Department of Environmental Biology

Arid Zone Ant Communities of Western Australia

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ABSTRACT

This thesis is prepared in three parts; the first part is a study of the ant species of the southern Carnarvon Basin, which was undertaken in order to determine the patterns of ant species distribution in this arid zone area. The distribution patterns were looked at in terms of biogeographical regions and they demonstrated the transitional nature of this particular area. Recommendations to alter the border between the South-west Province and the Eremaean Province were supported. The next chapter of this thesis analysed ant species from long unburnt and burnt areas of three main vegetation types (two *Triodia* species grasslands and *Acacia aneura* woodlands) in the Gibson Desert Nature Reserve. This study was carried out to observe the recovery of ant populations after fire. The results provided further evidence that invertebrates are measurably impacted by fire in the arid zone. The final chapter is a comparison of these two arid zone studies with six other ant community studies from throughout Western Australia. It demonstrated the uniqueness of some arid zone sites as well as related each study to each other according to their ant communities.

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INTRODUCTION

This thesis is prepared in three parts, the first two of which focus upon ant communities of two little-studied areas of Western Australia (WA), namely the southern Carnarvon Basin and the Gibson Desert. The final chapter is an agglomeration and analysis of ant community studies from different areas in this State. This chapter aims to put in context how ant communities of these two arid areas relate to those from other parts of WA.

Ant communities have been recognised as indicators of biological diversity for a wide range of environments around the world, and hence are commonly used in assessments of environmental change (Andersen, 1990). The Carnarvon Basin and the Gibson Desert are two very different areas within WA's arid zone, and are comprised of, and surrounded by, a spectrum of land uses. These two areas have been focused on by the Department of Conservation and Land Management and have been biologically assessed for very different reasons. The studies have resulted in inventories of the biodiversity of the two regions. In the following two chapters, the ant species of these two areas are documented, providing an insight into the community interactions taking place in these arid zone sites.

The biological survey of the southern Carnarvon Basin was undertaken between 1994 - 1995 by the Department of Conservation and Land Management, Environment Australia and the Western Australian Museum. Physical, and much biological, data were collected and subsequently published in a book, as a supplement to the Records of the Western Australian Museum (Burbidge *et al.*, 2000). The remaining invertebrate collection was archived at the WA Museum, which provided this opportunity to work on the ant material. This is particularly important since the ant communities in this area of WA have been largely understudied.

This work has been prepared as a supplement to the book (Burbidge *et al.*, 2000) and will be submitted to the Records of the Western Australian Museum for publication. The full reference will be: Gunawardene, N.R. and Majer, J.D. (submitted) Ants of the southern Carnarvon Basin, Western Australia: an investigation into patterns of association. *Records of the Western Australian Museum.*

The next chapter of this thesis forms part of an ongoing biological survey being carried out in the Gibson Desert Nature Reserve by the Department of Conservation and Land Management and the University of Nebraska at Omaha. The study is focused on vegetation regeneration after fire, with an emphasis on the viability of the area for the re-introduction of native fauna to the Reserve. The vegetation study is being co-ordinated by Professor Tom Bragg of the University of Nebraska.

My part of the study involved the collection and identification of ant specimens in unburnt and burnt treatments of the vegetation plots in 2002, to supplement the assessment of the area's biodiversity. This study complements existing research on the effect of fire on invertebrates in the arid zone of WA and their use as indicators of regeneration.

This chapter will be presented as a paper to the 34th Australian Entomological Society / Invertebrate Biodiversity and Conservation Combined Conference, 2003. The paper will be written as a manuscript for publication in the proceedings of the conference. The full reference will be:

Gunawardene, N.R. and Majer, J.D. (submitted) An investigation into the effect of fire on ant communities in the Gibson Desert Nature Reserve, Western Australia. *Records of the Queen Victoria Museum and Art Gallery.*

Although much has been written about the ant communities in various regions of WA, little has been done in the arid regions of this State. In the final chapter, these and existing studies will be pulled together as a comprehensive comparative analysis of communities. In this chapter, the relationships between various ant communities are discussed, providing an insight into some of the community interactions within this complex and significant group of insects.

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Ants of the southern Carnarvon Basin, Western Australia: An investigation into patterns of association

Abstract – A study of the ant species of the southern Carnarvon Basin was carried out in order to identify the patterns of species diversity and associations across a transitional landscape. The study yielded 35 genera and 243 species of ants, 81 of which were restricted to single sites within the study area. Twelve assemblages of associated species were found, with members having a predominantly Eremaean biogeographic distribution, with some Bassian elements. The suggestion by Gibson *et al.*, (2000) to push the boundary of the South-west Province south and west was supported by the ant species in this study, as there were more Eremaean affinities in two of the southern sites in the study area. Species assemblages were positively associated with temperature, rainfall, longitude and altitude, but genera assemblages yielded a more latitudinal variation.

Key words: Ant species, ant genera, biogeographic origin, patterns of association, latitudinal gradient southern Carnarvon Basin.

INTRODUCTION

The Australian ant fauna has been noted as one of the most complex animal groups in Australia and has also been ranked as one of the richest known ant faunas in the world (Greenslade and Greenslade, 1989; Andersen and Burbidge, 1992; Andersen, 1993; Shattuck, 1999). Out of the 16 subfamilies recognised in the world, 10 are found in Australia, containing 103 genera, and 1275 described species, with at least as many again undescribed. It has been found that at any one site, up to 150 species can coexist (Abensperg-Traun, 1992; Shattuck, 1999). This abundance of species identifies ants as a major influence on the functioning of any habitat, through mechanisms such as seed dispersal (Drake, 1981), predator-prey interactions (Rossbach and Majer, 1983) nutrient cycling (Greenslade and Thompson, 1981) and in the maintenance of soil quality (Lobry De Bruyn, 1999).

Comprehensive studies of the Western Australian (WA) ant fauna have been carried out in some regions of the State, but the information available remains fragmented (Andersen, 1993). There are a number of areas where the ant fauna has not been looked at in any great detail or in some cases at all. To date, due to a paucity of research in many areas of WA, a thorough list or map of species occurrences is unavailable. Studies of Australia's arid zone have revealed high species richness compared to arid zones in other regions of the world (Morton, 1982; Andersen, 1997). Also, research in specific regions such as the mesic semi-arid areas to the south, has demonstrated a great diversity of species (Andersen and Burbidge, 1992). This indicates that WA should be home to a great diversity of ants, as it is the largest state in Australia and has a substantial percentage covered by the arid zone in the north and mesic, semi-arid areas to the south.

The Carnarvon Basin in WA lies in a large sedimentary basin that is traversed by a number of biogeographic regions. It includes the Shark Bay World Heritage Area, which has had Aboriginal presence for at least 18,000 years and was explored by Europeans almost 400 years ago. The hinterland is predominantly made up of pastoral leases, interspersed with national parks and nature reserves. It is in an area where the northern climatic and biogeographic zones meet and merge with the southern zones (Burbidge *et al.*, 2000a).

Preliminary studies on the flora and fauna in and around the Carnarvon Basin suggest a highly diverse biota. However, until the comprehensive faunal and floristic study of the southern Carnarvon Basin was jointly carried out by Environment Australia (EA), the Department of Conservation and Land Management (CALM) and the Western Australian Museum (WAM), there was no survey that combined climatic and geological variables with biotic factors such as vegetation and invertebrate distribution. The 13 sites chosen for the study were largely distributed around the southern portion of the Basin, which included the crossover zones for the Eremaean and South-western Provinces (Burbidge *et al.*, 2000a). The book that resulted from this study included chapters on climate, geology, flora, various vertebrate groups and invertebrate groups such as spiders and centipedes (Burbidge *et al.*, 2000b).

Biological inventorying is an important part of environmental management as it allows those involved to make responsible decisions regarding areas that have high biodiversity which support complex ecosystems (Greenslade, 1985; Stork and Samways, 1995). Incorporation of biodiversity survey data with geographical data should provide the basis for understanding broad-scale patterns across Australia, thus allowing comprehensive databases for flora and fauna to be established. These databases could then be utilized in environmental assessment procedures, in rapid biodiversity assessment studies and for providing support for gazetting conservation areas (Stork and Samways, 1995).

The current paper documents the ant species in the southern Carnarvon Basin for 12 of the 13 sites, identifies species assemblages, and investigates how these are related to the geographic and climatic variables in this region. It represents the first thorough inventory of ants in a transitional zone from the northern to the southern fauna, and contributes to a better perception of the distributions of the ant fauna in WA.

METHODS

Study area

The ant species collected were part of a large comprehensive floristic and faunal study carried out in a 75,000 km^2 region of WA (23°00'S – 28°30'S, 112°30'E – 115°30'E). The study area extended from the bottom of the Cape Range Peninsula (near the Minliya River) outwards to the Kennedy Range and Gascoyne Junction, with a southern extension to the Murchison River (see Figure 1). The study area includes a number of biogeographic entities, namely the Geraldton Sandplains and the Carnarvon Region of the Interim Biogeographical Regionalisation of Australia (IBRA). The whole study area traverses Beard's South-western Phytogeographic Province (SWBP) in the south and the Eremaean Province to the north (Burbidge *et al.*, 2000a).

These boundary areas represent the meeting of the arid and southern mesic areas of WA, resulting in high biodiversity and ecological complexity. The Department of Conservation and Land Management and WAM chose this area for surveys in order to supplement and improve the knowledge of the patterns of distribution of plants and animals in this highly varied and ecologically significant system (Burbidge *et al.*, 2000a).

As a result of the high degree of variability within the region, 13 study sites were positioned in a stratified random array across the study area, stretching from Cape Cuvier in the north to the Zuytdorp cliffs in the south. The sites incorporated the typically northern *Acacia* shrub lands and the southern *Eucalyptus* woodlands and heaths, interspersed with hummock and tussock grasslands upon low dunes along the coastline (Keighery *et al.*, 2000).

These sites were coded as: BB- Bush Bay; BO- Boolathana; CU- Cape Cuvier; EL- Edel Land; GJ- Gascoyne Junction; KE- Kennedy Range; MA- Mardathuna; MD- Meedo; NA- Nanga; NE- Nerren Nerren; PE- Peron Peninsula; WO- Woodleigh; and ZU- Zuytdorp (see Figure 1). Each survey area had five quadrats positioned so as to

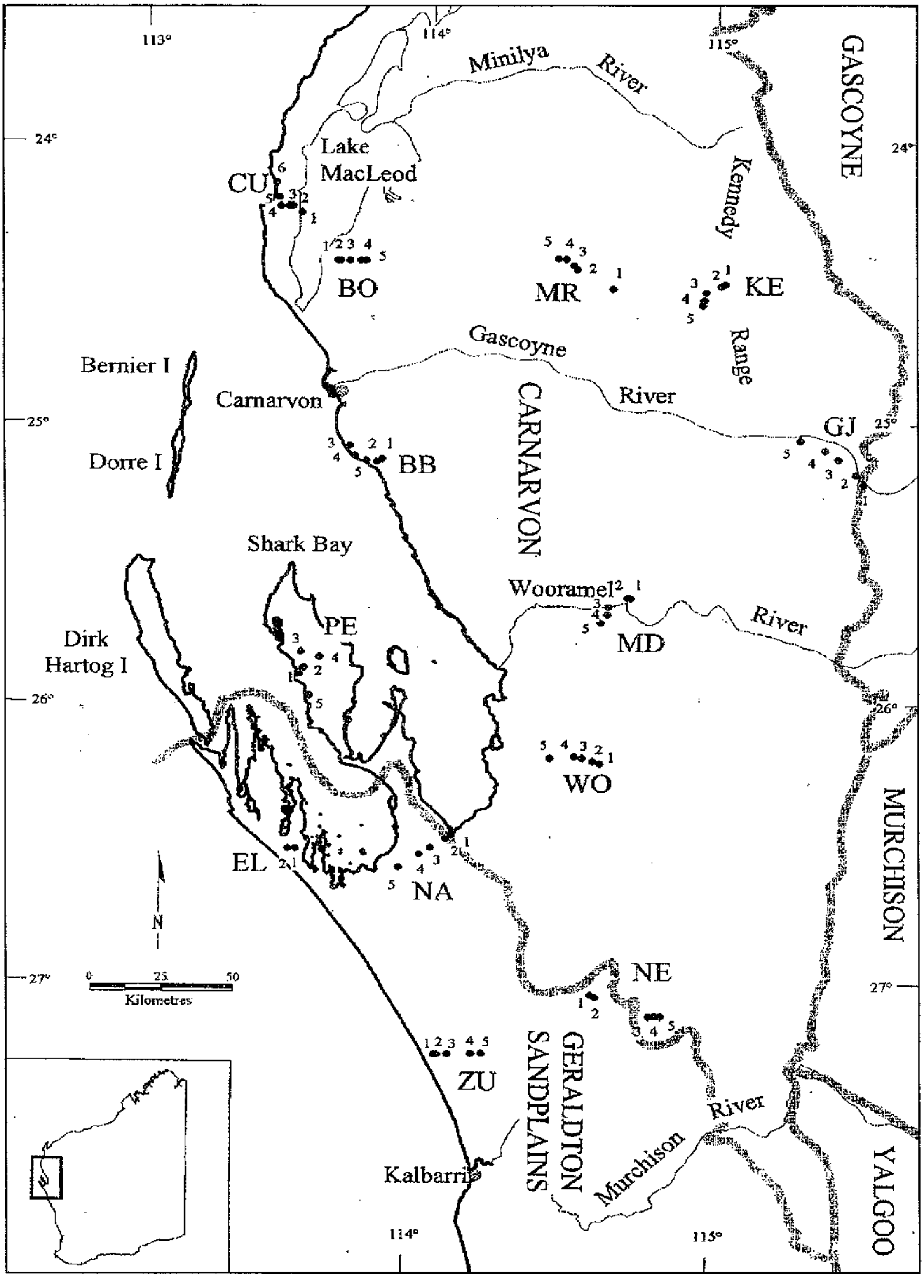


Figure 1 Map of the southern Carnarvon Basin study site, displaying the 13 survey areas and their corresponding quadrats that were investigated during the survey. Edel Land (EL) was the only area not included in the current study. The map also shows the major geographic boundaries that traverse the region.

sample a variety of characteristics. Two exceptions were CU, which had six quadrats and EL, which had only two. For the ant study, only 12 survey areas were sampled, as the samples from EL were unavailable. Each of the 61 quadrats contained five traps, totalling 305 pitfall traps representing an array of the stratigraphic units of the area but with a degree of pseudo-replication within the survey areas.

Vegetation

The vegetation study conducted by Keighery *et al.,* (2000) revealed nine major vegetational groups. Six of these groups contained vegetation typical of the Carnarvon region and two groups had vegetation typically found in the Irwin (Geraldton Sandplains) region. The last group consisted of one quadrat, NE2, which had unresolved vegetation affinities.

The vegetation assemblages of groups 1-4 (containing all quadrats of BB, BO, CU, GJ, MD, WO and KE 3-5, MR 1-2, 4-5, NA 1-2, PE 1-4) were the most species-rich and widespread across the study area. These were made up of both coastal and inland *Acacia* shrub lands, interspersed with *Eucalyptus* or *Melaleuca* woodlands. There was a high saline influence within the plots in site group 1 (quadrats BB1, BB3, BO2, CU1 and PE2), with a number of *Halosarcia* and *Atriplex* species, which are saline-adapted.

Group 5 was mainly *Eucalyptus – Callitris* or *Eucalyptus – Acacia* woodland on red sands. The quadrats in this group were PE5, and all of NE except NE2. Group 6 had vegetation characteristics that were very similar to those of group 5, but differed in that these quadrats were located on top of the Kennedy Range (MR3, KE1 and KE2). NE 2 did not fall into any particular vegetation type, and so was therefore given its own unique group. It was unusual in that it contained no annuals and was mainly *Banksia* woodland on yellow and red sands. It was hypothesized that this area was a transitional zone between the *Eucalyptus* woodlands of group 5 and the limestone heaths of group 9 (Keighery *et al.*, 2000).

The last two groups, as mentioned above, were very similar to Irwin vegetational characteristics and only differed from each other in that group 8 had *Eucalyptus* woodlands over red dunes (NA 3-5), whereas group 9 (ZU1-5) was woodland over a limestone heath. All vegetation assemblage details can be found in Keighery *et al.*, (2000).

Climate and geomorphology

The climate of the region also reflects the variability in the landscape. Lying in a transitional region, the area is affected by the typical winter rainfall patterns of the southwest, as well as the monsoonal summer conditions of the north (Wyrwoll *et al.*, 2000a). Geological and geomorphological patterns are described in Wyrwoll *et al.*, (2000b). They can briefly be categorised as being mainly alluvial plains with some aeolian processes and scattered low-lying saline areas. Ten regions and morphological features traversed the study area.

All quadrats in CU and BO were located in the MacLeod Region, which was comprised of marine and aeolian/alluvial sediments. With Lake MacLeod being the main morphological feature of the area, it is characterised by a number of linear calcareous sand dunes and tidal flats. The Kennedy Region includes all quadrats of KE and is characterised by extensive scree slopes around the plateau, which also boasts some of the largest sand dunes in the area.

Quadrats MR2-5 fell into the Mardathuna Regions, that has mainly dune covered calcrete areas with associated coastal and riverine settings. MR1 falls out of this region and into the more non-calcareous gradational soils of the Binthalya Region.

The Carnarvon Coastal Plain includes BB1-5 and GJ2-5 together, as it stretches over a large portion of the study sites. Although the sites are located on opposite sides of the study site, they are both found to the south of the Gascoyne River. This area would have been placed in the massive alluvial deposition area of the Gascoyne River deltas. GJ1 sits outside this area in the Bidgemia Region and would be the furthest inland of all the sites.

Sites PE1-5 and NA1-5 are placed together in the Peron Region, as they are located in and around the coast of the Peron Peninsula. Linear dunes traverse the large undulating sandplains of the area, with a number of interdunal corridors containing evaporite pans (birridas).

