The biogeography and structure of ant communities were examined over a 12-month period at a dry open eucalypt forest in south-eastern Queensland. Three sites were monitored, each with a distinct long-term burning history: burned annually since 1952, burned periodically since 1973, and unburned since 1946. A total of 89 species from 42 genera was recorded over all trapping periods, with the richest genera being *Iridomyrmex*, *Camponotus* and *Pheidole*, each with eight species. Site species richness was 74, 63 and 43, respectively, at the annually burned, periodically burned and the unburned site. We compared the ant community in this forest with those at other forested sites in eastern Australia. Overall, the south-eastern Queensland community was located on the overlap between the Bassian and Torresian zones (not dominated by either element), while the functional-group composition resembled those of both tropical savannas and cool-temperate woodlands. There were readily discernible differences between sites in terms of biogeographical and functional-group composition; and between the unburned site and both burned sites in terms of abundance and species richness. The relative abundance of *Iridomyrmex* spp. increased with burning frequency while the relative abundance of Bassian species decreased with burning frequency. Species richness and abundance at the burned sites were similar, but substantially higher than at the unburned site. The community characteristics of the three sites were readily distinguishable, indicating that ant communities may play a valuable role in detecting ecological changes in forested landscapes in south-eastern Queensland.

### Introduction

Ants are ideal indicators of ecological change in the Australian terrestrial environment because of their ubiquitously high abundance and diversity, their ecological importance at all trophic levels, their well-understood dynamics in relation to stress and disturbance, and the extent to which their responses reflect general ecological change (Majer 1983; Greenslade and Greenslade 1984; Andersen 1990, in press). Ants have a long history of use as indicators of ecosystem restoration following mining (Majer 1984, 1985; Majer *et al.* 1984; Andersen 1993a, 1997; Jackson and Fox 1996), and more recently have been incorporated into the monitoring programmes of other resource-based industries, including forestry (Neumann 1992; Oliver 1993; York 1994).

The use of invertebrates as bio-indicators is most effective when supported by detailed knowledge of the community dynamics of the local fauna. This is true for experimental manipulation at the landscape scale, which typically involves limited replication (Carpenter

Some ant surveys have already been conducted in south-eastern Queensland [e.g. North Stradbroke Island (Drake 1981; Majer 1985) and the Cooloola region (Greenslade and Thompson 1981)], but the ant fauna of production forests in the Gympie region is largely unknown. Here we describe patterns of community organisation, biogeography and seasonality of ant communities of forests dominated by spotted gum [*Corymbia citriodora* (Hook.) K. D. Hill & L. A. S. Johnson] at Bauple State Forest, in order to provide baseline information for the future use of ants as indicators of ecological change associated with forest management practices.

## Methods

### Study Site

Bauple State Forest (25°55'S, 152°40'E) is an open forest located approximately 40 km north of Gympie in south-eastern Queensland. Mean annual rainfall is approximately 1100 mm and more than 50% of this falls in the summer months, between December and March. Bauple State Forest is reserved for timber production, and has been harvested selectively in the past for timber products such as treated electrical poles, mill timber and agricultural fencing material.

The dominant canopy trees are *Corymbia citriodora* and *Eucalyptus drepanophylla* F. Muell. ex Benth., while the understorey is composed chiefly of *Acacia aulacocarpa* Cunn. ex Benth. and *Acacia leiocalyx* (Domin) Pedley. The understorey plant *Alphitonia excelsa* (Cunn. ex Fenzl) Reissack ex Benth. and the introduced weed *Lantana camara* L. commonly occur in patches where soils are deeper and more fertile.

Three compartments in Bauple State Forest have been subjected to experimental burning regimes as follows: (i) annually burned in spring since 1952 (314 ha); (ii) periodically burned in spring at 3–5-year intervals since 1973 (423 ha), including 1994, the year of this study; and (iii) unburned since at least 1946 (296 ha). Annual and periodic burning treatments have resulted in a reduction of woody understorey plants and the development of a grassy understorey dominated by *Themeda triandra* Forsskal and *Imperata cylindrica* (L.) Rätischel, while the absence of fire at the unburned site has resulted in a heavy litter layer and the establishment of a greater proportion of fire-sensitive understorey plants and a reduction in the dominance of grasses.

### Sampling

Two plots were established in each compartment (annually burned, periodically burned and unburned) in April 1994. The original burning treatments were not replicated (i.e. only a single compartment was used for each treatment). So the plots we established do not represent true replicates, and were used to sample variation within sites. Each plot consisted of a grid of nine (3 × 3) pitfall traps spaced at 5-m intervals. Pitfalls comprised test tubes of 18 mm diameter inserted into permanent sleeves, broadly following the method of Majer (1978). The preservative used was 70% ethanol to which a small quantity of glycerol had been added. Digging-in effects (Greenslade 1973) were minimised by establishing plots several weeks prior to opening traps. Ants were sampled by opening traps for seven days each month from May 1994 to April 1995. Pitfall traps are likely to provide a good indication of the relative abundance of species foraging on the ground (Andersen 1991a), but bias against arboreal and cryptic species (Andersen and Reichel 1994). Hence it is largely the epigeaic component of the ant fauna that is the subject of this paper.

### Analysis

Ants were sorted to species, but in most cases were unable to be named with certainty owing to the poor species-level taxonomy of Australian ants. Unidentified species within a genus were therefore distinguished by a letter code (sp. A, sp. B etc.), which applies only to this study. Voucher collections are held at both the Queensland Forestry Research Institute, Gympie, and at the CSIRO Tropical Ecosystems Research Centre, Darwin. Species abundances in each trap were square-root transformed to avoid distortions caused by large numbers of individuals falling into a few traps (Southwood 1978; Andersen 1983, 1991a). Abundance for a plot of nine pitfalls was determined by summing the transformed abundances from individual traps. Data from the two plots within a site were pooled for most analyses.

Each species was described as having Eyrean (arid), Bassian (cool temperate) or Torresian (tropical) affinities, or as being Widespread, according to the species-group to which it belongs. Such designations were based on Andersen's understanding of the biogeography of the Australian ant fauna, following and extending those designations published elsewhere (e.g. Andersen 1992, 1993b; Andersen and Clay 1996;

Reichel and Andersen 1996). Species were also classified into functional groups according to their habitat requirements and competitive interactions, following Greenslade (1978) and Andersen (1990, 1995). These groups are as follows: Dominant Dolichoderinae; Subordinate Camponotini; Hot, Cold, and Tropical Climate Specialists; Cryptic Species; Opportunists; Generalised Myrmicinae; and Specialist Predators.

Ant species richness, abundance and composition were compared across sites. The absence of comparative pre-burn data obviously constrains any interpretation of apparent fire effects, given that the two plots within each site do not represent treatment replicates. The effects of fire on these ant communities have been detailed elsewhere (Vanderwoude *et al.* 1997) and are therefore not a focus of this paper.

The relationship of the different faunas between plots was examined by means of the multivariate package PATN (Belbin 1993). Abundance data for all sampling periods were combined and transformed by  $\log(n + 1)$ . Plots were classified with the Bray–Curtis index of similarity. An agglomerative dendrogram was then constructed using the unweighted pair group mean average (UPGMA) method.

#### *Meteorological Data*

The relationships between maximum and minimum temperatures, and ant abundance and richness, were explored by linear regression for each sampling period. Temperature records were obtained from the nearest official meteorological recording station (Gympie, some 40 km south of the study area).

## Results

### *Species Richness and Composition*

A total of 89 species from 42 genera was recorded over all trapping periods, with the richest genera being *Iridomyrmex*, *Camponotus* and *Pheidole*, each with eight species (Table 1). The most abundant species were *Iridomyrmex* sp. B [*rufoniger* (Lowne) group], representing 21% of all ants found in traps, *Rhytidoponera* ?*metallica* (F. Smith) (12%), *Crematogaster* sp. A (8%), *Pheidole* sp. E (8%), *Pheidole* sp. F (4%), *Aphaenogaster longiceps* (F. Smith) (4%), *Iridomyrmex* sp. A (3%), *Rhytidoponera victoriae* (E. Andre) (3%) and *Monomorium* sp. A (3%).

Site species richness was 74, 63 and 43, respectively, at the annually burned, periodically burned and unburned sites. Species accumulation was plotted against cumulative species records (summing the number of species detected each month) at each site (Fig. 1). This demonstrates that observed differences reflect real differences in species richness, and are not simply artefacts of between-site differences in the number of individuals falling into pitfall traps owing to differences in the structure of ground vegetation. Individual plot richness was 56 and 53 (annually burned); 50 and 58 (periodically burned); and 31 and 37 (unburned). Plot richness was therefore similar at the two burned sites, implying that species turnover across plots was greater within the annually burned site, given its higher total species richness.

Sixteen species were found exclusively at the annually burned site, nine at the periodically burned site and three at the unburned site. Species rank–abundance curves (Fig. 2) show that relative numerical dominance was greatest at the annually burned site (where the most-abundant species contributed to 32% of all ants trapped) and least at the unburned site. The dendrogram showing the relationships between plots (Fig. 3) indicates a clear distinction between the four burned plots and the two unburned ones. The two periodically burned plots were also particularly similar to each other.

### *Biogeography*

Most of the 89 species recorded represent either Widespread (40%) or Bassian (29%) taxa, with 20% and 11% having Torresian and Eyrean affinities, respectively. The biogeographic structure of the ant communities was extremely similar across sites in terms of numbers of

burned; U, unburned), captured by pitfall trapping at Bauple between May 1994 and April 1995

Functional groups: DD, Dominant Dolichoderinae; SC, Subordinate Camponotini; HCS, Hot Climate Specialist; TCS, Tropical Climate Specialist; CCS, Cold Climate Specialist; C, Cryptic Species; O, Opportunist; GM, Generalised Myrmicinae; SP, Specialist Predator. Biogeography: T, Torresian; E, Eyrean; B, Bassian; W, Widespread. Abundance data were square-root transformed at pitfall level. +, <0.01%

Species	Functional group	Biogeography	Site A	Site P	Site U	Total	%
<b>Ponerinae</b>							
<i>Anochetus</i> sp. A ( <i>graeffei</i> Mayr gp)	SP	T	0	2	0	2	+
✓ <i>Bothroponera</i> ? <i>oculata</i>	SP	T	2	3	7	12	0.3
✓ <i>Bothroponera</i> sp. nr <i>porcata</i> (Emery)	SP	T	1	7	0	8	0.2
<i>Brachyponera</i> <i>lutea</i> (Mayr)	C	T	5	5	0	10	0.2
<i>Heteroponera</i> ? <i>imbellis</i> (Emery)	CCS	B	2	2	26	30	0.7
<i>Hypoponera</i> sp. A	C	W	1	0	0	1	+
<i>Leptogenys</i> <i>angustinoda</i> Clark	SP	T	1	0	0	1	+
✓ <i>Mesoponera</i> <i>australis</i> (Forel)	SP	T	0	0	7	7	0.2
<i>Rhytidoponera</i> ? <i>metallica</i> (F. Smith)	O	W	129	185	161	475	11.5
✓ <i>Rhytidoponera</i> sp. nr <i>rufithorax</i> Clark	O	E	41	24	0	65	1.6
✓ <i>Rhytidoponera</i> <i>victoriae</i> (E. Andre)	O	B	10	3	108	121	2.9
<i>Sphinctomyrmex</i> sp. A	C	T	0	0	1	1	+
<b>Myrmicinae</b>							
<i>Adlerzia</i> <i>frogatti</i> (Forel)	HCS	E	5	0	0	5	0.1
✓ <i>Aphaenogaster</i> <i>pythia</i> Forel	O	W	4	2	0	6	0.1
✓ <i>Aphaenogaster</i> <i>longiceps</i> (F. Smith)	O	W	1	3	153	157	3.8
<i>Cardiocondyla</i> ? <i>nuda</i> (Mayr)	O	T	3	0	0	3	0.1
✓ <i>Colobostruma</i> sp. A	SP	B	4	0	1	5	0.1
<i>Crematogaster</i> sp. A	GM	W	161	169	2	332	8.1
<i>Crematogaster</i> sp. B	GM	W	2	12	0	14	0.3
✓ <i>Crematogaster</i> sp. C	GM	W	2	25	1	28	0.7
✓ <i>Epopostruma</i> sp. A	SP	B	0	0	1	1	+
<i>Eurhopalothrix</i> <i>australis</i>	C	T	8	0	0	8	0.2
<b>Brown &amp; Kempf</b>							
<i>Mayriella</i> <i>abstinens</i> Forel	TCS	T	4	0	0	4	0.1
<i>Mayriella</i> <i>overbeckii</i> Viehmeyer	TCS	T	1	0	0	1	+
<i>Meranoplus</i> sp. A	HCS	W	2	0	0	2	+
<i>Meranoplus</i> sp. B	HCS	W	4	0	0	4	0.1
<i>Monomorium</i> sp. A	GM	W	55	44	11	110	2.7
<i>Monomorium</i> sp. B	GM	W	24	33	1	58	1.4
<i>Monomorium</i> sp. D	CCS	B	2	9	0	11	0.3
<i>Monomorium</i> <i>flavipes</i> (Clark)	CCS	B	0	10	0	10	0.2
<i>Monomorium</i> sp. G	GM	W	22	41	8	71	1.7
<i>Pheidole</i> sp. A	GM	T	37	28	8	73	1.8
<i>Pheidole</i> sp. B	GM	W	18	1	5	24	0.6
<i>Pheidole</i> sp. C	GM	W	13	4	10	27	0.7
<i>Pheidole</i> sp. E	GM	W	140	126	43	309	7.5
<i>Pheidole</i> sp. F	GM	W	75	65	19	159	3.9
<i>Pheidole</i> sp. G	GM	W	7	7	5	19	0.5
<i>Pheidole</i> sp. I	GM	W	12	2	7	21	0.5
<i>Pheidole</i> sp. J	GM	T	20	2	0	22	0.5
<i>Oligomyrmex</i> sp. A	C	T	0	0	1	1	+
<i>Solenopsis</i> sp. A	C	W	39	28	2	69	1.7
<i>Strumigenys</i> <i>perplexa</i> (F. Smith)	C	T	2	0	0	2	+
<i>Tetramorium</i> sp. A	O	E	2	0	86	88	2.1
( <i>striolatum</i> Viehmeyer gp)							
<i>Tetramorium</i> sp. B	O	E	15	0	0	15	0.4
( <i>striolatum</i> Viehmeyer gp)							