The Victoria Plateau includes a variety of sites; these are WO1-2, NE1-5, ZU3-5 and MD4-5 and they are all generally characterised by gently undulating sand plains and small dune fields. The Wooramel Region (MD1-3) is transitional between the Carnarvon Region and the Carbla Plateau. It has soils associated with the drainage valley of the Wooramel River. The Carbla plateau (WO3-5), on the other hand, has well-developed limestone ridges that are similar to the Edel Region, containing EL1-2 and ZU1-2. The difference in the Edel Region is the type of limestone, which in this case happens to be Tamala limestone with more yellow rather than red sands dominating the dune formations. Further details of each individual quadrat are described in Wyrwoll *et al.*, (2000b).

Field sampling

Invertebrate pitfall traps were placed at 13 sites throughout the study area. Two types of pitfall traps were used. 'Wet' traps were 25 L buckets (300 mm diameter x 400 mm depth) dug into the ground, with the rim flush with the ground surface. Five 10 cm holes were then cut into the lids and a piece of chicken wire placed below the lid to allow vertebrates to escape. Each bucket contained approximately 3.5 L of a mix of ethylene glycol, formalin (1%) and water (10%). Five traps were placed at 5m intervals along a transect at each quadrat. The traps were left open for one year from August 1994 to August 1995 and were cleared three times (September, January and May) before the final clearance at the end of the trapping period. All the samples were returned to the laboratory to be cleaned and stored in 75% ethanol (Harvey *et al.*, 2000).

'Dry' traps used to collect vertebrate fauna were located in the same quadrats but were slightly smaller (125mm diameter x 500mm depth) and were connected by flywire drift fences (McKenzie *et al.*, 2000). Two 5-day trapping efforts in September 1994 and May 1995 yielded a number of invertebrate samples as the traps were cleared daily during the 5 day period. All samples from these traps were stored in 75% ethanol. All ant species were removed and sorted to species level. The species were then identified in the laboratory and restored to their permanent storage units. All specimens are lodged in the WAM collection, and vouchers of each species are lodged in the Curtin University of Technology Ant Collection.

Data analysis

All ant species were entered into a data matrix as being either present or absent at any particular quadrat trap. Species occurrences from the wet and dry trap types were combined, as differences in sampling efforts could not be quantified. Only presence/absence data were analysed, as analyses of relative abundances of ant species are often problematic due to the tendency of the data to be spatially clumped and biased due to sampling method and effort (Longino, 2000).

Biogeographical affiliations

Each species' biogeographical affiliation was then estimated using distribution criteria based on previous collections of the ant species across WA and Australia. In the case of new species, biogeographical affiliations were based on distribution patterns apparent from the current study. The biogeographic terms used were derived from regions determined by Nix, (1982), combining phytogeographic and bioclimatic characteristics. These terms were - Bassian (south-western, seasonal); Eremaean or Eyrean (arid); and Torresian (northern, seasonal). Ants were listed as 'widespread' if they fell into all three of the above categories.

Numerical and statistical analyses

The ant species matrix was analysed using PATN, a numerical analysis program developed to show patterns in species composition (Belbin, 1993). All species that occurred at only one quadrat ('uniques') were removed. These uniques were placed in a separate matrix and analysed by comparing the total number of species at each quadrat with the total number of uniques in order to expose patterns in the occurrences of uniques at any one site.

A Czekanowski association measure was used to compare each quadrat's species assemblages with every other quadrat and to group the quadrats according to greatest similarity. Species assemblages were exposed by using a 'two-step' association measure, which determined the quantitative relationship between each species with every other species. The distribution of each species pair was then analysed using 'unweighted pair group arithmetic averaging' (UPGMA). This resulted in a dendrogram, which displayed each quadrat and its corresponding similarity to every other quadrat. The dendrogram was then used to determine a cut-off point from where similar quadrats could be grouped together. This was then displayed as a table of all species, which exposed groupings according to species rather than by quadrat.

Each species assemblage was then analysed in terms of the physical attributes of each quadrat. Eleven climatic variables recorded from ANUCLIM and 17 soil and geomorphic attributes were derived from sub-samples collected at a depth of 5-10 cm from 20-30 regularly dispersed points at each quadrat (Harvey *et al.*, 2000). These values were looked at in terms of ant species at each quadrat using a general linear interactive model, GLIM (NAG, 1986). This was done so as to explore any relations between physical and biological variables. A forward stepwise regression model was produced for each species assemblage to determine environmental variables that were significantly associated with species richness of each quadrat.

The relationship between each environmental variable and the quadrat groups derived from the UPGMA analysis was explored using a Kruskal-Wallis Test. This was done to determine if there were any significant associations between the quadrat groups (revealed by the species assemblages) and physical attributes of each survey area.

The species distribution was then analysed in terms of whole survey areas. Species data for individual quadrats were bulked within each survey area and analysed using the same two-step procedure used to reveal species assemblages. This was then repeated for genera to expose any differences between species and genus analyses. The grouped survey areas were analysed in terms of environmental factors using the same Kruskal-Wallis Test mentioned above. Eleven of the 17 climatic variables and 4 geographic variables (latitude, longitude, altitude and distance from the coast) were utilised, as the soil and geomorphological indices were deemed too variable to average for each survey area.

RESULTS

Species identification

Over the 1-year trapping period, approximately 115, 000 trap nights yielded a large collection of invertebrates. The preserved samples available were the September 1994 wet trap collection, the September 1994 dry trap collection and May 1995 dry trap collection. These were analysed to produce 35 genera and 243 species of ants and potentially one completely new *Melophorus* species (see Table 1). The study also revealed range extensions for a number of ants previously not thought to be in WA or formerly thought to be confined to the SWBP. Preserved samples from the other collection periods (January, May and August 1995) and from survey area EL were not available from WAM. Fifty-eight percent of the species could be positively identified, with many of the remaining taxa placed in species complexes and assigned Australian National Insect Collection (ANIC) numbers and Curtin University Ant Collection (JDM) numbers for future identification.

The most speciose genus was *Camponotus*, with 42 species, while *Iridomyrmex* and *Melophorus* followed close behind, with 31 and 30 respectively. Only one species of *Camponotus*, *C. gibbonotus* was found at all 12 survey areas, whereas three species of *Iridomyrmex* (*I. chasei*, *I. chasei concolor* and *I. dromus*) and two species of *Melophorus* (*M.* ANIC sp. 3 and *M.* JDM sp. 176) were ubiquitous throughout. *Melophorus ludius sulla* was the most ubiquitous ant, as it was found at 40 of the 61 quadrats studied. *Camponotus gibbonotus* was present at 36 quadrats and *I. chasei* at 33 quadrats.

Biogeographic distribution

All the species collected and their possible biogeographic origins across WA are displayed in Table 1. There were a number of species that were placed in more than one biogeograhpic region (BR), in some cases due to uncertainty as to their true biogeographic origin. There were 35 species that traversed both the Bassian and Eremaean zones and 23 that spanned Eremaean and Torresian zones. A number of species (43) were considered widespread, i.e. found in all three BR's. The majority of species found in the study area were Eremaean in distribution. This can be seen in Figure 2, which shows the percentages of each species assemblage that falls into each BR.

Species richness and assemblage composition

The species occurrences for all quadrats were analysed after the removal of 'unique' species. Eighty one 'unique' species were removed from the data matrix and these are listed in Table 2. The quadrats MR5 and ZU3 yielded the greatest number of

Table 1 List of all ant species collected and identified in the 1994-1995 southern Carnarvon Basin survey and their biogeographic affiliations. Some species traverse more than one biogeographic region due to uncertainty of their origin or because they traverse more than one region. Species have been listed as widespread if they occur in all three biogeographic regions. #Indicates potentially new species to WA.

Subfamily	Species	Bassian	Eremaean	Torresian	Widespread
Myrmeciinae	*Myrmecia callima* (Clark)		*		
	Myrmecia desertorum Wheeler	*	*		
	Myrmecia elegans (Clark)	*	*		
	Myrmecia?elegans (Clark) #		*		
	Myrmecia hilli (Clark)		*		
	Myrmecia urens gp. JDM sp. 1	*			
	Myrmecia nr. *urens* gp. JDM sp. 71	*			
	Myrmecia urens gp. JDM sp. 728	*			
	Myrmecia ?varians #	*	*		
	Myrmecia sp. nr *pilosula*		*		
Cerapachyinae	*Cerapachys brevicollis* (Clark)	*			
	Cerapachys brevis (Clark)				*
	Cerapachys clarki (Crawley)	*			
	Cerapachys fervidus (Wheeler)				*
	Cerapachys gilesi (Clark)	*			
	Cerapachys greavesi (Clark)	*			
	Cerapachys incontentus Brown		*		
	Cerapachys sjostedti Forel	*	*		
	Cerapachys JDM sp. 741		*		
	Cerapachys JDM sp. 1049		*		
	Cerapachys JDM sp. 1103	*			
Ponerinae	*Anochetus armstrongi* MacAreavy	*	*		
	Leptogenys clarki Wheeler				*
	Leptogenys darlingtoni Wheeler		*		
	Leptogenys nr. *tricosa* JDM sp. 1021			*	
	Odontomachus ruficeps Smith				*
	Pachycondyla denticulata gp. JDM sp. 730		*		
	Pachycondyla lutea (Mayr)				*
	Pachycondyla piliventris regularis Forel		*		
	Rhytidoponera crassinoda (Forel)		*	*	
	Rhytidoponera dubia gp. JDM sp. 904		*		
	Rhytidoponera foveolata Crawley	*	*		
	Rhytidoponera metallica (Smith)				*
	Rhytidoponera metallica gp. JDM sp. 1097		*		
	Rhytidoponera metallica gp. JDM sp. 1098 #		*		
	Rhytidoponera micans Clark		*		
	Rhytidoponera taurus (Forel)		*	*	
	Rhytidoponera tyloxys Brown and Douglas		*	*	
	Rhytidoponera violacea (Forel)				*
	Rhytidoponera JDM sp. 736		*		
Myrmicinae	*Anisopheidole antipodum* (Smith)	*			
	Aphaenogaster barbigula Wheeler	*			
	Colobostruma cerornata Brown	*	*		
	Crematogaster cornigera gp. JDM sp.126				*
	Crematogaster dispar Forel	*			
	Crematogaster frivola Forel		*		
	Crematogaster queenslandica gp. JDM sp. 428	*			
	Crematogaster queenslandica gp. JDM sp. 1099			*	
	Crematogaster queenslandica gp. JDM sp. 1100			*	
	Crematogaster JDM sp. 859	*	*		
	Epopostruma quadrispinosa (Forel)		*		
	Meranoplus dichrous Forel		*		
	Meranoplus fenestratus Smith	*			
	Meranoplus JDM sp. 74				*
	Meranoplus JDM sp. 423	*	*		

Table 1 (cont.)

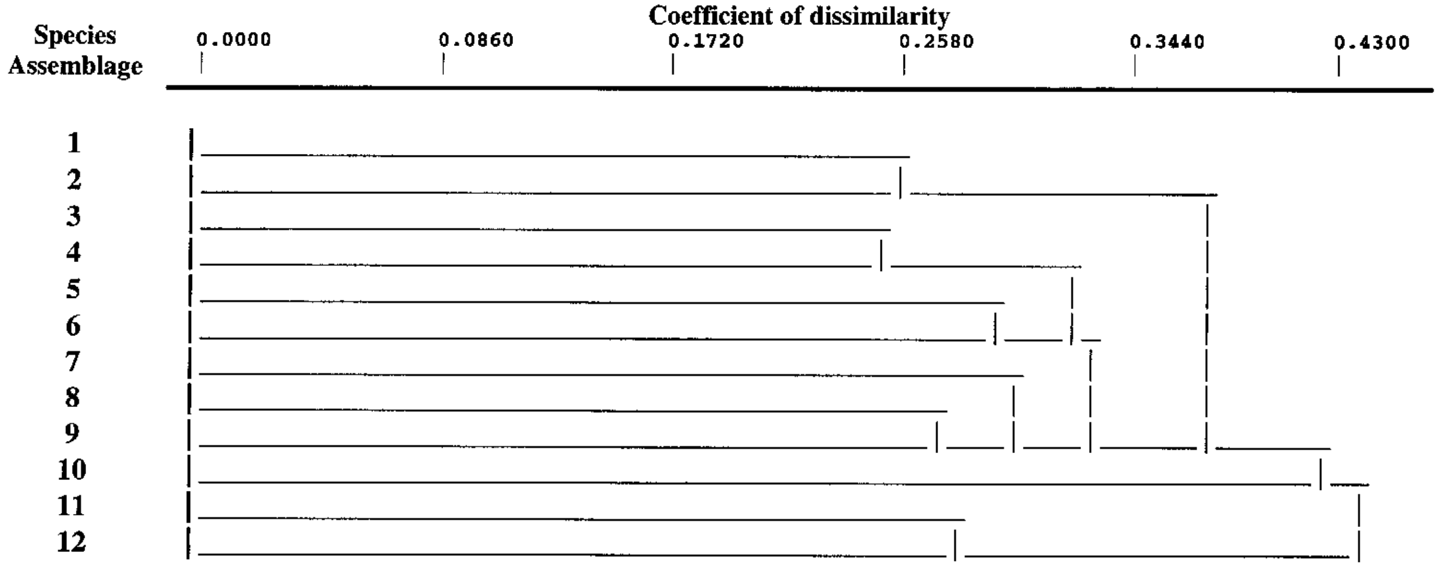
Myrmicinae (cont.)	*Meranoplus* JDM sp. 424	*			
	Meranoplus JDM sp. 679		*		
	Meranoplus JDM sp. 866	*			
	Meranoplus JDM sp. 1071		*		
	Meranoplus JDM sp. 1101		*		
	Monomorium aithoderum Heterick	*	*		
	Monomorium anthracinum Heterick	*			
	Monomorium disetigerum Heterick		*	*	
	Monomorium eremophilum Heterick		*		
	Monomorium fieldi Forel				*
	Monomorium laeve Mayr				*
	Monomorium leae Forel	*	*		
	Monomorium legulus Heterick		*		
	Monomorium nanum Heterick	*	*		
	Monomorium rothsteini Forel				*
	Monomorium rufonigrum Heterick	*	*		
	Monomorium silaceum Heterick			*	
	Monomorium sordidum Forel				*
	Monomorium striatifrons Heterick				*
	Monomorium sydneyense Forel				*
	Monomorium whitei Wheeler		*		
	Pheidole ?bos Forel (JDM sp. 164)	*	*		
	Pheidole deserticola Forel		*		
	Pheidole hartmeyeri Forel	*	*		
	Pheidole nr. *variabilis* JDM sp. 177				*
	Pheidole JDM sp. 338		*		
	Pheidole JDM sp. 558	*			
	Pheidole JDM sp. 681		*		
	Podomyrma adelaidae (Smith)				*
	Podomyrma christae (Forel)	*	*		
	Solenopsis belisarius Forel	*			
	Solenopsis clarki Crawley	*			
	Strumigenys quinquedentata Crawley	*	*		
	Tetramorium impressum (Viehmeyer)				*
	Tetramorium sjostedti Forel		*	*	
	Tetramorium spininode Bolton		*		
	Tetramorium striolatum Viehmeyer				*
	Tetramorium nr. *striolatum* Viehmeyer	*			
	Tetramorium viehmeyeri Forel	*			
	Tetramorium JDM sp. 461		*		
	Tetramorium JDM sp. 515	*			
	Tetramorium JDM sp. 884	*	*		
	Tetramorium JDM sp. 1007		*		
	Tetramorium JDM sp. 1072	*	*		
Dolichoderinae	*Bothriomyrmex flavus* Crawley	*			
	Bothriomyrmex JDM sp. 232	*			
	Doleromyrma darwiniana (Forel)	*			
	Dolichoderus formosus Clark	*			
	Dolichoderus glauerti Wheeler	*			
	Dolichoderus JDM sp. 838		*		
	Iridomyrmex agilis Forel		*		
	Iridomyrmex agilis gp. JDM. sp. 85	*			
	Iridomyrmex bicknelli Emery				*
	Iridomyrmex bicknelli azureus Viehmeyer		*		
	Iridomyrmex bicknelli brunneus Forel				*
	Iridomyrmex cephaloinclinus Shattuck		*		
	Iridomyrmex chasei Forel				*
	Iridomyrmex chasei concolor Forel				*
	Iridomyrmex discors Forel	*			
	Iridomyrmex dromus Clark				*
	Iridomyrmex exsanguis Forel				*
	Iridomyrmex greensladei Shattuck	*			
	Iridomyrmex hartmeyeri Forel		*		

Table 1 (cont.)