Table 1. *continued*

Species	Functional group	Biogeography	Site A	Site P	Site U	Total	%
<b>Dolichoderinae</b>							
<i>Bothriomyrmex</i> sp. A	C	B	0	0	1	1	+
<i>Doleromyrma</i> sp. A	O	B	1	3	3	7	0.2
<i>Dolichoderus scrobiculatus</i> (Mayr)	CCS	B	3	0	0	3	0.1
<i>Iridomyrmex</i> sp. A	DD	W	84	46	6	136	3.3
<i>Iridomyrmex</i> sp. B	DD	E	562	282	29	873	21.2
[ <i>rufoniger</i> (Lowne) gp]							
<i>Iridomyrmex</i> sp. D	DD	W	1	5	42	48	1.2
✓ <i>Iridomyrmex</i> sp. nr <i>agilis</i> Forel	DD	E	0	17	0	17	0.4
<i>Iridomyrmex</i> sp. F	DD	W	1	1	0	2	+
<i>Iridomyrmex</i> sp. G	DD	W	1	0	17	18	0.4
<i>Iridomyrmex</i> sp. H	DD	W	1	0	0	1	+
✓ <i>Iridomyrmex</i> ? <i>gracilis</i> Lowne	DD	B	3	8	14	25	0.6
✓ <i>Leptomyrmex cnemidatus</i> Wheeler	TCS	T	1	5	2	8	0.2
<i>Tapinoma</i> sp. A ( <i>minutum</i> Mayr gp)	O	W	3	0	0	3	0.1
<i>Technomyrmex</i> sp. A	O	W	15	11	0	26	0.6
<b>Formicinae</b>							
✓ <i>Camponotus</i> ? <i>aeneopilosus</i> Mayr	SC	B	15	18	1	34	0.8
<i>Camponotus</i> sp. A ( <i>rubiginosus</i> Mayr gp)	SC	W	0	1	0	1	+
✓ <i>Camponotus</i> sp. C ( <i>claripes</i> Mayr gp)	SC	W	0	2	0	2	+
✓ <i>Camponotus</i> sp. nr <i>consobrinus</i> (Erichson)	SC	B	19	16	2	37	0.9
<i>Camponotus</i> sp. D ( <i>claripes</i> Mayr gp)	SC	W	2	7	5	14	0.3
✓ <i>Camponotus</i> sp. nr <i>nigriceps</i> (F. Smith)	SC	B	0	2	0	2	+
<i>Camponotus suffusus</i> (F. Smith)	SC	B	1	0	0	1	+
<i>Camponotus</i> sp. B ( <i>novaeollandiae</i> Mayr gp)	SC	T	1	0	0	1	+
<i>Melophorus</i> sp. A [ <i>aeneovirens</i> (Lowne) gp]	HCS	E	7	15	0	22	0.5
<i>Melophorus hirsutus</i> Forel	HCS	E	2	9	4	15	0.4
<i>Melophorus</i> sp. A	HCS	E	1	16	4	21	0.5
<i>Melophorus</i> sp. B	HCS	E	6	4	0	10	0.2
✓ <i>Notoncus</i> sp. A [ <i>lectatomoides</i> (Forel) gp]	CCS	B	9	2	0	11	0.3
✓ <i>Notoncus</i> sp. B ( <i>enormis</i> Szabo. gp)	CCS	B	33	8	0	41	1.0
✓ <i>Opisthopsis pictus</i> Emery	SC	T	3	2	0	5	0.1
✓ <i>Opisthopsis rufithorax</i> Emery	SC	T	0	3	0	3	0.1
<i>Paratrechina</i> sp. A [ <i>minutula</i> (Forel) gp]	O	W	11	20	2	33	0.8
<i>Paratrechina</i> sp. B ( <i>vaga</i> Forel gp)	O	W	43	2	68	113	2.7
<i>Paratrechina</i> sp. C ( <i>obscura</i> Mayr gp)	O	W	6	1	6	13	0.3
✓ <i>Polyrhachis ammon</i> (Fabricius)	SC	T	2	7	1	10	0.2
<i>Polyrhachis ornata</i> Mayr	SC	T	1	0	0	1	+
<i>Polyrhachis</i> sp. A ( <i>sidnica</i> Mayr gp)	SC	B	0	2	0	2	+
<i>Polyrhachis</i> ( <i>Chariomyrma</i> ) sp. A	SC	T	0	2	1	3	0.1
<i>Polyrhachis phryne</i> Forel	SC	B	0	2	0	2	+
<i>Prolasius</i> sp. nr <i>nitidissimus</i> (E. Andre)	CCS	B	18	20	1	39	0.9

The most abundant functional groups were Generalised Myrmicinae (particularly species of *Pheidole*; 31% of total ants), Opportunists (particularly species of *Rhytidoponera*; 28%) and Dominant Dolichoderinae (species of *Iridomyrmex*; 27%). These three groups together accounted for 86% of all ants, despite contributing only 41% of total species. Subordinate Camponotini, Hot Climate Specialists, Cryptic Species and Specialist Predators, combined, also contributed 41% of total species but represented only 8% of ants in traps. Functional-group composition varied markedly across sites (Fig. 5). The relative abundance of Dominant Dolichoderinae was 12% at the unburned site, 25% at the periodically burned site and 37% at the annually burned site. Opportunists represented 65% of all ants at the unburned site, compared with less than 20% at the other sites.

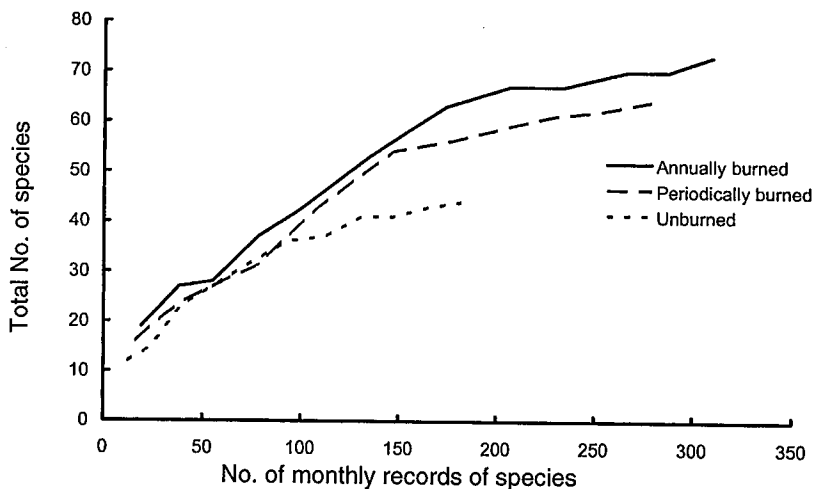


Fig. 1. Cumulative number of species detected against the cumulative number of monthly records of species, for each site between May 1994 and April 1995.

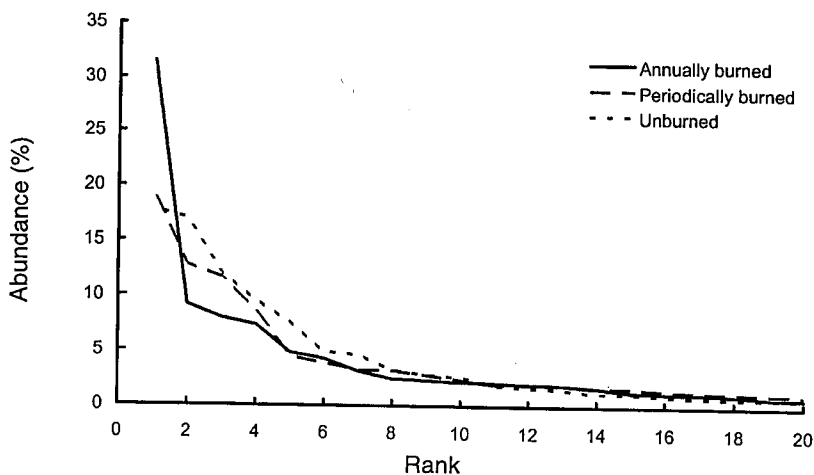


Fig. 2. Species rank-abundance curves for the first 20 taxa at each site.

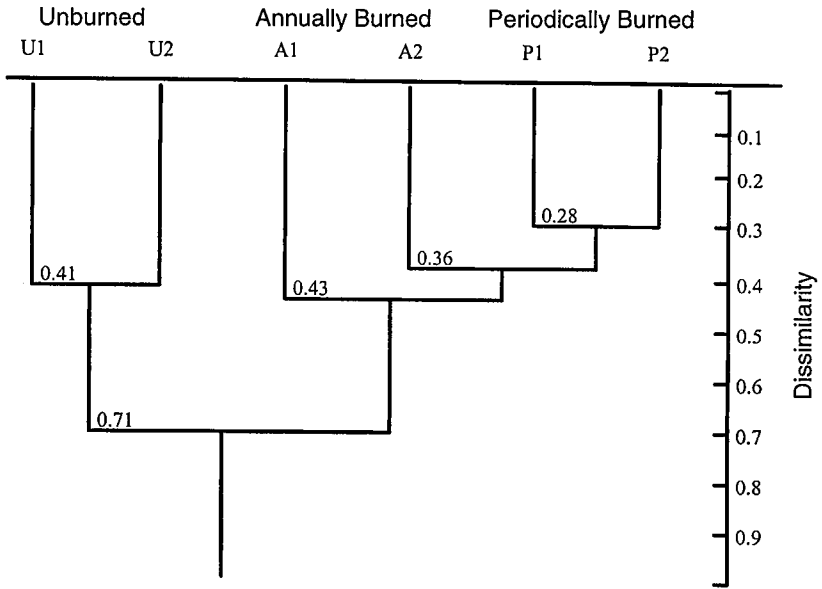
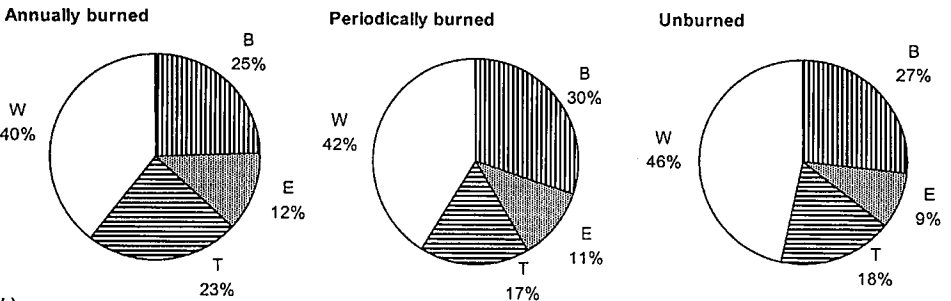
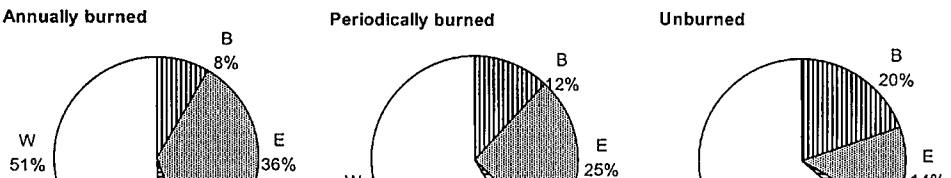


Fig. 3. Agglomerative dendrogram demonstrating the relative similarity of plots in terms of ant communities. Abundance data were used and transformed by  $\log(n + 1)$ .

(a)



(b)



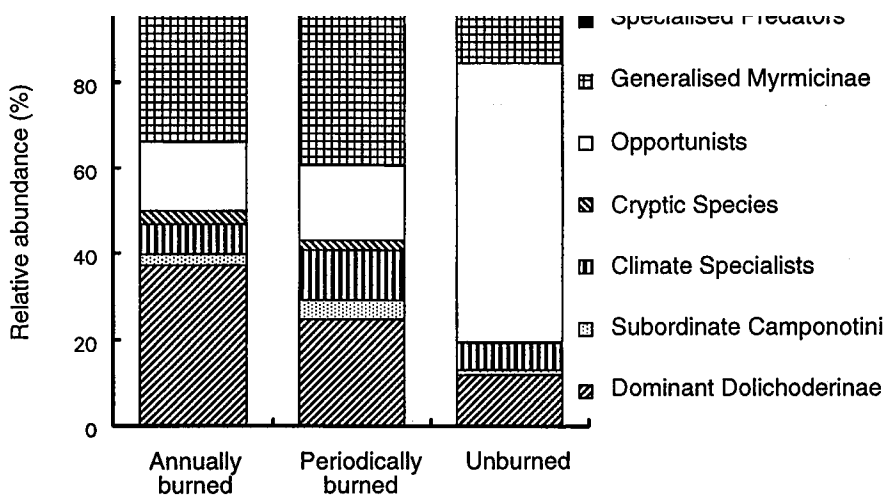


Fig. 5. Relative abundance of functional groups at each site, summed over all trapping periods.