Dolichoderinae (cont.)	*Iridomyrmex hartmeyeri* gp. JDM sp. 327		*	*	
	Iridomyrmex lividus Shattuck		*		
	Iridomyrmex mattiroloi continentis Forel		*	*	
	Iridomyrmex mattiroloi splendens Forel	*			
	Iridomyrmex mattiroloi complex JDM sp. 449	*			
	Iridomyrmex reburrus Shattuck			*	
	Iridomyrmex rufoniger suchieri Forel	*			
	Iridomyrmex rufoniger suchieri complex JDM sp.390	*	*		
	Iridomyrmex nr. *rufoniger suchieri* JDM sp. 314	*	*		
	Iridomyrmex sanguineus Forel			*	
	Iridomyrmex viridiaeneus Viehmeyer		*		
	Iridomyrmex JDM sp. 130		*		
	Iridomyrmex JDM sp. 133	*			
	Iridomyrmex JDM sp. 319		*		
	Iridomyrmex JDM sp. 597			*	
	Iridomyrmex JDM sp. 843		*		
	Iridomyrmex JDM sp. 846		*		
	Iridomyrmex JDM sp. 1028		*	*	
	Ochetellus glaber gp. JDM sp. 19				*
	Ochetellus JDM sp. 851	*	*		
	Papyrius nitidus (Mayr)	*			
	Tapinoma JDM sp. 78				*
	Tapinoma JDM sp. 981				*
Formicinae	*Calomyrmex glauerti* Clark	*			
	Calomyrmex ANIC sp. 1	*			
	Camponotus arcuatus Mayr		*		
	Camponotus ?arcuatus gp. JDM sp. 694		*		
	Camponotus capito ebenithorax Forel	*	*		
	Camponotus chalceus Crawley	*			
	Camponotus cinereus Mayr	*	*		
	Camponotus cinereus amperei Forel		*		
	Camponotus clarior Forel		*		
	Camponotus claripes Mayr				*
	Camponotus claripes minimus Crawley	*	*		
	Camponotus claripes gp. JDM sp. 63	*			
	Camponotus claripes gp. JDM sp. 229	*			
	Camponotus nr. *claripes* complex JDM sp. 767	*			
	Camponotus claripes complex JDM sp. 779	*	*		
	Camponotus claripes gp. JDM sp. 939		*		
	Camponotus claripes gp. JDM sp. 1073	*	*		
	Camponotus discors Forel			*	
	Camponotus discors complex JDM sp. 309	*			
	Camponotus cf. *discors* complex JDM sp. 1104		*		
	Camponotus dromas Santschi		*		
	Camponotus dryandrae McArthur and Adams	*			
	Camponotus ephippium gp. JDM sp. 598		*		
	Camponotus gasseri (Forel)				*
	Camponotus gibbonotus Forel				*
	Camponotus gouldianus Forel		*		
	Camponotus lownei Forel				*
	Camponotus lownei complex JDM sp. 179	*	*		
	Camponotus lownei complex JDM sp. 761	*			
	Camponotus lownei complex JDM sp. 772		*		
	Camponotus novaehollandiae gp JDM sp. 144			*	
	Camponotus nigroaeneus gp nr JDM sp. 108	*			
	Camponotus oetkeri Forel				*
	Camponotus prosseri Shattuck and McArthur (in press)	*	*		
	Camponotus prostans Forel	*			
	Camponotus rufus Crawley	*			
	Camponotus scratius Forel	*			
	Camponotus tasmani Forel		*		
	Camponotus terebrans (Lowne)	*			

Table 1 (cont.)

Formicidae (cont.)	*Camponotus tricoloratus* Clark		*	*	
	Camponotus whitei Wheeler				*
	Camponotus wiederkehri Forel		*	*	
	Camponotus wiederkehri gp. JDM sp. 924	*			
	Camponotus JDM sp. 26	*			
	Melophorus nr. *aeneovirens* JDM sp. 545		*	*	
	Melophorus bagoti Lubbock		*	*	
	Melophorus bruneus McAreavey	*	*		
	Melophorus bruneus complex JDM sp. 472		*		
	Melophorus bruneus complex JDM sp. 791	*			
	Melophorus bruneus complex JDM sp. 951	*			
	Melophorus curtus Forel			*	
	Melophorus insularis Wheeler				*
	Melophorus iridescens gp. JDM sp. 1034		*		
	Melophorus ludius sulla Forel		*	*	
	Melophorus mjobergi Forel				*
	Melophorus turneri Forel				*
	Melophorus turneri perthensis Wheeler				*
	Melophorus wheeleri Forel		*	*	
	Melophorus wheeleri complex JDM sp. 783	*			
	Melophorus wheeleri complex JDM sp. 1077		*		
	Melophorus ANIC sp. 3 (JDM 59)				*
	Melophorus JDM sp. 176				*
	Melophorus JDM sp. 199		*		
	Melophorus ?JDM sp. 470		*		
	Melophorus JDM sp. 500	*			
	Melophorus JDM sp. 532		*	*	
	Melophorus JDM sp. 618		*		
	Melophorus JDM sp. 699		*		
	Melophorus JDM sp. 784		*		
	Melophorus JDM sp. 787		*		
	Melophorus JDM sp. 1063		*		
	Melophorus JDM sp. 1070	*	*		
	Melophorus JDM sp. 1102	*			
	Melophorus JDM sp. 1105 #			*	
	Notoncus capitatus Forel		*		
	Notoncus gilberti Forel	*			
	Opisthopsis haddoni rufoniger Forel		*	*	
	Opisthopsis rufithorax Emery	*			
	Paratrechina minutula (Forel)				*
	Paratrechina minutula gp. JDM sp. 916		*		
	Plagiolepis squamulosa Wheeler	*			
	Polyrachis ammonoeides Roger	*			
	Polyrachis gravis Clark				*
	Polyrachis macropa Wheeler		*	*	
	Polyrachis nr. *macropa* Wheeler		*	*	
	Polyrachis schwiedlandi complex JDM sp. 1010		*	*	
	Polyrachis sidnica complex JDM sp. 390	*			
	Polyrachis cf. *sidnica* complex JDM sp. 671	*	*		
	Polyrachis (*Campomyrma*) JDM sp. 118	*	*		
	Polyrachis (*Campomyrma*) JDM sp. 670		*		
	Polyrachis (*Campomyrma*) JDM sp. 703		*	*	
	Polyrachis (*Campomyrma*) JDM sp. 805		*		
	Polyrachis (*Campomyrma*) JDM sp. 901		*		
	Stigmacros aemula (Forel)		*	*	
	Stigmacros pilosella (Viehmeyer)		*		
	Stigmacros reticulata Clark	*	*		
	Stigmacros spinosa McAreavy		*	*	
	Stigmacros termitoxena Wheeler		*	*	
	Stigmacros JDM sp. 188	*			
	Stigmacros JDM sp. 341				*
	Stigmacros JDM sp. 1067	*	*		



Species Assemblage	B	E	T	W
1	16	30	20	**34**
2	**38**	25	0	**38**
3	21	**50**	29	0
4	33	**50**	8	8
5	**43**	**57**	0	0
6	31	**50**	13	6
7	33	**44**	6	17
8	**50**	**50**	0	0
9	33	33	17	17
10	32	**58**	11	0
11	**50**	**50**	0	0
12	**56**	31	6	6

Figure 2 The percentages of species in each phytogeographical region for each of the 12 species assemblages. Percentages greater than 33% are highlighted and used to depict the predominant biogeographic affiliations of each assemblage (**B** = Bassian, **E** = Eremaean, **T** = Torresian, **W** = widespread). Only Assemblage 1, which consisted of one quadrat, showed a predominantly widespread distribution, perhaps indicating that many of the ants were common species.

Table 2 List of all species that occurred at only one quadrat throughout the whole study area. The location of each quadrat is shown in Figure 1. These species were considered 'unique' and were not included in any analyses of data as it cannot be determined whether their occurrence in a particular quadrat was accidental (tourist) or whether thc species was actually found in the area (resident).

Subfamily	Species	Quadrat	Subfamily	Species	Quadrat	Subfamily	Species	Quadrat
Myrmeciinae	*Myrmecia elegans*	NE3	Myrmicinae (cont.)	*Pheidole* JDM sp. 338	MR3	Formicinae (cont.)	*Camponotus dromas*	NE5
	Myrmecia ?elegans	NE4		*Pheidole* JDM sp. 681	KE3		*Camponotus dryandrae*	KE3
	Myrmecia hilli	KE2		*Podomyrma adelaidae*	ZU3		*Camponotus ephippium* gp. JDM sp. 568	NE2
	Myrmecia urens gp. JDM sp. 1	CU5		*Podomyrma christae*	NE1		*Camponotus gasseri*	ZU2
	Myrmecia nr. *urens* gp. JDM sp. 71	ZU3		*Strumigenys quinquedentata*	CU6		*Camponotus gouldianus*	BB2
	Myrmecia urens gp. JDM sp. 728	ZU3		*Tetramorium* nr. *striolatum*	WO5		*Camponotus lownei* complex JDM sp. 179	PE2
	Myrmecia sp. nr *pilosula*	PE5		*Tetramorium* JDM sp. 1072	KE4		*Camponotus novaehollandiae* gp JDM sp. 144	MD3
Cerapachyinae	*Cerapachys* JDM sp. 741	WO3	Dolichoderinae	*Bothriomyrmex flavus*	ZU2		*Camponotus prostans*	BO5
	Cerapachys JDM sp. 1049	MD5		*Bothriomyrmex* JDM sp. 232	NA3		*Camponotus whitei*	NE2
	Cerapachys JDM sp. 1103	NA5		*Dolichoderus formosus*	NE4		*Camponotus wiederkehri* gp. JDM sp. 924	KE1
Ponerinae	*Leptogenys* nr. *tricosa* JDM sp. 1021	MR5		*Dolichoderus glauerti*	NA2		*Camponotus* JDM sp. 26	NE3
	Pachycondyla denticulata gp. JDM sp. 730	NE1		*Iridomyrmex agilis* gp. JDM sp. 85	NA3		*Melophorus bruneus* complex JDM sp. 791	MD4
	Rhytidoponera dubia gp. JDM sp. 904	BB1		*Iridomyrmex exsanguis*	KE3		*Melophorus curtus*	MR3
	Rhytidoponera metallica gp. JDM sp. 1097	NA3		*Iridomyrmex reburrus*	BB1		*Melophorus iridescens* gp. JDM sp. 1034	MD1
	Rhytidoponera JDM sp. 736	KE3		*Iridomyrmex rufoniger suchieri* complex JDM sp. 390	CU2		*Melophorus* JDM sp. 532	GJ1
Myrmicinae	*Anisopheidole antipodum*	NA4		*Iridomyrmex* nr. *rufoniger suchieri* JDM sp. 314	NE4		*Melophorus* JDM sp. 618	KE3
	Crematogaster cornigera gp. JDM sp.126	NE1		*Iridomyrmex* JDM sp. 843	GJ4		*Melophorus* JDM sp. 787	NE1
	Epopostruma quadrispinosa	MD3	Formicinae	*Camponotus arcuatus*	MR3		*Melophorus* JDM sp. 1070	GJ3
	Meranoplus dichrous	BB1		*Camponotus ?arcuatus* gp. JDM sp. 694	CU5		*Melophorus* JDM sp. 1105	NE4
	Meranoplus fenestratus	NE5		*Camponotus capito ebenithorax*	KE4		*Opisthopsis rufithorax*	NE4
	Meranoplus JDM sp. 423	MR5		*Camponotus chalceus*	ZU2		*Papyrius nitidus*	ZU5
	Meranoplus JDM sp. 866	NA4		*Camponotus cinereus amperei*	NE4		*Polyrachis* nr. *macropa*	GJ4
	Meranoplus JDM sp. 1071	NA4		*Camponotus* nr. *claripes* complex JDM sp. 767	KE4		*Polyrachis* (*Campomyrma*) JDM sp. 118	ZU1
	Monomorium aithoderum	NA3		*Camponotus claripes* complex JDM sp. 779	MR5		*Polyrachis* (*Campomyrma*) JDM sp. 703	PE3
	Monomorium anthracinum	BB3		*Camponotus claripes* gp. JDM sp. 939	MD3		*Polyrachis* (*Campomyrma*) JDM sp. 901	KE1
	Monomorium silaceum	MD3		*Camponotus claripes* gp. JDM sp. 1073	BO3		*Stigmacros pilosella*	MD3
	Monomorium whitei	BB1		*Camponotus discors* complex JDM sp. 309	CU2			

xspecies, with 45 species in total; NE4 followed as a close second with 44 species. Overall, the Nerren Nerren survey area (NE) had the highest record of species; a total of 89. 'Uniques' did not make up large proportions of each quadrat's total species but two quadrats had up to 20% of their species only occurring at that particular quadrat (KE3 and MD3). The Nerren Nerren survey area had the highest number of 'uniques' out of all the survey areas, with 18% of its total species occurring only there.

The PATN analysis of the species data yielded a two-way table that grouped the species into 12 assemblages (see Table 3). These assemblages were then associated with the quadrats to reveal eight quadrat groupings. These eight quadrat groups are displayed in Figure 3 as a dendrogram, showing the measure of dissimilarity between quadrat groups.

Assemblage 1 appeared to be a large mix of species, possessing no particular association with any quadrat group. All the other assemblages demonstrated some degree of clustering within one or two quadrat groups. Assemblage 2 had a majority of species falling into quadrat Group 4, which was characterised as being 'near coastal sand dunes and plains'; the assemblage was classified as mostly Bassian and widespread in biogeographic affinities.

Assemblage 3 had close associations with the same quadrat group, though the majority of the assemblage had an Eremaean distribution and contained more Torresian representatives than Bassian. Assemblage 3 had a weak clustering in Group 5, which was composed of only NE quadrats, two of which were in the SWBP. This variability in the NE environment is demonstrated by Assemblage 5, which has an almost equal balance of Eremaean and Bassian species (see Figure 2).

Quadrat group 1 was unusual in that it cannot be technically considered a group, as it contains one single quadrat, BB1. Bush Bay 1 was a unique quadrat in terms of its geomorphology, being a claypan area (Wyrwoll *et al.*, 2000b) but it is also unusual in that out of all the other taxa studied during the survey (Burbidge *et al.*, 2000b), ants were the only taxon that separated out this quadrat noticeably. Assemblage 8 was unique within the assemblages in that it contained only two species of ant, which were present only within Group 6 quadrats. The geomorphologic characteristic of these quadrats was

Table 3 Two -way table showing the quadrats grouped according to the 12 species assemblages. Unique species have been removed from the matrix. Each asterisk represents a species occurrence at that quadrat, the locations of which are shown in Figure 1. A dark highlighted box means >40% of species fall in this group; lighter highlighted boxes means an additional 30% of species fill this group; unhighlighted boxes contain the remaining species from each assemblage.

Group no.	1	2	3	4	5	6	7	8
Quadrat codes / species	B B 1	CMCGMKK URUJREE 2444312	GKGGMMMMMGMKMMKWWWWW JEJJDDDDDJRERREOOOOO 13355412321525421453	BBBBBBBCPNNNNZPPP BBBOOOOUEAAAAUEEE 25415345224353345	NNNNN EEEEE 13245	BBPCN BOEUA 32111	CC UU 36	ZZZZ UUUU 1245
Assemblage 1								
Anochetus armstrongi	*		`     *`	`                *`		` **`		`   *`
Iridomyrmex sanguineus	*		` *            *   *`	`**`		`*`		
Leptogenys clarki			`              ***`	`***   *       **`		`*****`		
Odontomachus ruficeps	*		`     *`	`**   *     **`		`*** *`		
Rhytidoponera violacea				` *          **  *`	` *  *`	`*  **`	` *`	
Camponotus claripes		`   *`	`   *  **      *****`	`             *`	`*   *`			
Pheidole hartmeyeri	*		`      ***        **`	`            * **`	`*   *`			
Melophorus bruneus complex JDM sp. 472	*		`   ****     **    *`	`*** **  *`	`   *`			` *`
Monomorium laeve			` *   ****  **`	` **          *`				
Leptogenys darlingtoni			`    **          ***`					
Aphaenogaster barbigula		` *`	`                 *`	`   **   *** *****`	`  * *`	`*`		`** *`
Melophorus insularis		`*******`	`             * *`	`** **  **********`	`*`			` *`
Pachycondyla lutea	*	`    **`		`  ******* *******`	`**`		`*`	`   *`
Solenopsis clarki	*		`        *    *  *`	`* * *    *   ****`	`    *`		`*`	
Iridomyrmex mattiroloi splendens		`  *  *`	` *   *    ****  **`	`******  *   ***`	`  *`	`*`		`****`
Melophorus ANIC sp. 3		`***`	`       * *****  *`	`** ****   * *** *`	` ***`		`*`	`  *`
Pachycondyla piliventris regularis			`           ***`	`*  ****** *****`	`*****`	`**  *`		`***`
Melophorus JDM sp. 176	*	`  *** *`	`   *    * ** *    *`	` *   *      **`	`  ***`	` **`	`*`	`  *`
Monomorium sordidum	*	`***`	`  *  ** **  *`	`     *    **** **`	`* **`	` *`		`  **`
Pheidole nr. *variabilis* JDM sp. 177	*	`   ** *`	`   *   * **      *`	`*  ***** * * * **`	`  **`	` *`		` ***`
Meranoplus JDM sp. 74		`  *   *`	`     *   **`	`*  **    *   **`	`    *`			` *`
Camponotus oetkeri		`*     *`		` * **  * ***`	` * *`		`**`	
Iridomyrmex JDM sp. 133		`   ****`	`*     *          ***`	`***      ****   *`	`** *`	`    *`		
Tetramorium nr. *striolatum*		`* * *`	`      *           *`	`* * *  * * * *`	`****`		`*`	` *`
Camponotus gibbonotus	*	` * ****`	`********************`	`*** ******** ***`	`*****`	`****`		`  *`
Iridomyrmex chasei concolor		` *** *`	`************* ***  *`	`** *** ** *******`	`****`	`*****`		` * *`
Melophorus ludius sulla		`**  ***`	`* ****** ** ********`	`   **** *********`	`*****`	` *`	`*`	`   *`
Iridomyrmex dromus		`**  **`	`*** **** ***** * *`	`*******  ***** **`	` ****`	`  * *`	` *`	` ***`
Rhytidoponera micans		`* ** *`	`***** ******  ******`	`**********  * ***`	`** **`	`**`	`*`	
Melophorus turneri		`   ***`	`*********  * *  *  *`	`   * ****       *`	`*****`	`    *`	`*`	` ***`

Table 3 (cont.)

Melophorus turneri		***	********* * * * *	* **** *	*****	*	*	***
Monomorium fieldi		******	***** **** ****** *	* ** * *** *	** *	*	*	* **
Monomorium rothsteini	*	*	** ***** ******* ***	**** * ***	* *			**
Iridomyrmex mattiroloi continentis		* *	* ******** ** * * *	* **	*****	**		*
Iridomyrmex chasei	*	** **	******** **********	** ****** ***	*	*	*	*
Melophorus wheeleri complex JDM sp. 783		**	** *** ******	******** **			*	
Monomorium disetigerum	*	**** *	*********** * ** **	** ***** *		**	**	
Pheidole ?bos (JDM sp. 164)	*	** *	****** * ** *	* **** **** ** *		* *		
Melophorus turneri perthensis	*	** ***	* ****** *	* * ** * **				*
Polyrachis schwiedlandi complex JDM sp. 1010		* ****	* ** ****** ***	* *** *	*			
Rhytidoponera tyloxys		***	*** * ** ***	* * * **	***			* *
Monomorium sydneyense		* *	* * ** *	* * * * **	**			
Melophorus nr. *aeneovirens* JDM sp. 545		* *	* ***	**** * *	*			
Tetramorium impressum			* * * *	** ** * *		**		
Tapinoma JDM sp. 981		**	* ** * *	*** *		**		
Melophorus JDM sp. 1102		**	* * *	* * *	**	*		**
Stigmacros spinosa		**	* *	* * *	* *			
Camponotus wiederkehri gp. JDM sp. 924	*	* ****	* * ***** ***	** ***	*			
Melophorus bagoti		** ****	* ***** * * *	****				
Rhytidoponera crassinoda	*	** ****	** ** ** *	*		**		
Opisthopsis haddoni rufoniger		* * *	* ** * *	* *				
Iridomyrmex hartmeyeri gp. JDM sp. 327		**** **	** * * **	*** **				
Pheidole deserticola		* ***	* ** *	* * *		*		
Iridomyrmex rufoniger suchieri		* **	*		*			
Rhytidoponera taurus	*	* ***	***	*				
Assemblage 2								
Camponotus claripes gp. JDM sp. 229			*	* * * * *				***
Iridomyrmex bicknelli			** * *	* ** *				***
Camponotus scratius		*		* * **** * *			*	***
Cerapachys brevis		*		** ** * *				*
Crematogaster frivola				* **** *		*	*	**
Iridomyrmex JDM sp. 846				* * *** *			*	*
Melophorus JDM sp. 500	*	*		*	*			***
Rhytidoponera metallica			*	**	* *		*	****
Meranoplus JDM sp. 424			*	*	*			**
Assemblage 3								
Camponotus lownei		*	*	* *	** *			
Iridomyrmex bicknelli brunneus		*	*	* * **	*			

Table 3 (cont.)

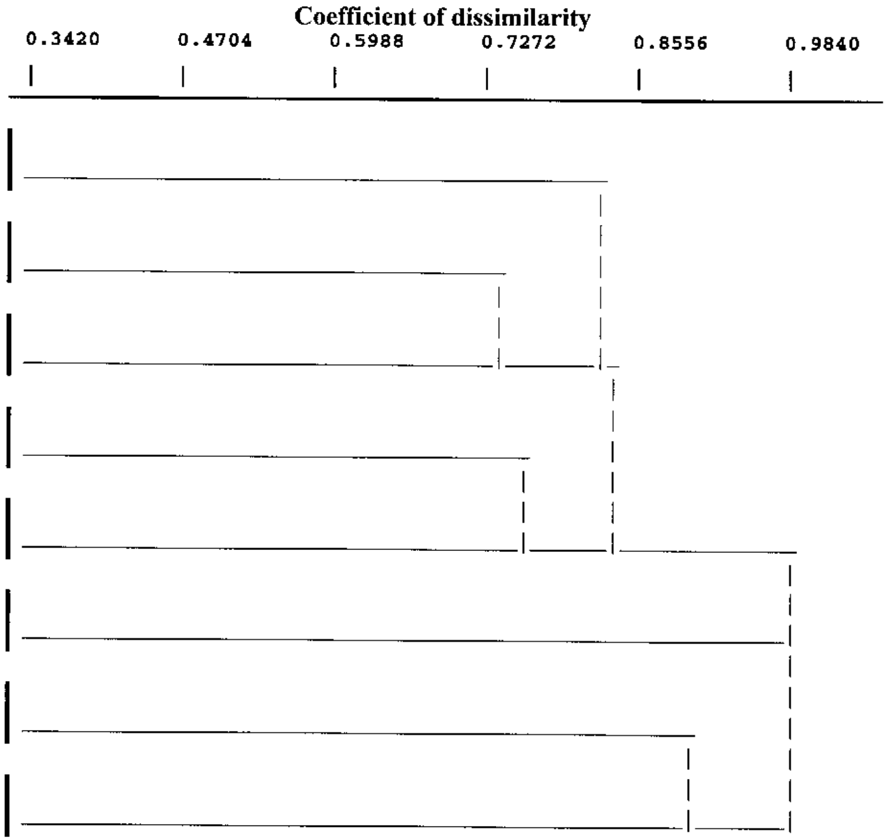
Rhytidoponera metallica gp. JDM sp. 1098				* ***	* *			
Cerapachys fervidus			*	* ** *		*		
Iridomyrmex discors		*		* *	*			
Melophorus bruneus		*	* *	* * * *	*			
Assemblage 4								
Calomyrmex ANIC sp. 1			* ****		* **			
Crematogaster queenslandica gp. JDM sp. 1100		*	***	* * *	***			
Iridomyrmex agilis			* ** ** ***		*	**		
Camponotus discors		*	** ****** *					
Iridomyrmex hartmeyeri			** * * * *	*				
Meranoplus JDM sp. 679		*	* ***					
Polyrachis macropa	*		* ** ** **	*				
Iridomyrmex viridianeus			* *					
Tetramorium spininode		*	** *					
tramorium viehmeyeri		*	**	*				
Melophorus JDM sp. 699			* *					
Camponotus tasmani			* *	*				
Solenopsis belisarius			*	*		*		
Cerapachys greavesi			* * *	*		*		*
Tapinoma JDM sp. 78			*	*** * *	*	*		*
Colobostruma cerornata		*	*					*
Stigmacros JDM sp. 1067	*		*					*
Iridomyrmex cephaloinclinus			* *					
Iridomyrmex lividus			*			*		
Iridomyrmex JDM sp. 1028			**					
Pheidole JDM sp. 558			**					
Polyrachis (*Campomyrma*) JDM sp. 670		*	* *					
Assemblage 5								
Camponotus clarior				*	*			
Myrmecia ?varians				*	*			
Iridomyrmex JDM sp. 130		*	*		*			
Camponotus nigroaeneus gp nr JDM sp. 108					* *			
Camponotus prosseri		*			** *			
Assemblage 6								
Camponotus tricoloratus		*	*	* *	* *			
Melophorus JDM sp. 199			* *** *	**	*****			
Melophorus JDM sp. 784			* *	* *	* *			
Tetramorium JDM sp. 515			*	**	*			

Table 3 (cont.)

Iridomyrmex mattiroloi complex JDM sp. 449			**	*		*		
Rhytidoponera foveolata			*****	*				
Melophorus mjobergi			**	**				*
Iridomyrmex greensladei			**	*	**	*		
Meranoplus JDM sp. 1101			**		**			
Stigmacros termitoxena			**	*	***			
Monomorium leae	*		*		*			
Stigmacros JDM sp. 188			*		*			
Tetramorium JDM sp. 1007			*		**			
Assemblage 7								
Camponotus cf. *discors* complex JDM sp. 1104			*	*				
Camponotus lownei complex JDM sp. 761		*		*				
Camponotus lownei complex JDM sp. 772				**				
Paratrechina minutula				***	*			
Melophorus JDM sp. 1063			*	****	*			
Myrmecia desertorum	*			*****				
Monomorium eremophilum			**	***				
Tetramorium JDM sp. 461			*	***		*		
Cerapachys brevicollis			*	*				
Melophorus bruneus complex JDM sp. 951				*		*		
Crematogaster queenslandica gp. JDM sp. 1099		*		**			*	
Stigmacros JDM sp. 341			*	*				
Crematogaster JDM sp. 859			*	*				
Monomorium striatifrons			*	*				
Assemblage 8								
Cerapachys gilesi						***		
Melophorus wheeleri complex JDM sp. 1077						****		
Assemblage 9								
Cerapachys incontentus	*			*				
Iridomyrmex JDM sp. 597	*			*				
Polyrachis gravis	*	*		**				
Polyrachis sidnica complex JDM sp. 390			*	**				
Tetramorium JDM sp. 884				**				
Assemblage 10								
Calomyrmex glauerti		*	****					*
Cerapachys sjostedti		***	*					*
Cerapachys clarki		*		*				*
Polyrachis cf. *sidnica* complex JDM sp. 671		*		*				**

Table 3 (cont.)

Doleromyrma darwiniana	*	* *		*		*		
Monomorium nanum	*	*	* *	*		*		
Iridomyrmex JDM sp. 319		*	** *					
Melophorus wheeleri		*	* *			*		
Dolichoderus JDM sp. 838		*			*			
Polyrachis (Campomyrma) JDM sp. 805		*			*			
Iridomyrmex bicknelli azureus		**						
Myrmecia callima		**						
Tetramorium sjostedti		**						
Notoncus capitatus		* *						
Assemblage 11								
Camponotus cinereus				* *	*			
Crematogaster dispar		*		* *	*			
Monomorium rufonigrum	*		*	*		*		
Monomorium legulus				*	*			
Ochtellus JDM sp. 851				**				
Assemblage 12								
Camponotus claripes minimus				** *				*
Melophorus ?JDM sp. 470			*	*				*
Plagiolepis squamulosa					*			**
Camponotus claripes gp. JDM sp. 63								* *
Camponotus rufus								****
Paratrechina minutula gp JDM sp. 916				*				*
Stigmacros aemula			*	*				*
Camponotus terebrans				* *				**
Crematogaster queenslandica gp. JDM sp. 428				*	*			***
Notoncus gilberti				*	*			**
Stigmacros reticulata				* **				**
Ochtellus glaber gp . JDM sp. 19							**	*
Polyrachis ammonoeides				*			**	*



Quadrat	Group no.	Geomorphologic characteristics
BB1	1.	Small sand lunettes on claypans
CU2, 4; MR3-4; GJ4; KE1, 2	2.	Dune slopes
GJ1-2, 3,5; KE3-4, 5; MD 1-5; MR1-2, 5; WO1-5	3.	Scree slopes and alluvial flats
BB2, 4-5; BO1, 3-5; CU5; PE2-5; NA2-5; ZU3	4.	Near coastal sand dunes and plains
NE1-5	5.	Southern inland yellow sand plains (Eucalyptus woodlands of Victorian Plateau)
BB3; BO2; CU1; NA1; PE1	6.	Samphire bushlands
CU3, 6	7.	Near coastal deep dune slopes
ZU1-2, 4-5	8.	Tamala limestone with shallow sand mantle (Proteaceous shrubland of Victorian Plateau)

Figure 3 Dendrogram showing the groupings of quadrats according to similarity of species composition, based upon the two-way table generated by the species co-occurrence matrix (Table 3). The cut-off for the degree of dissimilarity between sites was set at 0.7272. If a dendrogram line did not meet this cut-off point, the quadrats were considered too dissimilar to be grouped together. Brief generalisations of the grouped quadrats are displayed in the final column; the location of each quadrat is shown in Figure 1.

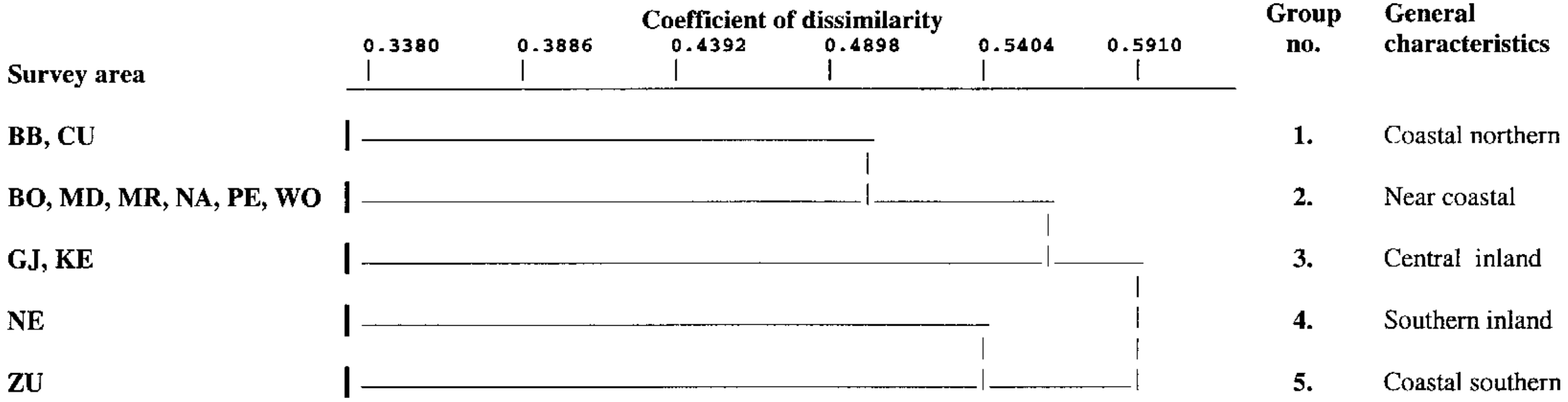
‘samphire bushland,’ and these were the only sites in the study area with this characteristic. These two ants *Cerapachys gilesi* and *Melophorus wheeleri* complex JDM sp.1077 are very different in that the former is a common ant around the Perth hinterland and the latter is more common in the drier Eremaean regions to the north. This is further demonstrated by Figure 2 which shows that 50% of the species in Assemblage 8 had a Bassian origin and the other half had an Eremaean distribution. Both species have been recorded for the SWBP, but presumably it is the first time that both species were associated with the saline areas of samphire bushland. No other assemblage was associated with this group of quadrats.

Figure 4a displays an analysis of the species in terms of survey areas, instead of individual quadrats. This revealed five groupings of survey areas on the basis of species. These survey area groups (numbered clouds) are displayed in Figure 5a, which reveals a separation of north and south faunas (clouds 1 and 3:4 and 5), as well as inland and coastal assemblages (clouds 1:3 and 4:5). This pattern was further simplified in Figure 4b, where ant genera analysed against the survey areas revealed a slightly different association. The survey area groups in Figure 5b further emphasize a more north : south separation (clouds 2:4).

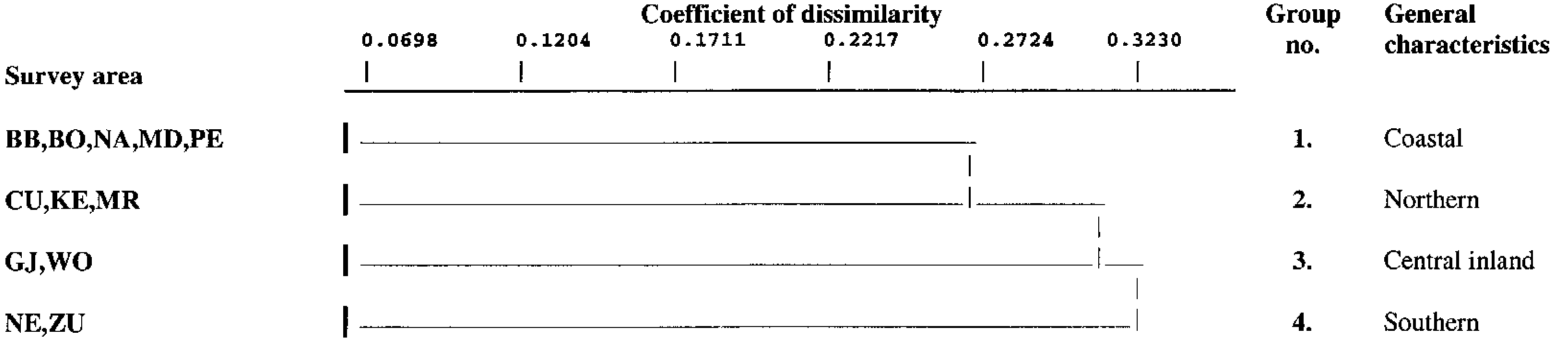
Environmental variables

The environmental parameters revealed some correlations with the patterns of distribution in terms of species, as well as with genera. Regarding the 12 species assemblages, almost all environmental variables were significantly associated ($P > 0.05$) except for stoniness, over-bank stream flow and soil exchangeable sodium. As each species assemblage varied greatly in size, the GLIM analysis demonstrated patterns in only the largest assemblage (Assemblage 1). Although less than 50% of the scaled deviance could be explained by the model in this case, precipitation appeared to be a significant component.

The environmental variables associated with the five survey area groups revealed some further patterns. There appeared to be a pattern relating species distribution within the five groups to maximum temperature, precipitation during the wet season, altitude, longitude and coastal distance. This was reflected somewhat by the four survey area groups generated by the genera assemblages, as they showed an association with temperature, precipitation and latitude

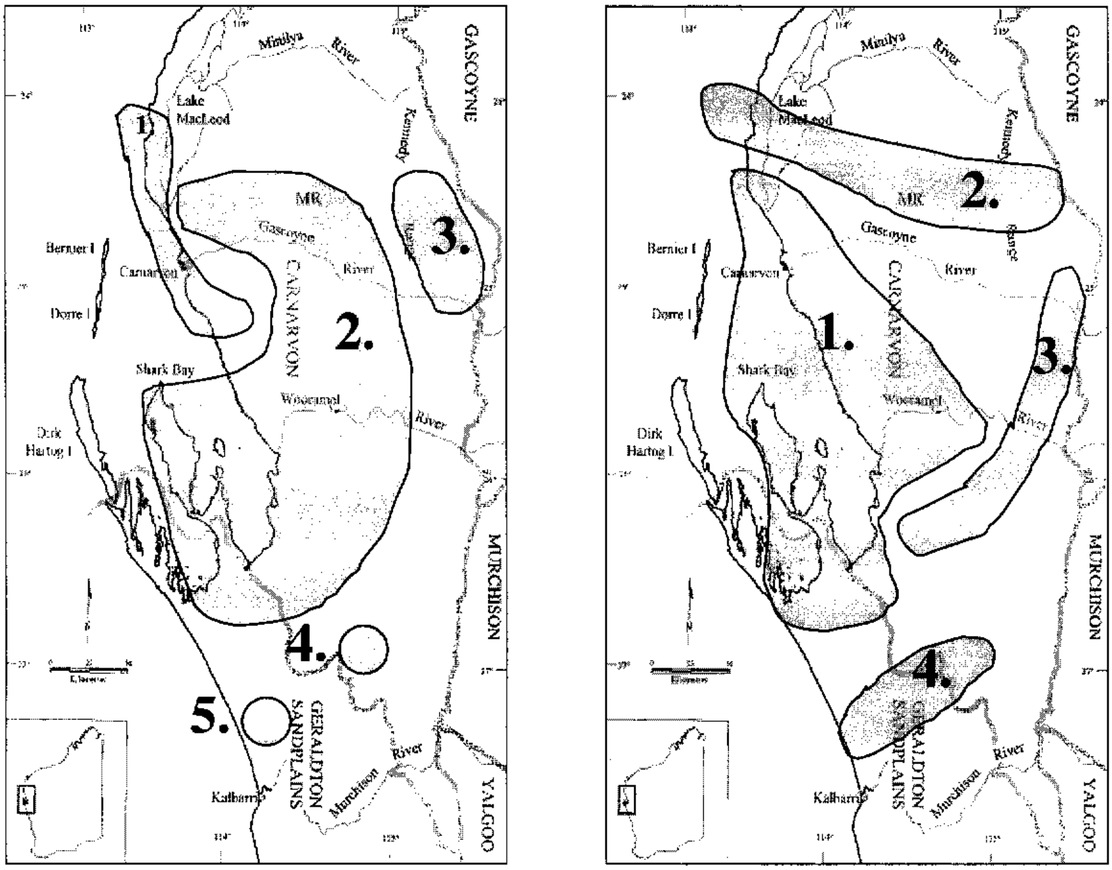


a) Species by survey area



b) Genus by survey area

Figure 4 Dendrograms showing the groupings of survey areas according to similarity of a) species composition and b) genus composition, based upon two-way tables generated by the species/genus co-occurrence matrix for each survey area. Brief generalisations of the grouped survey areas are displayed in the final column.



a) Species assemblage

b) Genus assemblage

Figure 5 The southern Carnarvon Basin study area. Each shaded cloud shows the groupings of survey areas exhibiting similarities in terms of a) species assemblage and b) genus assemblage. The numbers on the clouds correspond to the survey area groups displayed in Figures 4a and b.