### Seasonality

Both abundance and species richness were higher at all sites in the warmer months, between October and February (Fig. 6). There were significant positive linear relationships between mean maximum temperature and ant abundance but no such relationships for minimum temperature. Species richness at the periodically burned and the annually burned sites, but not at the unburned site, was also significantly correlated with mean maximum temperatures (Table 2).

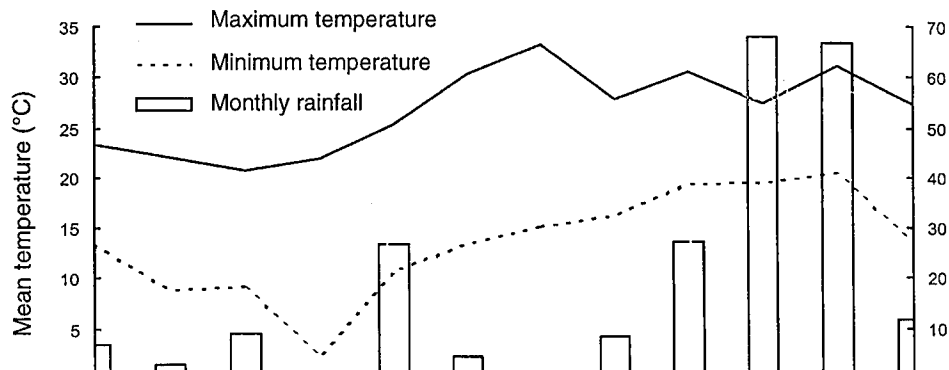
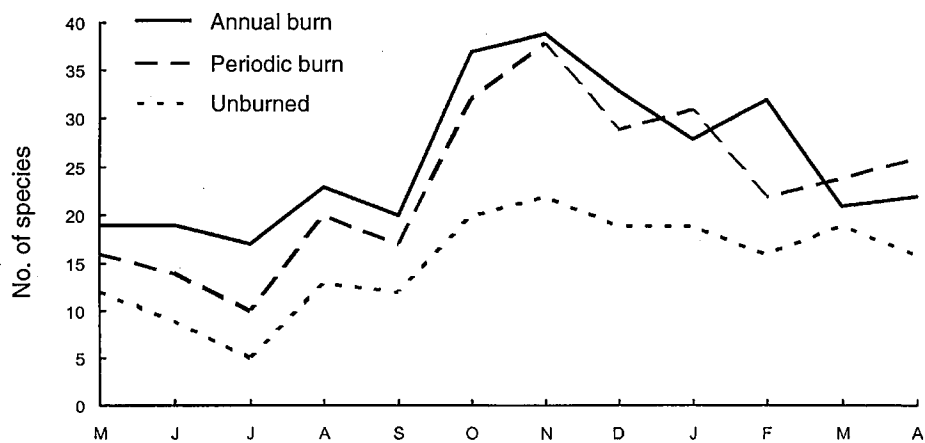
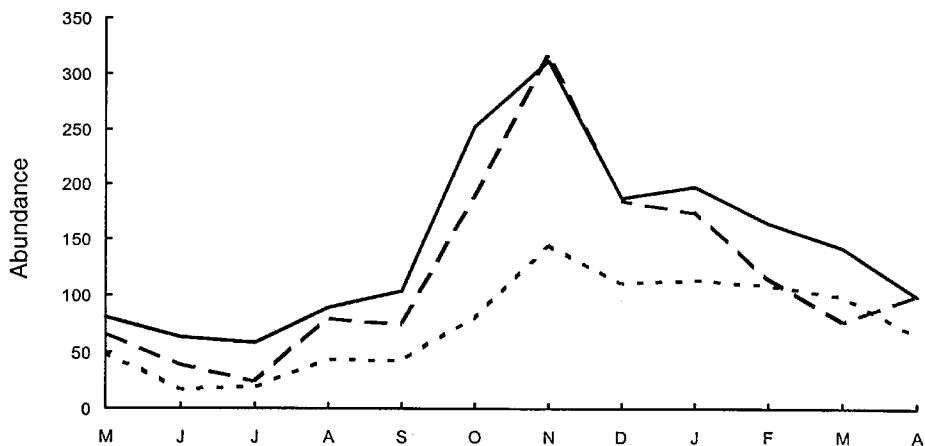
**Table 2. Regression equations and correlation coefficients ( $r$ ) for the relationships between maximum temperature during sampling and ant abundance and number of species**

$n = 24$ ;  $r = 0.537$  at  $P = 0.01$

Site	Regression equation	$r$
Abundance		
Annually burned	$y = 8.5x - 155.3$	0.801
Periodically burned	$y = 8.2x - 159.1$	0.764
Unburned	$y = 4.5x - 84.1$	0.849
Species richness		
Annually burned	$y = 1.05x - 11.6$	0.733
Periodically burned	$y = 1.14x - 21.4$	0.830
Unburned	$y = 0.6x - 4.6$	0.368

There were marked differences between species in seasonal activity patterns (Fig. 7). Abundance of some species was highly correlated with mean maximum temperatures; for example, *Iridomyrmex* sp. B ( $r^2 = 0.8438$ ,  $n = 12$ ) and *Rhytidoponera* ?*metallica* ( $r^2 = 0.6509$ ,  $n = 12$ ) (Fig. 7a). Similar patterns were also shown by *Aphaenogaster longiceps*, *Notoncus* sp. B and species of *Paratrechina*. However, *Stigmacros* ?*intacta* and *Prolasius* sp. nr *nitidissimus*