Table 4 The climatic and geographical variables associated with the 5 survey area groups generated by the species assemblages and 4 survey area groups generated by the genera assemblages. Only significant values ($P < 0.05$) revealed by a Kruskal-Wallis Test are given.

a) Species by survey area

Environmental variable	***P***
Maximum warmest period temperature	.048
Temperature annual range	.056
Warmest quarter temperature	.029
Annual average precipitation	.025
Wettest quarter precipitation	.049
Coldest quarter precipitation	.033
Altitude	.006
Longitude	.050
Coastal Distance	.023

b) Genus by survey area

Environmental variable	***P***
Annual average temperature	.009
Warmest quarter temperature	.046
Coldest quarter temperature	.034
Annual average precipitation	.050
Warmest quarter precipitation	.037
Coldest quarter precipitation	.043
Latitude	.009

(see Table 4). These patterns of association with environmental variables for survey areas reflect the patterns seen in Figures 5a and b. The differences between species assemblages and genus assemblages are characterised by the fact that the species assemblages are separated by altitude, longitude and coastal distance, while genera assemblages were separated by latitude. Figure 5a shows a separation from coastal areas to inland, and from lowland to highland, whereas Figure 5b demonstrates a separation from north to south, with less of a coastal to inland separation.

DISCUSSION

Biodiversity and biogeography

The ants of the southern Carnarvon Basin demonstrate a high degree of species richness, as the total number of species recorded for the area is quite high compared to studies conducted elsewhere in WA (Rossbach and Majer, 1983; Andersen, 1992; Doronila and Fox, 1997; Majer and Nichols, 1998). Although some of the 243 species could not be confidently placed in only one biogeographic region, overall there was a greater tendency for species to have an Eremaean distribution than Bassian, and much less a Torresian or widespread distribution. The overlap between Eremaean and Bassian elements of this study demonstrates the transitional nature of this area.

This distribution may be useful in delineating boundaries for conservation, as we can better understand the boundaries where species composition becomes distinctly arid or distinctly southern. Vanderwoude *et al.*, (1997) suggest that proportions of species in each biogeographic group can be used as indicators of biogeographic regions. In this case, more information would be required in order to place each species into one definite biogeographic group.

A majority of the ant species are represented in the SWBP, with a number of them being present at the limit of their ranges in the southern survey areas NA, NE and ZU. Gibson *et al.*, (2000) suggest that the phytogeographic boundary established by Beard should be located more to the south and to the west in order to exclude some of the arid vegetation types found around Shark Bay. This proposition is supported by this study in the fact that the NA survey area (technically located in the SWBP) did not separate out from the more northern survey areas, in contrast with ZU. The species assemblage at NE also contains fauna that are considered more Eremaean, therefore both these sites (NA and NE) should not be included in the SWBP. If the SWBP boundaries were moved more south and west, this would better account for the species occurrence at these two sites.

Nerren Nerren was unusual in that its quadrats spanned the phytogeographic boundary between the south-west and arid regions. Its high number of 'unique' species corresponds to the fact that the vegetation at NE2 was also assigned a unique vegetation group. This site may represent a change-over area between the wetter south and drier north and perhaps requires further scrutiny.

Patterns of association related to environmental variables

While Gibson *et al.*, (2000) found that the vegetation boundaries were highly correlated with edaphic factors, (supporting their suggestion to move the phytogeographical boundary), the ant species assemblages did not seem to focus on any particular soil factor. Lobry De Bruyn, (1999) suggests that ants are good soil quality indicators in natural and rural environments. Although the results from this current study support this idea, the broad base and wide range of the research area perhaps clouds any definite soil factor associations that could be derived from the ant species distribution. Each individual species assemblage was assessed against the environmental variables (not shown in this paper), but no further clarity was gained by these analyses.

Disturbance could also have played some role in the groupings of assemblages, as particular survey areas were more disturbed than others. Examples of this are Woodleigh station and Gascoyne Junction, both of which were highly grazed (Group 3 in Figure 5b). Both sites had the lowest number of species, with the majority of them being commonly found in urban and disturbed environments (e.g. *Iridomyrmex rufoniger* group and *Melophorus turneri* group species). Species assemblages, on the other hand, do not group these two survey areas together, instead placing GJ with KE. This pairing could be explained by looking at the vegetational major site groups, which place KE 3-5 with GJ 1-3, 5 in Group 4; the vegetational group was defined as inland *Acacia* shrubland, perhaps influencing the ant species distribution (Keighery *et al.*, 2000).

Climate, on the other hand, appeared to play a prominent role in the distribution of the ant species. Both the quadrat and survey area analyses showed significant associations with temperature and rainfall. Although the quadrat analyses demonstrated significance for all climatic variables, the survey area data was able to give more specific associations. Ants have been positively correlated with temperature in other studies (Briese and Macauley, 1981; Vanderwoude *et al.*, 1997), which demonstrates their relation to vegetation and to soils, as both these factors would heavily influence ant species distribution (Greenslade and Thompson, 1981; Morton, 1982; Andersen, 1993).

The relationship between rainfall and temperature can be seen through the data gathered by Wyrwoll *et al.*, (2000a), as the seasonality of rainfall in the area is directly correlated with highs and lows of temperature. There is an increasing amount of variability in mean precipitation moving northwards in the study area, due to irregularity of summer monsoonal rainfall. This trend is reversed in the more southern areas, which are subjected to regular winter rains.

The separation of southern and northern faunas reflects these precipitation differences, which may be further enhanced by the coastal – inland differences in rainfall volume. Rainfall, or lack of, can influence ant species distribution to a great degree. For example, it results in a more *Iridomyrmex* - dominated landscape in the arid areas and a more cryptic, epigaeic species - dominated landscape in wetter areas (Greenslade, 1985). While species abundances were not calculated, the current study shows a more *Camponotus / Melophorus* - dominated landscape, which may indicate some underlying influence such as higher inland temperatures and lower coastal temperatures during summer.

The nature of the species composition observed in this study supported the two major groups of ant genera established by Greenslade and Greenslade, (1989). Based on broad ecological and geographical trends, they separated the 'core' groups of ants (Group **I**: *Iridomyrmex, Melophorus* and *Camponotus*) from the other more specialised genera (Group **II**) such as *Monomorium, Pheidole* and *Rhytidoponera.*

Using data derived from different eastern states' studies, they hypothesized that high competition from Group **I** species would reduce species diversity of Group **II** species, but in situations where the ratio of Groups **I/II** is low, the high diversity may be due to areas being in transition zones where Group **I** taxa are outside their climatic optima. This theory is supported by results of this study, as it shows that there is a relatively low ratio between the Group **I** species (103 spp.) to Group **II** species (89 spp.).

Wyrwoll *et al.*, (2000a) also found that there was a more pronounced north – south gradient for mean coldest quarter temperature, which is in concordance with the genus assemblages, generated for the survey areas. Table 4b shows that there is a significant association between genera assemblages and coldest quarter temperature; Figure 5b further demonstrates this, showing that the assemblages display a more north – south separation of survey area groups. Recent studies have found that species richness in ants can be related to latitudinal gradients, even at small scales (Gotelli and Ellison, 2002). Though the current study site spanned roughly only four latitudinal degrees, latitude was significantly associated with the genera assemblages (see Table 4b).

While species assemblages did not have a significant association with latitude, perhaps a further study of species richness may generate a relationship. It would be of interest to see whether genus to species ratios can be made more predictive over smaller latitudinal gradations. This generic level association may also be indicative of the state of ant taxonomy of the area and the lack of sufficient phylogenetic research for the ant species and their complexes.

Overall, there is a difference between species and genus assemblages; the former closely following vegetational patterns, while the latter tends towards latitudinal gradients. Genus richness has been found to be an inadequate indicator of species richness, as there is a high amount of variability in species to genus ratio depending on the region (Andersen, 1995). While the southern sites NA and ZU displayed a relatively lower ratio (i.e. similar numbers of species and genera) than the northern survey areas, NE separated out again in that it had a ratio more similar to the northern survey areas. This discrepancy also appeared in the CU and BO survey areas, which also showed very low ratios. In this case, it appears that the species to genus ratio follows the trend found in southern semi-arid zones and northern semi-arid zones, where the mixing of genera (cool temperate genera from the south and tropical genera from the north) causes a lower ratio (Andersen, 1995). This lends further support to the fact that this area is a major transitional zone, which therefore should be taken into consideration as a biogeographically and ecologically significant area.

The general ant species distribution appears to follow the modified phytogeographic zones suggested by (Gibson *et al.*, 2000), but more research on individual species would be required in order to establish ranges and provide a concrete basis for determining biogeographic origin. This study contributes to a growing pool of data that can be used to compile a complete bio-inventory of ant species for Western Australia.

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An investigation into the effect of fire on ant communities in the Gibson Desert Nature Reserve, Western Australia

Abstract - A total of 71 ant species was identified from twelve 2500m^2 plots in an area within the Gibson Desert Nature Reserve. The 12 plots were established in unburnt and burnt areas of three main vegetation types: *Triodia basedowii* grassland, *Triodia shinzii* grassland, and *Acacia* woodland. Twenty-nine ant species occurred exclusively in recently burnt sites, 16 species were exclusive to unburnt sites and the remaining 26 occurred in both site types. Functional group analyses revealed a predominance of Subordinate Camponotini and Opportunists at the unburnt sites, whereas Dominant Dolichoderinae and Generalist Myrmicinae were more common in burnt sites. Non-metric multi-dimensional scaling of the ant species revealed a separation of burnt and unburnt sites, although the differences were more marked between the unburnt and burnt *Acacia* plots than the *Triodia* plots. Vegetation structural data, taken simultaneously, were also analysed using principal component analysis, and revealed a difference between burnt and unburnt plots in terms of percent cover of herbs, soft grasses and bare ground. Analysis of ant species composition in relation to vegetation parameters showed a correlation between ants with percent cover of live and dead spinifex. These findings provide further evidence that burning in arid ecosystems has a measurable impact on the biota, including the invertebrate fauna.

Key words: Ant species, functional groups, fire, spinifex grassland and Gibson Desert Nature Reserve.

INTRODUCTION

The arid region of Australia is well known for its fire-adapted vegetation and the 60,000 year-old burning practices of the Aboriginal 'fire-stick' farmers (Hodgkinson and Griffin, 1982). Western Australia's (WA) arid interior has some of the largest tracts of mulga (*Acacia aneura*) woodlands and hummock plains (*Triodia* sp.) outside of pastoral leases or aboriginal lands (Allan and Southgate, 2002). Hence, the land is potentially subject to natural fire regimes that existed prior to Aboriginal land practices (i.e. infrequent, patchy burns of high intensity occurring every 20 - 50 years), and these may have long-term effects on the native vegetation and fauna (Burrows *et al.*, 1991; Hodgkinson, 2002).

Fire is an important management tool in Australian landscapes, and the effects of these fires have been recorded for a variety of ecosystems and faunal groups (Coy, 1994). The effects of prescribed, low-intensity fires in woodlands on specific invertebrate groups have been comprehensively documented (York, 1999), but the effects on invertebrate communities of the arid interior has, as yet, been little studied.

The central arid region of WA has been under-investigated in terms of its fauna and flora due to its remoteness and subsequent high travel and research costs. However, the Department of Conservation and Land Management (CALM) has been conducting comprehensive vegetation and faunal surveys in the Gibson Desert Nature Reserve (GDNR) in recent years. Vegetation studies were initiated in 1999 to assess the post-fire changes in plant species and vegetation structure, and to evaluate suitable environments for possible re-introduction of native mammals (see Christensen and Burrows, 1994; Burrows *et al.*, in press).

As the fire regime experienced by this area over the last 50-100 years is most likely to be different from those experienced prior to European settlement, the fire-adapted plant community is expected to have been altered (Allan and Southgate, 2002). Any changes in habitat structure would presumably affect the success of re-establishment of native fauna to the area, as such species may depend on historic fire regimes associated with favourable habitats (Burrows *et al.*, 1991; Anon., 2002). Investigations into the post-fire changes in flora and invertebrate fauna can shed light on the time-frame for regeneration of the biota. This would allow mammal rehabilitation workers to determine appropriate sites and times for the re-introduction of endangered species.

Invertebrates have been used as indicators of regeneration after major environmental disturbances such as mining, logging, and fire (Jackson and Fox, 1996; Majer and Nichols, 1998; van Heurck and Abbott, 2003). The need to assess both short- and long-term effects of fire on invertebrate communities has now been recognised, as invertebrates have proven to be robust indicators of habitat recovery after fire (Friend and Williams, 1996). If invertebrate populations are changed, then the animals that prey upon them may also be affected (O'Dowd and Gill, 1984). As a result, it is important to have a full understanding of an area in terms of its vegetation and invertebrate populations in order to determine its environmental "condition" and conservation value.

The ant fauna of the arid regions of Australia is highly speciose and plays a major role in the ecology of the landscape (Morton, 1982; Andersen, 1990). Ants are commonly used as indicators of a variety of environmental effects, but investigations into the effects of fire on ants in coastal, pastoral and mining restoration areas have revealed a gamut of post-fire responses (Friend, 1994). This prompts the need to look closely at post-fire re-colonisation patterns in specific environments, such as the understudied arid zone of WA.

The aim of the current study is to compare the patterns of distribution of ant species in recently burnt (14 months prior) and long unburnt (burnt 15 - 30 years ago) sites in three main vegetation types in the GDNR. These are *Triodia basedowii* (TB) buckshot plains; *Triodia schinzii* (TS) sand plains; and *Acacia aneura* (AW) woodland. Vegetation surveys of each site conducted simultaneously allows for some assessment of the relationship between ant species distribution and plant species and vegetation structure. As this is the first study of ant species in the Gibson Desert, it contributes to a growing body of data concerning arid zone ant communities across WA and Australia.

METHODS

Study area

The GDNR is an 18,900 km square area located at the centre of WA (see Figure 1). It is 900 km inland from the west coast and has an average annual rainfall of 220 mm (Beard, 2002). The vegetation studies were carried out during winter, due to the difficulty of travelling to the area during the high temperatures of summer. Soils are predominantly red sand with some clay pans and dune formations scattered throughout the area. *Triodia* grasslands interspersed with *Acacia aneura* woodlands dominate the vegetation (Burrows *et al.*, in press).

The study was carried out along the western perimeter of the GDNR and focused around the Eagle Bore Campsite (24° 42' – 24° 45' S, 124° 46' – 124° 48' E) administrated by CALM (see Figure 2). Six sites were established within the three vegetation types of *Triodia basedowii* (TB) buckshot plains, *Triodia shinzii* (TS) sand plains and *Acacia aneura* (AW) woodlands. Three sites (Plots 3-4, Plots 7-8 and Plots 11-12, respectively corresponding to the vegetation types noted above) were placed in areas that had previously been burnt (natural wildfire) between 14 (Plots 7-8) and 40 years ago (Plots 3-4 and 11-12). These sites were labelled as unburnt. The other three sites (Plots 1-2, Plots 5-6 and Plots 9-10) were located adjacent to these plots (0.5 - 1km apart) and had been burnt 14 months prior to the study. Each plot

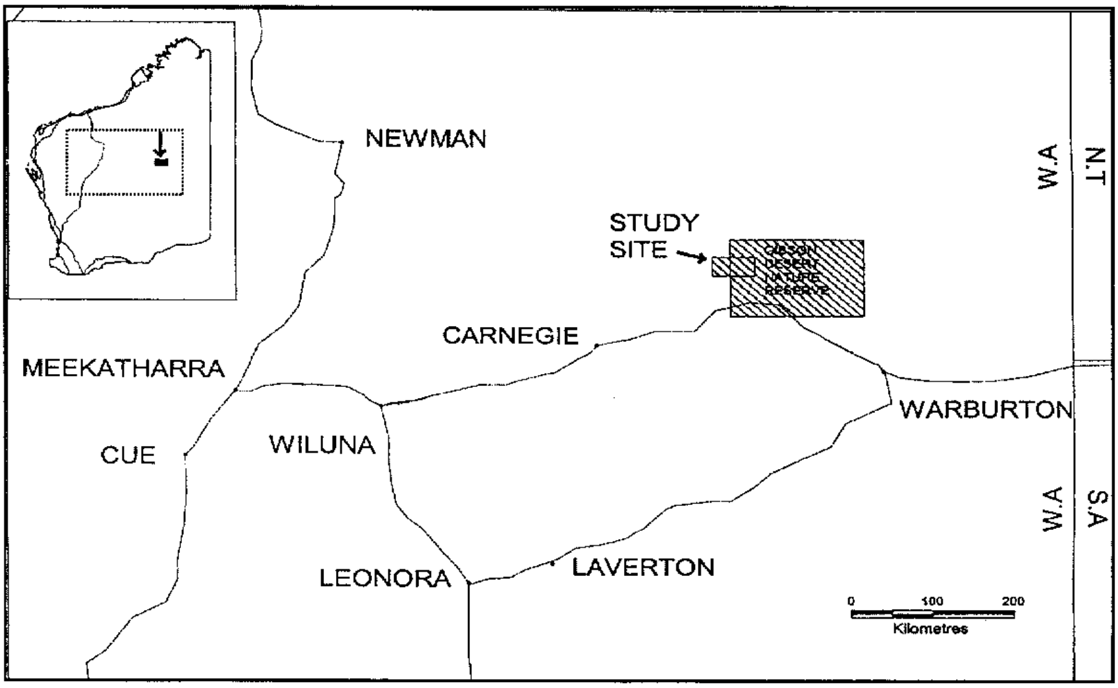


Figure 1 Map of the Gibson Desert Nature Reserve and the location of the study area within the reserve (modified from Anon., 2002).

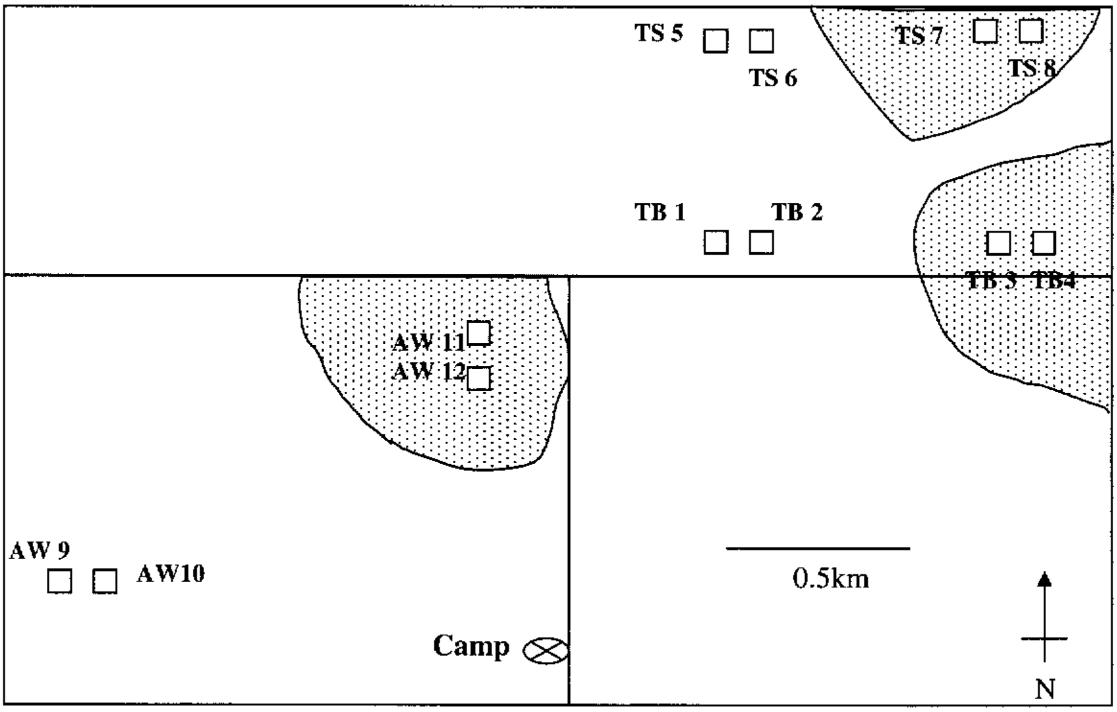


Figure 2 Map of the Eagle Bore campsite in the Gibson Desert Nature Reserve, showing the locations of the 12 plots. The area demarcated by stipple represents unburnt areas. Plots TB1, TB2, TB3 and TB4 are within *Triodia basedowii* grasslands, plots TS5, TS6, TS7 and TS8 are within *T. shinzii* grasslands and plots AW9, AW10, AW11 and AW12 are within *Acacia* woodlands.

measured 50m x 50m, and was replicated with a site placed 20m adjacent to it (see Figure 2). Representative photographs of each unburnt and burnt site in the three vegetation types are shown in Figure 3.

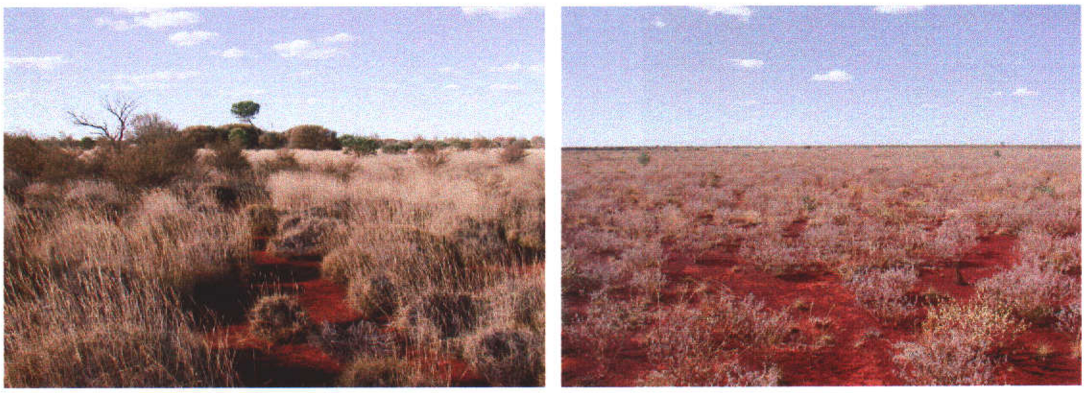
Sampling method

Pitfall traps were used to sample ground-dwelling invertebrates. Plastic containers (100mm x 150mm), with approximately 250ml of ethylene glycol, were set into PVC sleeves (100mm x 250mm) and were left out for 5 days from 15th – 20th August 2002. The PVC sleeves had been inserted roughly four weeks prior to placement of the traps in order to reduce the 'in digging' effect of placing pipes in the ground (Bestelmeyer *et al.*, 2000). Each plot had two transects with five traps each, set 10m apart along the opposite sides of each 50m x 50m block. After five days, the contents of the 10 traps from each plot were strained, washed and amalgamated into one storage vial containing 70% ethanol. All samples were returned to the laboratory and ant specimens were sorted and identified to species or species complex. Once identified, ant species were placed in permanent storage at the Curtin University of Technology Ant Collection. All other invertebrate taxa are lodged at the Western Australian Museum.

Functional group analysis

The ant species were analysed in terms of their functional group, as there is a paucity of ecological and behavioural data on individual ant species. Functional groupings allow for broad-spectrum analysis of ant species, as they are based on behavioural generalisations of each ant genus. These groups were established by Greenslade and Thompson, (1981) and were based upon the ecology (habitat and competitive interactions) of key genera; this classification has been refined and is subsequently used in a variety of studies where specific behavioural data are lacking (Andersen, 1990; Andersen, 1997).

These functional groups are: Dominant Dolichoderinae (DD), comprised of *Iridomyrmex* species, which dominate many of the arid regions of Australia, and the more southern inhabiting *Anonychomyrma* genus; Sub-ordinate Camponotini (SC)



a) *Triodia basedowii* grasslands

b) *Triodia shinzii* grasslands

c) *Acacia aneura* woodlands

Figure 3 Photographs of the three main vegetation types in the Gibson Desert Nature Reserve study area, showing the unburnt control plots (left column) and the burnt treatment plots (right column). Photographs were taken by Professor Tom Bragg of the University of Nebraska at Omaha.

represented by *Camponotus* and *Polyrachis* species, which can often co-exist with DD due to their submissive behaviour and temporal separation of activity; Climate Specialists (CS), consisting of hot (or cold) climate specialists such as *Melophorus*, which temporally separate their activity by foraging during the hottest parts of the day or year; Cryptic Species (CR) which are small species, predominantly from the Ponerinae and Myrmicinae subfamilies, that nest and forage mainly within soil and litter; Generalized Myrmicinae (GM), which are made up of species from the genera *Monomorium, Pheidole* and *Crematogaster* [(*N.B.* many of the species within these genera have been found to be quite specific in their behaviour (Briese and Macauley, 1981)]; Opportunists (OP) (mostly species of *Rhytidoponera, Tetramorium* and *Paratrechina*), which are commonly found in disturbed environments as they are poor competitors and are unspecialised in their behaviour; and Specialised Predators (SP), consisting of representatives from many of the larger Ponerinae, Cerapachyinae and Myrmeciinae subfamilies, whose large solitary foragers prey upon other arthropods (Greenslade and Thompson, 1981; Andersen, 1991). These groups were used to analyse ant species occurrence in burnt and unburnt sites.

Vegetation survey

Structural and species data for vegetation at each site were recorded along two diagonal transects criss-crossing a plot (NE-SW and NW-SE). Cover of 12 vegetation structural parameters was measured along the two diagonal transects and combined to estimate the average cover for the whole quadrat. Parameters were: percent cover of *Triodia basedowii* (TB); *T. schinzii* (TS); soft grasses (SG); herbs (H); woody shrubs (WS); small trees (ST); dead spinifex (DS); dead herbs (DH). Dead wood (DW), the average height of *T. basedowii* (HtB), other vegetation (HtO) and the amount of bare ground (BG) were also measured along the transects. Cover, frequency and distribution of individual plant species were also measured

Analysis of the data

Ant species were entered into a presence/absence data matrix for each site in order to reduce the effects of the high degree of variability of individual species abundances.

Although this kind of representation often reduces the 'weighting' of particular species in a matrix (i.e. ignoring the rarity or abundance of certain species), it eliminates the need for difficult transformations that may cloud the actual data (Clarke and Warwick, 1994). Also, analyses of relative abundances of ant species are often problematic due to their tendency to be spatially clumped (Longino, 2000).

The statistical package PRIMER v5 was used to conduct all statistical tests (Clarke and Gorley, 2001). Non-metric multi-dimensional scaling (MDS) was used to construct a spatial analysis of the similarity of ant species occurrences at each of the sites. A Bray-Curtis similarity measure was utilised to compare each species occurrence at each site against every other species (Kruskal, 1964).

A two-way crossed ANOSIM (analysis of similarities) using unburnt and burnt treatments against vegetation type was also conducted to determine if the difference between treatments and among sites was significant. A breakdown of the Bray-Curtis similarity matrix was carried out using a similarity percentages procedure (SIMPER) on the ant species to determine species that contributed the most to differentiating between the unburnt and burnt sites, as well as between the three vegetation types (Clarke, 1993).

The same analyses (MDS, ANOSIM, SIMPER) were carried out with the vegetation structural data to expose any similarity in trends between the ant species distribution and vegetation structure. A draftsman's plot (scatterplot matrix) was constructed for the vegetation to ensure that there were no variables that were highly correlated such that they induce collinearity. A principal components analysis (PCA) was then carried out to determine the main vegetational structural components differentiating the site treatments (Chatfield and Collins, 1980).

An analysis involving the similarity matrices of the biotic (ant species) and the abiotic (vegetation structure) variables was then carried out using the BIO-ENV procedure in the PRIMER package in order to select the abiotic variables that were most associated with ant species distribution (similar to a best subset regression analysis).

A RELATE procedure was used to determine the correlation (Spearman's Rank) between the similarity matrices generated for plant species (in terms of cover and frequency) and ant species occurrence across all 12 plots. A SIMPER analysis was also carried out to reveal the specific plant species that differentiated unburnt and burnt sites.

RESULTS

Species diversity

The five trap nights yielded a total of 71 ant species in 16 genera (see Table 1). A majority of the species were positively identified, with only 20 placed into species groups. These species were assigned Australian National Insect Collection (ANIC) numbers and Curtin University Ant Collection (JDM) numbers for future identification. The number of species that occurred at solely the burnt sites was 29, while only 16 species were restricted to the unburnt sites, the remaining 26 species being found at both site types. *Iridomyrmex* was the most speciose genus with 15 representative species, while *Camponotus* and *Melophorus* followed closely with 11 species each. All other genera were represented by between one and seven species. Many of these species have wide distributions in arid and semi-arid areas of WA, with some species also found in wetter regions of the south-west, including the Perth metropolitan area.

Functional group analysis

The Dominant Dolichoderinae group was represented solely by *Iridomyrmex,* and members of this genus were fairly well distributed across the unburnt and burnt sites (see Figure 4). Only 3 of the 15 *Iridomyrmex* species were found exclusively at the unburnt sites, these being *Iridomyrmex viridiaeneus* (a "meat ant"), *Iridomyrmex innocens*, and *Iridomyrmex discors*.

Of the 11 *Camponotus* species (SC) collected, only two species were restricted to the unburnt sites, these being *C. dryandrae* and *C. prostans.* Both are common mesic species; *C. dryandrae* is usually found in the wheatbelt areas WA and *C. dromus* is often collected in the south-west. *Melophorus* species were mostly found within the burnt sites, with some of the more commonly occurring species having a widespread distribution (e.g., *M. turneri* and *M. wheeleri*) [*N.B. Melophorus* species are favoured by large expanses of insolated soils, such as are commonly found in burnt sites (Andersen, 1991)]. Most of the *Monomorium* species (Generalised Myrmicinae) appeared to be widespread throughout the sites, but a majority of the *Pheidole* species were found in the burnt plots only. This may be related to the seed harvesting behaviour of some *Pheidole*

Table 1 List of all species collected during the Gibson Desert Nature Reserve survey. Species occurrences at each site are listed in the left hand column. The locations of each of the 12 plots are displayed in Figure 2. Vegetation types are indicated below the site number; **TB** - *Triodia basedowii* grassland, **TS** – *Triodia shinzii* grassland and **AW** – *Acacia* woodland. **B** indicates burnt sites and **U** indicates unburnt sites. The final three columns display a summary of the species that occurred at only burnt plots (**B**), only unburnt plots (**U**) or which occurred at both burnt and unburnt plots (**W**).

Plot no. **Subfamily/ Species**	**1** **BTB**	**2** **BTB**	**3** **UTB**	**4** **UTB**	**5** **BTS**	**6** **BTS**	**7** **UTS**	**8** **UTS**	**9** **BAW**	**10** **BAW**	**11** **UAW**	**12** **UAW**	**B**	**U**	**W**
Cerapachyinae															
Cerapachys fervidus (Wheeler)									*				*		
Cerapachys greavesi (Clark)			*						*						*
Ponerinae															
Odontomachus ruficeps Smith			*						*	*					*
Pachycondyla lutea (Mayr)					*								*		
Pachycondyla piliventris regularis Forel									*	*			*		
Rhytidoponera crassinoda (Forel)			*	*				*				*		*	
Rhytidoponera metallica (Smith)					*								*		
Rhytidoponera violacea (Forel)									*	*			*		
Rhytidoponera cf. sp. JDM 1052						*							*		
Myrmicinae															
Cardiocondyla nuda (Mayr)			*				*	*			*				*
Crematogaster dispar Forel	*							*							*
Meranoplus sp. JDM 424												*		*	
Meranoplus sp. JDM 674										*			*		
Monomorium disetigerum Heterick		*			*				*				*		
Monomorium fieldi Forel								*	*						*
Monomorium laeve Mayr					*						*				*
Monomorium leae Forel								*						*	
Monomorium rothsteini Forel		*	*			*			*						*
Monomorium sordidum Forel		*	*												*
Monomorium sydneyense Forel	*				*				*	*			*		
Pheidole ampla perthensis Crawley				*										*	
Pheidole ?bos sp. JDM 164									*				*		
Pheidole deserticola Forel									*				*		
Pheidole sp. nr. *variabilis* JDM 177	*	*				*			*	*			*		
Pheidole sp. JDM 536					*	*	*								*
Tetramorium sjostedti Forel				*										*	
Tetramorium striolatum Viehmeyer			*			*	*								*
Dolichoderinae															
Doleromyrma darwiniana (Forel)					*		*								*
Iridomyrmex agilis Forel	*	*			*		*	*		*					*
Iridomyrmex bicknelli Emery						*		*							*
Iridomyrmex cephaloinclinus Shattuck	*				*				*				*		
Iridomyrmex chasei Forel		*	*	*	*	*			*	*					*
Iridomrymex chasei concolor (Forel)	*	*		*	*	*	*	*	*	*	*	*			*
Iridomrymex discors Forel			*											*	
Iridomyrmex dromus Clark	*	*	*		*	*	*		*	*					*

Table 1 (cont.)