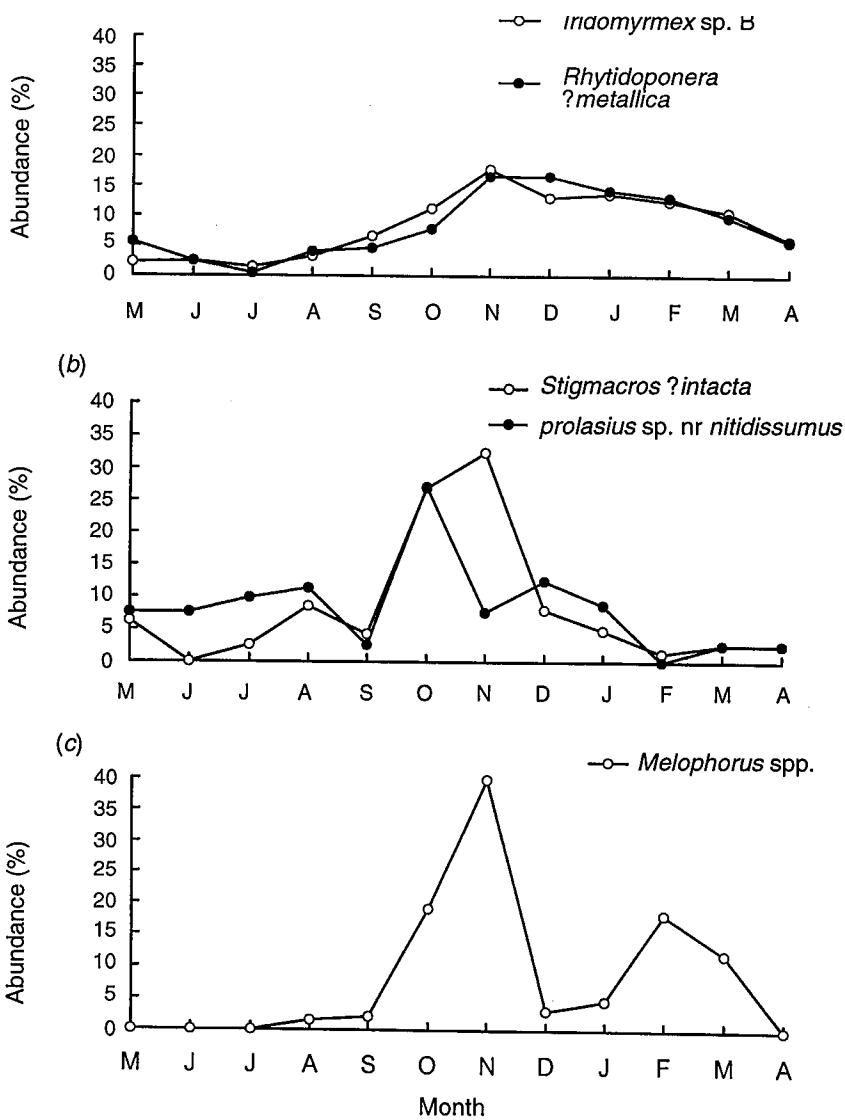
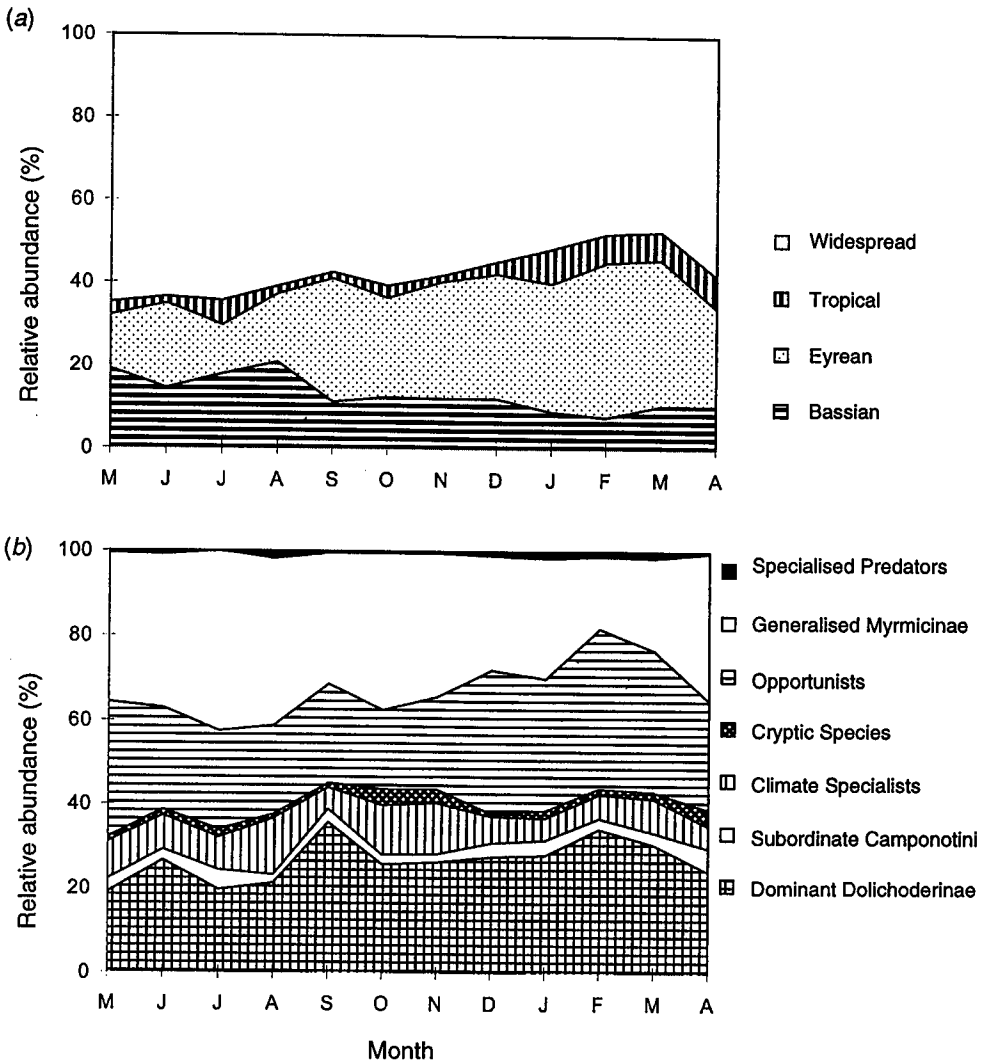


Fig. 7. Abundance of (a) *Iridomyrmex* sp. B [*rufoniger* (Lowne) group] and *Rhytidoponera* ?*metallica*, (b) *Stigmacros* ?*intacta* and *Prolasius* sp. nr *nitidissimus*, and (c) *Melophorus* spp. between May 1994 and April 1995. All data have been square-root transformed and results from all sites were pooled.

showed spring peaks (Fig. 7b) while the abundance of *Melophorus* spp. peaked in spring and late summer (Fig. 7c). These patterns were also evident at the unburned site, indicating that they were not simply artefacts of increased trappability following fire.

The relative abundance of Eyrean taxa increased during the warmer months (Fig. 8a) and the relative abundance of Bassian taxa increased during the cooler months. The relative dominance of functional groups showed little consistent seasonal variation (Fig. 8b) and the abundance of ants in all groups except Tropical Climate Specialists was correlated with the mean maximum temperatures recorded during sampling (Table 3). The Dominant Dolichoderinae ( $r = 0.8987$ ),



**Fig. 8.** Seasonal variation in (a) biogeographical profiles and (b) functional-group composition (data pooled across all sites).