Dolichoderinae (cont.)															
Iridomyrmex hartmeyeri group sp. JDM 327				*		*		*							*
Iridomyrmex mattiroloi continentis (Forel)					*								*		
Iridomyrmex innocens Forel			*	*										*	
Iridomyrmex rufoniger suchieri Forel		*		*		*			*						*
Iridomyrmex viridiaeneus Viehmeyer			*	*										*	
Iridomyrmex sp. JDM 319					*	*							*		
Iridomyrmex sp. JDM 320				*	*	*									*
Tapinoma sp. JDM 78				*				*						*	
Tapinoma sp. JDM 981	*	*			*	*	*	*		*					*
Formicinae															
Calomyrmex ANIC sp. 1 (JDM 190)				*							*	*		*	
Camponotus claripes minimus Crawley									*			*			*
*Camponotus dryandrae*McArthur and Adams			*								*			*	
Camponotus ephippium (Smith)										*			*		
Camponotus gibbonotus Forel	*	*	*	*	*			*		*	*	*			*
Camponotus inflatus Lubbock									*				*		
Camponotus oetkeri Forel			*											*	
Camponotus prosseri Shattuck and McArthur		*	*	*							*				*
Camponotus prostans Forel									*					*	
Camponotus sponsorum Forel									*	*			*		
Camponotus tasmani Forel										*			*		
Camponous wiederkehri Forel			*		*			*							*
Melophorus bruneus McAreavy											*			*	
Melophorus bruneus complex sp. JDM 472									*	*			*		
Melophorus bruneus complex sp. JDM 951					*	*							*		
Melophorus ludius sulla Forel	*				*	*	*	*				*			*
Melophorus turneri Forel			*	*					*	*					*
Melophorus wheeleri Forel		*	*						*	*					*
Melophorus wheeleri complex sp. JDM 971		*	*	*		*	*	*		*	*	*			*
Melophorus sp. ANIC 3 (JDM 59)					*								*		
Melophorus sp. JDM 176					*								*		
Melophorus sp. JDM 784									*				*		
Melophorus sp. nr. JDM 699						*							*		
Opisthopsis haddoni rufoniger Forel			*											*	
Paratrechina minutula (Forel)	*												*		
Paratrechina rosae (Forel)		*		*						*		*			*
Polyrachis (Hagiomyrma) sp. JDM 1089												*		*	

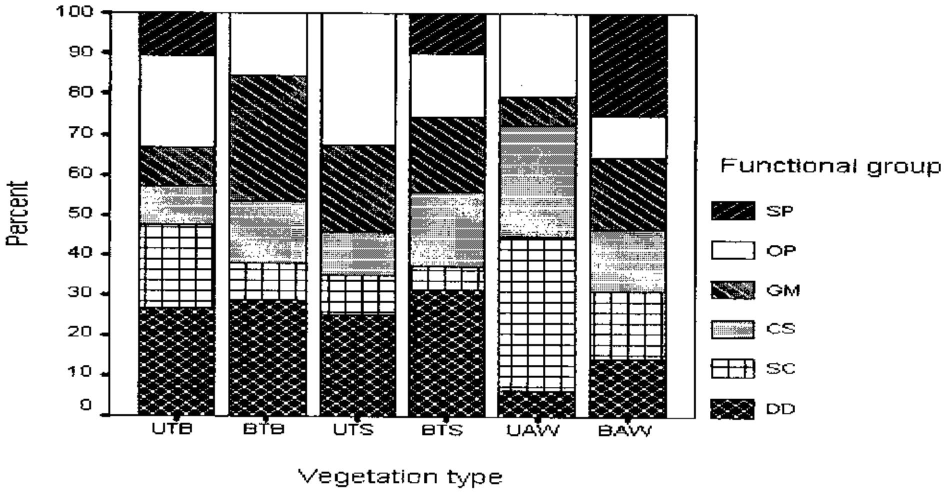


Figure 4 Graph showing the ant species according to the functional groups described earlier; **DD**- Dominant Dolichoderinae, **SC**- Sub-ordinate Camponotini, **CS**- Climate Specialists, **GM**- Generalized Myrmicinae, **OP**- Opportunists, and **SP**- Specialised Predators for each of the unburnt (**U**) and burnt (**B**) vegetation types; **TB**- *Triodia basedowii,* **TS**- *T. shinzii,* and **AW**- *Acacia* woodlands

species; recently burnt spinifex and other arid zone plants often set seed following fire, with growth occurring after the first rains (Allan and Southgate, 2002).

The Opportunist species were found in higher percentages at unburnt sites, regardless of vegetation type. There was some separation of genera within the group. Three of the four *Rhytidoponera* species appear to be more common in the burnt plots, whereas *Odontomachus ruficeps, Tetramorium striolatum, Doleromyrma darwiniana* and *Paratrechina rosae* occur at both site types. *Paratrechina minutula* species group and *Tapinoma* species had originally been placed in the sub-Cryptic Species group (Andersen, 1991; Andersen and Burbidge, 1992) but recent studies have now characterised these species as being more opportunist foragers rather than specialised litter dwellers (Andrew *et al.*, 2000). This inconsistency in their classification is perhaps reflected in the variability of their presence across the unburnt and burnt plots.

Arid zones are often characterised by an absence of Cryptic Species due to the generally low amounts of litter and subsequent lack of litter decomposers, the constituent prey for many of these ant species (Greenslade and Greenslade, 1977). Although litter depth was not measured as a vegetation structural parameter, it was observed that litter amounts were generally low at both unburnt and burnt site types.

The Specialist Predators group was represented by four species from two genera. The two *Pachycondyla* and one *Cerapachys* species were found solely in the burnt sites, with the other *Cerapachys* species present at both unburnt and burnt sites.

Overall, functional group analysis demonstrates a greater number of species in burnt sites in terms of Dominant Dolichoderinae, Climate specialists, Generalised Myrmicinae and Specialist Predators. The latter three groups were not consistent across all three vegetation types. Climate specialists decreased in number in burnt *Acacia* woodlands, Generalised Myrmicinae decreased in burnt *T. shinzii* and fewer Specialist Predators occurred in burnt *T. basedowii* plots than unburnt plots. Subordinate Camponotini and Opportunists had a larger percentage of their species occurring in the unburnt plots of all three vegetation types.

Statistical analyses

Multi-dimensional scaling (MDS) revealed a separation of ants in terms of burnt sites (see Figure 5), but with a greater separation between the mulga woodland sites than between the spinifex sites. ANOSIM revealed significant differences between the unburnt/burnt treatments ($P = 0.01$) and between the three vegetation types ($P = 0.04$). The results of the SIMPER analysis are shown in Table 2, and display the predominance of Dolichoderinae (two *Iridomyrmex* species) and Myrmicinae (*Pheidole* and *Monomorium*) at the burnt sites and opportunistic species at the unburnt sites. SIMPER analysis of the vegetation types (see Appendix, this chapter) show *Triodia* plots to contain more species, with the main difference between the two *Triodia* species being the presence of more *Camponotus* species in *T. basedowii* plots.

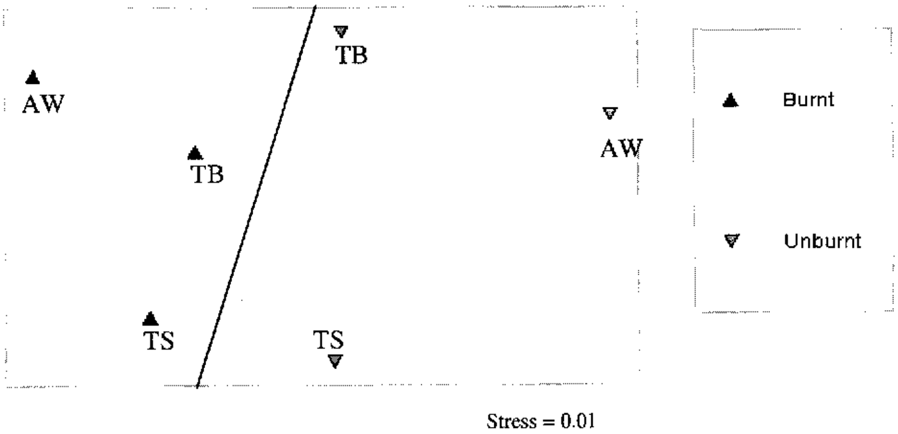
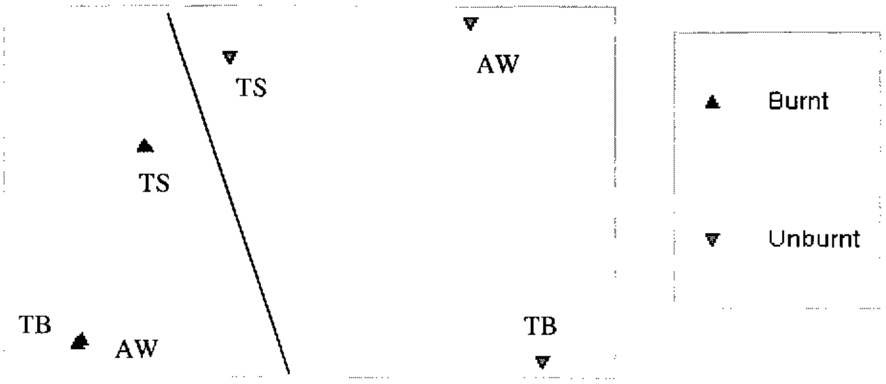


Figure 5 Ant species similarity matrix displayed as a plot of sites using non-metric multi dimensional scaling (MDS) to show the dissimilarity between ant species at unburnt sites and the corresponding burnt sites for the three vegetation types in the study. The labels indicate vegetation type; **TB**- *Triodia basedowii* grassland, **TS**- *Triodia shinzii* grassland, and **AW**- *Acacia* woodland.

Table 2 Ant species that have the greatest contribution to the differentiation between the unburnt and burnt plots.

Species (**Average dissimilarity: 67.8**)	**Unburnt average abundance**	**Burnt average abundance**	**Percentage contribution**	**Cumulative percentage**
Pheidole sp. nr. *variabilis* JDM 177	0.00	0.83	3.82	3.82
Iridomyrmex dromus	0.33	1.00	3.06	6.88
Cardiochondyla nuda	0.67	0.00	2.99	9.87
Monomorium sydneyense	0.00	0.67	2.92	12.79
Rhytidoponera crassinoda	0.67	0.00	2.79	15.57
Iridomyrmex chasei	0.33	0.83	2.78	18.35

Similar results were obtained for the plant structural data. The MDS showed a separation between the unburnt and burnt *Triodia* sites and *Acacia* sites (see Figure 6). An ANOSIM revealed similar results for the vegetation structure as it did with the ant species, with a significant difference between burn treatments (P = 0.01) and between vegetation types (P = 0.04), even though the burnt TB and AW sites were located very close together on the MDS. The SIMPER analysis indicated that height of other vegetation and the presence of *Triodia* were the main determinants of the difference between unburnt and burnt plots (see Table 3).



Stress = 0.00

Figure 6 Vegetation structure similarity matrix displayed for each site, using non-metric multi dimensional scaling (MDS) to show the degree of dissimilarity between vegetation structure for the three vegetation types in the study. The labels indicate vegetation type; **TB**- *Triodia basedowii* grassland, **TS**- *Triodia shinzii* grassland, and **AW**- *Acacia* woodland.

Table 3 Vegetation structure components that contributed to differentiating between unburnt and burnt plots.

Structural component (Average dissimilarity: 42.60)	Unburnt average abundance	Burnt average abundance	Percentage contribution	Cumulative percentage
Height other	0.56	0.27	20.98	20.98
% cover bare ground	0.40	0.63	16.99	37.97
% cover *Triodia shinzii*	0.21	0.05	13.50	51.47
Height of *Triodia basedowii*	0.32	0.14	13.37	64.84
% cover *Triodia basedowii*	0.16	0.05	12.10	76.94
% cover herbs	0.01	0.12	7.93	84.87

The above six vegetation variables accounted for nearly 85 percent of variability between unburnt and burnt treatments. One important variable is height of *T. basedowii,* as the only plots with significant cover of *T. basedowii* were the unburnt TB plots. This may have contributed to the wide separation of unburnt and burnt TB sites in the vegetation structure MDS in Figure 6.

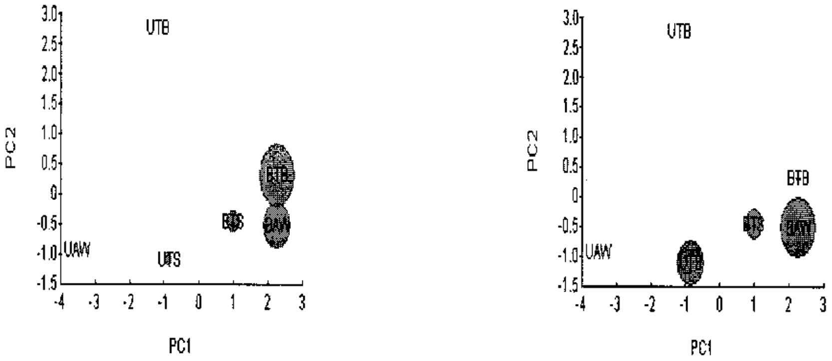
The amount of bare ground is also of interest, as there was not a very great difference between the unburnt and the burnt averages. This is most likely due to the general patchiness of spinifex and mulga landscapes, which would leave areas of exposed ground even in sections of old growth (Burrows *et al.*, 1991). Overall, the greatest differences between the unburnt and burnt plots are the presence of *Triodia* in the former and the greater percentage of bare ground and herb cover in the latter.

The draftsman's plot of the data revealed significant correlations (r > 0.8) between woody shrub, dead herb and small tree, which mean that these three variables could be viewed as representative of each other. The three variables were subsequently removed before performing the PCA. Principle component analysis revealed that the first two principal components accounted for 80 percent of the variation between the sites, allowing the sites to be displayed in two dimensions (Figure 7). The first principal component separated the burnt plots in terms of vegetation characteristics commonly found after fire, namely soft grasses, herbaceous plants and bare ground.

The second principal component focused more upon the upper strata of vegetation that would be found in unburnt sites, such as presence of live and dead spinifex and other tall vegetation. Analysis of the biotic and abiotic data in relation to each other (BIOENV) revealed that ant species occurrence was correlated (r = 0.7) with the following vegetation parameters: (i) percent cover *Triodia shinzii*; (ii) dead Spinifex; and (iii) dead wood.

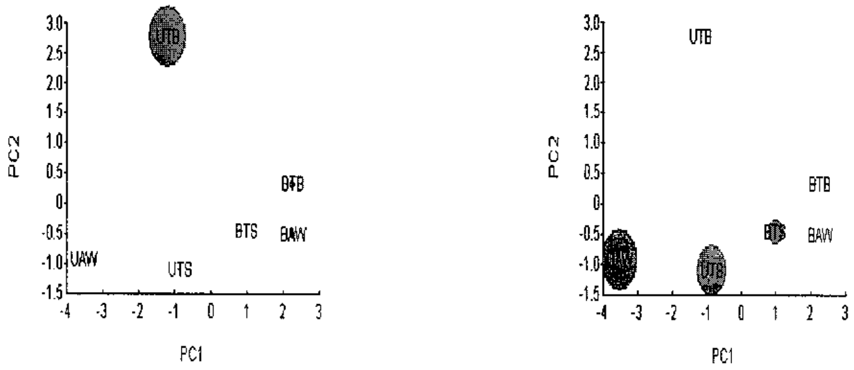
SIMPER analysis of plant species showed that *Halgania solanacea* is the only species whose frequency and cover is a main determinant of the differences between unburnt and burnt treatments for the current study (Tables 4 and 5). The species in Table 4 are mostly perennial herbs and annual soft grasses, which were found in the burnt sites only. The presence of these plants is typical of hummock grasslands regenerating after fire (Burbidge, 1985).

The frequency of these plants is predictably high at the burnt sites, as they would have been able to set seed and spread successfully within the 14 months after the fire. The SIMPER breakdown between vegetation types (see Appendix, this chapter) demonstrated a predominance of herbs and grasses at the *Triodia* sites as compared to the *Acacia* sites. This is also true for vegetation cover, where the *Triodia* species are a major component differentiating between sites.



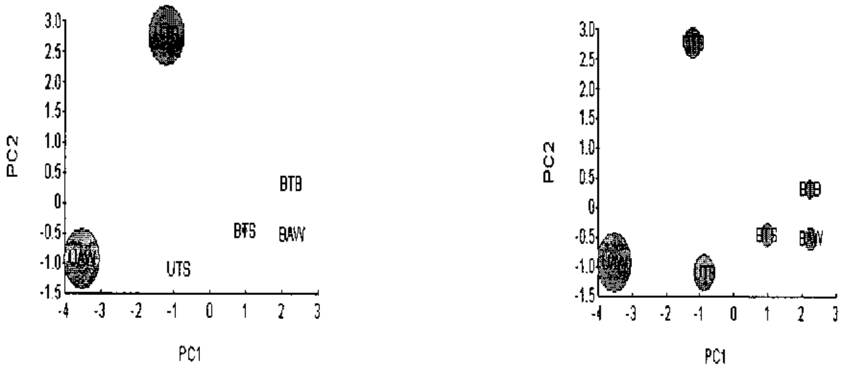
a) Herbs

b) Soft grass



c) *Triodia basedowii*

d) *Triodia shinzii*



e) Dead spinifex

f) Height of other vegetation

Figure 7 Principal component graphs of six vegetation structural variables that contribute the most to the first two component scores of the vegetation structure analysis.

Table 4 List of plant species that determined the differences between unburnt and burnt sites. The plant species were recorded in terms of frequency at each site. All plant species listed were more frequent in burnt plots.

Species Average dissimilarity: 66.03	Unburnt average abundance	Burnt average abundance	Percentage contribution	Cumulative percentage
Halgania solanacea	0.33	4.33	4.84	4.84
Sida spodochroma	0.33	3.83	4.44	9.27
Eriachne aristidea	0.67	3.67	3.65	12.93
Indigofera sp.	0.67	3.67	3.61	16.54
Goodenia azurea	1.83	4.00	3.39	19.93
Enneapogon caerulescens	2.17	4.17	3.31	23.24

Table 5 Plant species that determined the differences between unburnt and burnt sites. The plant species were recorded in terms of percent cover at each site.

Species Average dissimilarity: 67.76	Unburnt average abundance	Burnt average abundance	Percentage contribution	Cumulative Percentage
Triodia basedowii	4.00	1.50	7.34	7.34
Halgania solanacea	0.17	2.50	5.47	12.81
Triodia schinzii	1.50	1.00	4.03	16.84
Dicrastylis tomentosa	1.17	2.17	3.39	20.23
Acacia aneura	1.50	0.33	3.39	23.61
Indigofera sp.	0.33	1.83	3.32	26.93

The two spinifex species and *Acacia aneura* were measured as part of the vegetation structure survey, so the above data are in agreement with the PCA graphs displayed in Figure 7. The unburnt plots would naturally have a higher percent cover of these major vegetation types. *Dicrastylis tomentosa* and *Indigofera* sp. were common throughout the burnt plots and were in flower at the time of the study.