Subordinate Camponotini ( $r = 0.8035$ ) and Opportunists ( $r = 0.8261$ ) demonstrated the closest relationship with mean maximum temperatures while Specialist Predators ( $r = 0.6370$ ) and Cold Climate Specialists ( $r = 0.6451$ ) had the weakest (but still significant) correlation.

**Discussion**

maximum temperature during sampling and abundance of ants according  
to functional groups

$n = 12$ ;  $r = 0.708$  at  $P = 0.01$ ,  $r = 0.576$  at  $P = 0.05$

Functional group	$r$
Dominant Dolichoderinae	0.8987
Subordinate Camponotini	0.8035
Cryptic Species	0.7660
Opportunists	0.8261
Generalised Myrmicinae	0.7569
Specialist Predators	0.6370
Hot Climate Specialists	0.7126
Cold Climate Specialists	0.6451
Tropical Climate Specialists	Insufficient data

Bassian (29% of total species) and Torresian (20%) elements are well represented in the Bauple fauna, but the most-common ants were usually representatives of Widespread taxa such as *Rhytidoponera*, *Crematogaster*, *Pheidole* and *Aphaenogaster*. The most notable exception was *Iridomyrmex* sp. B (*rufoniger* group). This species is common throughout south-eastern Queensland, but its relatives are most characteristic of the central and southern arid zones (Andersen, unpublished records). Some Bassian taxa such as species of *Stigmacros*, *Prolasius* and *Notoncus* were reasonably abundant, but not so any Torresian taxa, which collectively represented only 4% of ants recorded in traps.

Although the proportion of individuals from each biogeographic group changed by 2–22% between sites (Fig. 4b), the proportion of species making up these groups was remarkably stable, varying by only 3–6% across sites (Fig. 4a). This suggests that the proportion of species belonging to each biogeographic group may be a better indicator of the biogeography of a particular region than the relative abundance of individuals. The three sites surveyed here are quite different structurally, ranging from tall forest with little or no understorey and a grassy ground layer to tall forest with a well-developed understorey and a ground layer lacking grasses and dominated by vines and dead timber. The similarity of the biogeographic profiles at these sites suggests that causes other than immediate habitat variables may be responsible, and this is one question for future studies to consider.

The functional-group profile at Bauple State Forest was similar to those of both tropical savanna and cool-temperate woodland, except for the mix of climate specialists (Table 4). Climate specialists contributed 25–30% of total species in each case, but are predominantly 'hot' in savannas and 'cold' in the cool-temperate zone, with a mixture of both recorded in the present study. This places Bauple in an overlap between these regions in much the same manner as do the biogeographical profiles.

### Seasonality

Ant activity was positively related to temperature, and the summer peaks described here are typical for ants of temperate climates (Whitford 1978; Briese and Macauley 1980; Andersen 1983, 1986). However, this seasonal pattern was not uniform across species, with several showing spring peaks. Spring peaks in activity have also been documented for *Plagiolepis* sp. in southern Australia (Andersen 1986). A small number of species in cool-temperate Australia forage exclusively during colder months (Andersen 1986), but such species were not recorded at Bauple. Species of *Melophorus* showed pronounced peaks in both spring and late summer that appear to correspond closely with mean maximum temperatures recorded for these periods. As species of *Melophorus* are known to be active for narrowly defined periods of high temperatures, the generally lower temperatures recorded for the trapping periods of December and February may have resulted in lower abundance for these months.

**ographic and functional-group composition at Bauple State Forest compared with other forested sites in northern and eastern Australia**  
 es of total species occurring at each site. Species richness was determined from the results of pitfall trapping over several seasons except in the monsoon  
 here other sampling methods were also used. References: 1, Anderson and Reichel (1994); 2, Andersen (1992b); 3, present study; 4, Andersen (1986); 5,  
 y (1996). Biogeography: T, Torresian; E, Eyrean; B, Bassian; W, Widespread. Functional groups: DD, Dominant Dolichoderinae; SC, Subordinate  
 S, Hot Climate Specialist; TCS, Tropical Climate Specialist; CCS, Cold Climate Specialist; C, Cryptic Species; O, Opportunist; GM, Generalised  
 Myrmicinae; SP, Specialist Predator

Vegetation	Location	Reference	Biogeography					Functional groups							
			T	B	E	W	DD	SC	HCS	TCS	CCS	C	O	GM	SP
Rainforest	Darwin, Northern Territory	1	68	2	2	28	0	26	2	0	6	17	25	19	4
Savanna	Kapalga, Northern Territory	2	30	0	19	51	8	10	23	0	5	3	19	25	9
Open forest	Bauple, Queensland	3	20	29	11	40	9	17	8	16	2	7	16	16	9
Woodland	Wilson's Promontory, Victoria	4	2	55	0	43	14	11	0	25	0	11	11	14	14
Mallee woodland	Wyperfeld, Victoria	5	1	35	30	34	9	20	17	16	2	11	11	10	14

(Fig. 6), and although activity was greater in warmer months than cooler months, the increase was much lower. The decreased insolation at ground level, greater microclimatic buffering and more complex understorey are the probable reasons for this difference in activity.

In temperate Australia, there is substantial seasonal variation in functional-group composition, with seasonal changes paralleling those occurring along biogeographical gradients spanning comparable temperature regimes (Andersen 1995). At cool-temperate sites, for example, composition during summer is similar to overall composition at sites at lower latitude. This contrasts with the situation in the tropics, where there appears to be little seasonal variation in functional-group composition (Andersen 1995). In the present study, the relative abundance of Eyrean taxa increased during the warmer months, and the Bassian fauna increased during the cooler months, but functional-group composition was not so strongly seasonal as it is in temperate southern Australia.

#### *Use of Ants as Bio-indicators*

The ant community patterns described here are to be used as baseline information for the future use of ants as indicators of ecological change associated with forest management practices. The sites surveyed had different fire management histories, and although fire effects were not a focus of the study, there is strong evidence that ant community composition was sensitive to fire management practices. The higher species richness, higher abundance of Eyrean and lower abundance of Bassian taxa, and higher abundance of Dominant Dolichoderinae with increasing fire frequency, all conform to known ant–fire relationships elsewhere in Australia (Andersen 1991b; York 1994; Vanderwoude *et al.* 1997). This points to the potentially valuable role played by ant-monitoring programmes in forest management.

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#### **References**

- Andersen, A. N. (1983). Species diversity and temporal distribution of ants in the semi-arid mallee region of northwestern Victoria. *Australian Journal of Ecology* **8**, 127–137.
- Andersen, A. N. (1986). Patterns of ant community organization in mesic southeastern Australia. *Australian Journal of Ecology* **11**, 87–97.
- Andersen, A. N. (1990). The use of ant communities to evaluate change in Australian terrestrial ecosystems: a review and a recipe. *Proceedings of the Ecological Society of Australia* **16**, 347–357.
- Andersen, A. N. (1991a). Sampling communities of ground-foraging ants: pitfall catches compared with quadrat counts in an Australian tropical savanna. *Australian Journal of Ecology* **16**, 273–279.
- Andersen, A. N. (1991b). Responses of ground-foraging ant communities to three experimental fire regimes in a savannah forest of tropical Australia. *Biotropica* **23**, 575–585.
- Andersen, A. N. (1992a). The rainforest ant fauna of the northern Kimberley region of Western Australia (Hymenoptera: Formicidae). *Journal of the Australian Entomological Society* **31**, 187–192.
- Andersen, A. N. (1992b). Regulations of 'momentary' diversity in exceptionally rich ant communities of tropical Australia. *American Naturalist* **140**, 410–420.
- Andersen, A. N. (1993a). Ants as indicators of restoration success at a uranium mine in tropical Australia. *Restoration Ecology* **1**, 156–167.
- Andersen, A. N. (1993b). Ant communities in the Gulf region of Australia's semi-arid tropics: species composition, patterns of organisation, and biogeography. *Australian Journal of Zoology* **41**, 399–414.
- Andersen, A. N. (1995). A classification of Australian ant communities, based on functional groups which parallel plant life-forms in relation to stress and disturbance. *Journal of Biogeography* **22**, 15–29.
- Andersen, A. N. (in press). Ants as indicators of ecosystem restoration following mining: a functional group approach. In 'Conservation Outside Nature Reserves'. (Eds P. Hale and D. Lamb.) pp. 319–325. (Centre for Conservation Biology, University of Queensland; Brisbane.)
- Andersen, A. N., and Clay, R. E. (1996). The ant fauna of Dangali Conservation Park in semi-arid South Australia: a comparison with Wyperfeld (Vic.) and Cape Arid (W.A.) National Parks. *Australian Journal of Entomology* **35**, 289–295.

- Andersen, A. N., and Reichel, H. (1994). The ant (Hymenoptera:Formicidae) fauna of Holmes Jungle, a rainforest patch in the seasonal tropics of Australia's Northern Territory. *Journal of the Australian Entomological Society* 33, 153–158.
- Belbin, L. (1993). 'PATN Pattern Analysis Package Users Guide.' (CSIRO Division of Wildlife and Ecology: Canberra.)
- Briese, D. T., and Macauley, B. J. (1980). Temporal structure of an ant community in semi-arid Australia. *Australian Journal of Ecology* 2, 107–120.
- Carpenter, S. R. (1990). Large-scale perturbations: opportunities for innovation. *Ecology* 71, 2038–2043.
- Drake, W. E. (1981). Ant–seed interaction in dry sclerophyll forest on North Stradbroke Island. *Australian Journal of Botany* 29, 293–309.
- Greenslade, P. J. M. (1973). Sampling ants with pitfall traps: digging-in effects. *Insectes Sociaux* 20, 343–353.
- Greenslade, P. J. M. (1978). Ants. In 'The Physical and Biological Features of Kunoth Paddock in Central Australia'. (Ed. W. A. Low.) pp. 109–113. CSIRO Division of Land Resources Technical Paper No. 4, Canberra.
- Greenslade, P. J. M., and Greenslade, P. (1984). Invertebrates and environmental assessment. *Environmental Planning* 3, 13–15.
- Greenslade, P. J. M., and Thompson, C. H. (1981). Ant distribution, vegetation, and soil relationships in the Cooloola–Noosa River area, Queensland. In 'Vegetation Classification in Australia'. (Eds A. N. Gillison and D. J. Anderson.) pp. 192–207. (CSIRO and the Australian National University Press: Canberra.)
- Hargrove, W. W., and Pickering, J. (1992). Pseudoreplication: a sine qua non for regional ecology. *Landscape Ecology* 6, 251–258.
- Jackson, G. P., and Fox, B. J. (1996). Comparison of regeneration following burning, clearing or mineral sand mining at Tomago, NSW: II. Succession of ant assemblages in a coastal forest. *Australian Journal of Ecology* 21, 200–216.
- Majer, J. D. (1978). An improved pitfall trap for sampling ants and other epigeic invertebrates. *Journal of the Australian Entomological Society* 17, 261–262.
- Majer, J. D. (1983). Ants: bio-indicators of minesite rehabilitation, land-use and land conservation. *Environmental Management* 7, 375–383.
- Majer, J. D. (1984). Recolonisation by ants in rehabilitated open-cut mines in northern Australia. *Reclamation and Revegetation Research* 2, 279–298.
- Majer, J. D. (1985). Recolonisation by ants of rehabilitated mineral sand mines on North Stradbroke Island, Queensland, with particular reference to seed removal. *Australian Journal of Ecology* 10, 31–48.
- Majer, J. D., Day, J. E., Kabay, E. D., and Perriman, W. S. (1984). Recolonization by ants in bauxite mines rehabilitated by a number of different methods. *Journal of Applied Ecology* 21, 355–375.
- Neumann, F. G. (1992). Responses of foraging ant populations to high-intensity wildfire, salvage logging and natural regeneration processes in *Eucalyptus regnans* regrowth forest of the Victorian Central Highlands. *Australian Forestry* 55, 29–38.
- Oliver, I. (1993). Rapid biodiversity assessment and its application to fauna conservation in production forests. In 'Rapid Biodiversity Assessment'. Proceedings of the Biodiversity Assessment Workshop, 3–4 May 1993. pp. 31–34. (Macquarie University: Sydney.)
- Reichel, H., and Andersen, A. N. (1996). The rainforest ant fauna of Australia's Northern Territory. *Australian Journal of Zoology* 44, 81–95.
- Reynoldson, T. B., Bailey, R. C., Day, K. E., and Norris, R. H. (1995). Biological guidelines for freshwater sediment based on Benthic Assessment of Sediment (the BEAST) using a multivariate approach for predicting biological state. *Australian Journal of Ecology* 20, 198–219.
- Southwood, T. R. E. (1978). 'Ecological Methods with Particular Reference to Insect Populations.' (Chapman and Hall: London.)
- Vanderwoude, C., Andersen, A. N., and House, A. P. N. (1997). Ant communities as bioindicators in relation to fire management of spotted gum (*Eucalyptus maculata* Hook.) forests in south-east Queensland. *Memoirs of the Victorian Museum* 56, 671–675.
- Whitford, W. G. (1978). Structure and seasonal activity of Chihuahua Desert ant communities. *Insectes*