The RELATE procedure demonstrated that the similarity matrices for ant species are highly correlated to the similarity matrices of plant species frequency ($P = 0.001$) and cover ($P = 0.001$). This perhaps indicated that the ant communities are responding more to plant species distribution rather than vegetation structure.

DISCUSSION

The results of the study suggest that ant species of the GDNR respond to fire. Invertebrate species richness has been shown to increase 14 -18 months after fire in a variety of environments such as alpine ash forest (O'Dowd and Gill, 1984), mallee woodlands (Andersen and Yen, 1985) and white box grassy woodlands (Greenslade, 1997). The same can be said of the *Triodia / Acacia* environment of this study, as there was an increase in the number of ant species in post-fire plots compared with their numbers in the unburnt plots, indicating the resilience of this group of insects. This finding agrees with the generally rapid recovery of invertebrate populations recorded in arid areas, which are more adapted to seasonal environmental stress (Fox and Fox, 1986; Friend, 1994; Friend and Williams, 1996).

The ant species captured in this study were not altogether representative of arid zone communities (Brian Heterick, pers. comm.). Significant arid zone members of the *Meranoplus diversus* group, *Dolichoderus* and *Stigmacros* genera were absent from this collection and other arid zone species such as *Polyrachis* and *Monomorium* (*Chelaner*) were very poorly represented. Other anomalies were the presence of mesic *Camponotus* species and prevalence of very common, disturbed area inhabitants such as *Iridomyrmex chasei, I. chasei concolor, Melophorus turneri, Rhytidoponera metallica* and *R. violaceae.* This prompts the question that if the area has not been disturbed by any human activity then what is the cause of the absence of the more arid zone specialists.

It is possible that the highly variable rainfall and the low night time temperatures during winter could influence the persistence of species in the area. Species such as the more mesic, wetter inhabiting *Iridomyrmex innocens* and *Camponotus prostans* may be able to compete with arid zone specialists during such periods. It would be necessary to measure physical variables, such as soil and climate, during multiple sampling periods in order to fully investigate the reasons why the ant species of this area are uncharacteristic of other arid zone ant surveys.

Functional group composition in the current study was also slightly different from those found in other unburnt and burnt landscapes. For example, the annually burnt areas of savannah in tropical Northern Territories support a community dominated more by Dominant Dolichoderines, Climate Specialists and Opportunists (Andersen, 1991). While the current study showed an overall increase in Dominant Dolichoderines and Climate Specialists in burnt plots, Opportunist species were in greater abundance in unburnt plots.

The preponderance of *Rhytidoponera* in the burnt plots raises the question whether this functional group needs to be analysed more carefully to determine which species are truly opportunists and which are not.

Across the three vegetation types, there were much higher numbers of Dominant Dolichoderinae in the *Triodia* (TB and TS) plots than the *Acacia* (AW) plots (unburnt and burnt), the reverse being true for the Subordinate Camponotini, which display an increase in the *Acacia* plots. A potential explanation is that Camponotini often seek nectar and honeydew as food sources, while Dolichoderines are more likely to seek out protein sources such as small invertebrates. The *Acacia* trees would have larger resources of nectar and honeydew-producing homopterans compared to the *Triodia* plots, and this may be the reason for the increased presence of these mostly day-foraging *Camponotus* species. The *Triodia* on the other hand may provide refugia for a number of invertebrate prey, often favoured by *Iridomyrmex*. *Iridomyrmex* species also tend to nest in open areas where insolation is high and as spinifex areas are notoriously patchy, these areas are ideal for the large conspicuous nests of this genus.

The distribution of these two functional groups (Dolichoderines and Camponotini) in terms of unburnt and burnt plots also follows the above trends in terms of the percentage of bare ground. However, the burnt areas had increased amounts of herbs and soft grasses, many of which were in bloom at the time of collection, increasing the availability of nectar. The increased nectar availability would also have influenced the populations of other invertebrates, which may have contributed to the high percentages of Dolichoderines in the burnt grasslands. The Camponotini may have moved to the *Acacia* woodlands to reduce competitive interactions with the Dominants as well as with other nectar feeding invertebrates.

Generalised Myrmicinae are not often found in close association with Dominant Dolichoderinae but, in this study, it appears that they are found in almost all burnt sites in high abundance. The *Pheidole* and *Monomorium* species captured are mainly small-to-minute species which are ubiquitous throughout WA and perhaps are able to coexist with the Dolichoderinae by foraging on slightly different food sources (such as small seeds).

The species that allow the unburnt and burnt plots to be most easily differentiated from one another are two members each from DD, GM and OP (see Table 2). This follows through from the functional group analysis, which shows that these groups of ants may be good indicators of the differences between unburnt and burnt sites across vegetation types in the study area. It would be of interest to study the change in community across time, as a number of studies have shown an overall reduction in species richness and a permanent change in ant community structure with proceeding years after fire (York, 1994a; York, 2000).

Andersen and Yen, (1985) brought attention to the sampling bias of pitfall traps that can occur if used after fire. This was further supported by York, (2000), who showed that 22 percent of total ant species collected in his study were detected by litter sampling rather than pitfall trapping. The increased amounts of exposed ground in burnt areas would allow for increased capture of ground foraging ants in these areas as compared to unburnt areas, where the ants are afforded shrubs and twigs as gangways and over passes.

Although pitfall traps have been universally accepted as the method for capturing ground dwelling invertebrates, subsequent studies should incorporate other methods of collection such as litter sampling (Winkler extraction) (Delabie *et al.*, 2000). For example, *Calomyrmex*, a common desert ant, is often found foraging on mid to upper vegetation strata and therefore may not be as readily captured in pitfall traps (Brough, 1976). As the one *Calomyrmex* species captured in this study was collected at only unburnt sites (AW and TB, which had generally taller vegetation), it is possible that other upper strata foraging ants were not collected.

The ant communities present in the *Triodia* unburnt and burnt sites are more similar to each other, perhaps signifying the rapid recovery of grasslands and their ant communities after fire. Burrows *et al.*, (1991) found that the patchiness of fire in spinifex grasslands allows for the persistence of swaths of unburnt grass between burnt areas. This would contribute to the impression that faster plant re-growth occurs in these formations, and it would also provide a bank for rootstock, seed and refuge for invertebrates. These surviving islands would promote faster re-colonisation of burnt areas.

The similarities between the ant communities in the unburnt *Triodia* sites may have also been influenced by the fact that the pitfall traps were positioned near the edges of the unburnt areas. Dangerfield *et al.* (2003) found that a mixture of ant species occurred up to 500 m away from a discrete edge between two distinct ecotones. The position of the traps in the Gibson study would indicate that a fair amount of overlap in unburnt/burnt ant communities would occur as the traps were located about 50 m from the discrete edges. Edge effects have been documented for a number of ecosystems demonstrating that there tends to be a change in communities close to edges as micro-habitats are altered. This may have been a factor influencing the study as the community of ants collected were mostly generalist species found throughout WA.

The vegetation MDS shows that the TS sites were more similar to each other, compared to the TB sites. The greater amounts of herbs and soft grasses in the unburnt TS (compared to the other unburnt sites) would have contributed to making the site appear more similar to its burnt counterpart. The presence of these "burnt" characteristics may have been due to the fact that the TS site was burnt relatively more recently (14 years ago) than the TB site (more than 40 years), and so might explain why the unburnt TS flora were more similar to the burnt TS compared to the two TB sites. The two TS sites were also located closer to each other, than the other vegetation types, which may have had implications for the recovery of the burnt site.

Other regeneration studies suggest that the proximity of areas under recovery to undisturbed sites may enhance re-colonisation by flora and fauna (Jackson and Fox, 1996). It is quite possible that the burnt TS site was able to recover more quickly due to seed crossing over from the unburnt site. *Triodia shinzii* displayed greater regrowth in its burnt plots compared to *T. basedowi* burnt plots. There are few long-term studies that have tracked regeneration after fire in spinifex grasslands.

The *Acacia* sites, on the other hand, are very different to each other. This is true in terms of both ants and vegetation, which perhaps has implications for the management of these *Acacia* woodlands. Allan and Southgate (2002) suggest that, due to *Acacia aneura's* sensitivity to fire, these areas should be excluded from current fire regimes of regular prescribed burns. York, (1994b) mentions that while ant species richness did not change with regular burns, the community structure varied greatly within different burning regimes.

Mulga woodland is often surrounded by, or interspersed with, spinifex. Hence the more fire-resilient spinifex often regenerates quickly after a large, high intensity fire, potentially suffocating any mulga re-growth. There has been an overall reduction in mulga woodlands in the arid areas of Australia due to altered fire patterns and human disturbance, especially of small remnant patches that are prone to spinifex encroachment (Allan and Southgate, 2002). This would have implications for ant fauna that are dependent on woody media for habitat (*e.g. Crematogaster* sp.) or protection from fire (Andrew *et al.*, 2000). The importance of dead wood is highlighted by the correlation between ant species occurrence and presence of dead wood, which was predominantly found in the *Acacia* woodland.

Overall, the ants appear to be responding to the vegetation in terms of differentiating between unburnt and burnt vegetation types, highlighting the fire-sensitivity of *Acacia* woodlands. The research suggests that while spinifex grassland may be resilient, time since fire may play a role in determining plant and ant communities. Further research should be undertaken to study the succession of the ant communities in this area to determine the appropriate fire management strategies to maintain the complex mosaic of these arid adapted ant and plant communities.

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APPENDIX

Ant species that have the greatest contribution to the differentiating between the three vegetation types; **TB**- *Triodia basedowii*; **TS**- *Triodia shinzii*; **AW**- *Acacia* woodland.

Species **Average dissimilarity: 66.17**	**TB average abundance**	**TS average abundance**	**Percentage contribution**	**Cumulative percentage**
Pheidole sp. JDM 536	0.00	0.75	3.61	3.61
Melophorus ludius sulla	0.25	1.00	3.42	7.03
Camponotus prosseri	0.75	2.26	3.42	10.45
Cardiochondyla nuda	0.25	0.50	2.61	13.60
Camponotus gibbonotus	1.00	0.50	2.61	15.67
Pheidole sp. nr. *variabilis*	0.50	0.25	2.56	18.23

Species **Average dissimilarity: 66.52**	**TB average abundance**	**AW average abundance**	**Percentage contribution**	**Cumulative percentage**
Camponotus prosseri	0.75	0.25	2.91	2.91
Iridomyrmex dromus	0.75	0.50	2.78	5.69
Calomyrmex ANIC sp. 1	0.25	0.50	2.78	8.47
Tapinoma sp. JDM 981	0.50	0.25	2.66	11.13
Iridomyrmex agilis	0.50	0.25	2.66	13.79
Iridomyrmex chasei	0.75	0.50	2.66	16.45

Species **Average dissimilarity: 74.32**	**TS average abundance**	**AW average abundance**	**Percentage contribution**	**Cumulative percentage**
Tapinoma sp. JDM 981	1.00	0.25	3.52	3.52
Pheidole sp. JDM 536	0.75	0.00	3.33	6.85
Melophorus ludius sulla	1.00	0.25	3.14	9.99
Iridomyrmex agilis	0.75	0.25	2.93	12.92
Calomyrmex ANIC sp. 1	0.00	0.50	2.70	15.62
Iridomyrmex dromus	0.75	0.50	2.46	18.08

List of plant species that determined the differences between the three vegetation types; **TB**- *Triodia basedowii*; **TS**- *Triodia shinzii*; **AW**- *Acacia* woodland. The plant species were recorded in terms of frequency at each site.

Species **Average dissimilarity: 56.07**	**TB average abundance**	**TS average abundance**	**Percentage contribution**	**Cumulative percentage**
Triodia shinzii	0.25	5.00	6.56	6.56
Keraudrenia integrifolia	0.25	4.00	5.24	11.80
Hibiscus burtonii	0.25	3.75	5.00	16.81
Kennedia prorepens	0.75	4.25	4.97	21.78

Species **Average dissimilarity: 66.58**	**TB average abundance**	**AW average abundance**	**Percentage contribution**	**Cumulative percentage**
Goodenia azurea	3.50	1.00	4.21	4.21
Eremophila forestii	1.25	2.50	4.10	8.31
Stackhousia murieata	2.25	0.00	3.54	11.85
Enneapogon caerulescens	2.50	2.50	3.51	15.37
Dicrastylis tomentosa	3.50	1.50	3.47	18.84
Halgania solanacea	2.50	1.75	3.13	21.96

Species **Average dissimilarity: 69.06**	**TS average abundance**	**AW average abundance**	**Percentage contribution**	**Cumulative percentage**
Triodia shinzii	5.00	0.00	5.17	5.17
Kennedia prorepens	4.25	0.00	4.43	9.60
Keraudrenia integrifolia	4.00	0.00	4.17	13.77
Dicrastylis tomentosa	5.00	1.50	3.97	17.74
Bonamia rosea	3.75	0.00	3.86	21.60

Plant species that determined the differences between the three vegetation types; **TB**- *Triodia basedowii*; **TS**- *Triodia shinzii*; **AW**- *Acacia* woodland. The plant species were recorded in terms of percent cover at each site.

Species **Average dissimilarity: 57.96**	**TB average abundance**	**TS average abundance**	**Percentage contribution**	**Cumulative percentage**
Triodia basedowii	4.00	0.75	9.77	9.77
Triodia shinzii	0.25	3.50	9.10	18.87
Keraudrenia integrifolia	0.25	2.25	5.53	24.40

Species **Average dissimilarity: 65.80**	**TB average abundance**	**AW average abundance**	**Percentage contribution**	**Cumulative percentage**
Triodia basedowii	4.00	3.50	5.14	5.14
Eremophila forestii	0.75	1.75	5.03	10.17
Halgania solanacea	2.00	1.25	4.78	14.95
Indigofera sp.	0.75	1.75	3.96	18.91
Goodenia azurea	1.75	0.50	3.67	22.58

Species **Average dissimilarity: 72.59**	**TS average abundance**	**AW average abundance**	**Percentage contribution**	**Cumulative percentage**
Triodia shinzii	3.50	0.00	7.14	7.14
Triodia basedowii	0.75	3.50	6.24	13.37
Dicrastylis tomentosa	2.75	0.50	4.81	18.19
Kennedia prorepens	2.25	0.00	4.64	22.83

An analysis of some ant communities across Western Australia

INTRODUCTION

Over the past few decades, following the identification of ant communities as robust indicators of environmental change, a variety of studies have documented communities in many regions of the country. To date, studies of ant species in the arid zone have shown them to be speciose and to play important roles in the functioning of this biome (Morton, 1982; Greenslade, 1985; Greenslade and Greenslade, 1989).

One of the main problems with studying ant community ecology has been the lack of behavioural and distributional information on individual species, and even whole genera. This has been improved in recent years with a variety of studies focusing on key genera such as *Iridomyrmex* (Shattuck, 1996), *Camponotus* (Shattuck and Barnett, http://www.ento.csiro.au/science/ants/formicinae/camponotus/ket/c_key_sp_groups.htm), and *Monomorium* (Heterick, 2001). Further work is necessary, as there are still many species that have not been assigned names and others whose geographic ranges are still being defined. Andersen, (http://www.consecol.org/vol1/iss1/art8) comments on the lack of information on ant species distribution at larger spatial dimensions, such as regional and continental scales. The lack of such information is an impediment to the utilisation of ants as bioindicators, as specific species appear to influence biota differently at a range of scales.

Australia's arid zone stretches through the centre of the continent and constitutes a large part of many States (see Figure 1). Western Australia (WA), being the largest state, has a significant proportion lying within this zone. Greenslade and Greenslade, (1989) carried out an analysis of arid and semi-arid invertebrates (mainly ants and collembola) in South Australian and Victorian ecosystems, revealing a variety of trends. The study was only conducted at the generic level in terms of ants, allowing only broad generalizations about the distribution of each genus.

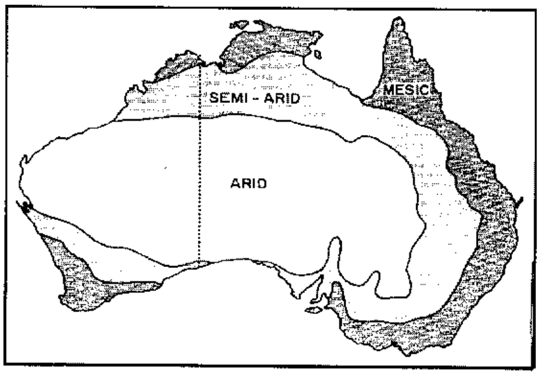

Figure 1 Map of Australia's major geographic zones (modified from Cogger, 1977). The dotted line denotes the State of Western Australia.

While there are a number of well-studied areas within WA in terms of ant species, these are mainly focused around the south-western, mesic zone of the state. A comprehensive key to species will soon be published for the ants of the South West Botanical Province of WA (Brian Heterick, *Ants of the South West Botanical Province*), and will be the first such key for the area. Surveys have been conducted outside of this area in the Kimberley Ranges and the Pilbara in the north (*e.g* Andersen and Majer, 1991) as well as in the south central goldfields and wheatbelt regions (*e.g.* Abensperg-Traun, 1992, Wallis *et al.*, 2001). Unfortunately, while many species have been successfully identified, numerous others are still awaiting species designation. A major problem in comparing these ant species collections across the State is the non-conformity of codes assigned to species awaiting confirmation of taxonomy.

In this chapter, I will compare the ant species from six other ant community studies with those that are reported in this thesis (see Figure 2 and Table1). Although other WA studies are available, these six studies were chosen because they utilised the same species codes (referring to Australian National Insect Collection (ANIC) and Curtin University Ant Collection (JDM) species codes) as the two studies in this thesis, hence providing the uniformity necessary for comparison. Three of the six studies surveyed ants for monitoring the success of restoration at rehabilitated mine sites and included control plots of native vegetation. The other three studies were conducted as part of larger projects that surveyed a variety of aspects of each ecosystem. These studies were compiled to provide a preliminary list of species that occur across WA and to demonstrate the diversity of ant communities that occurs in this significant zone.

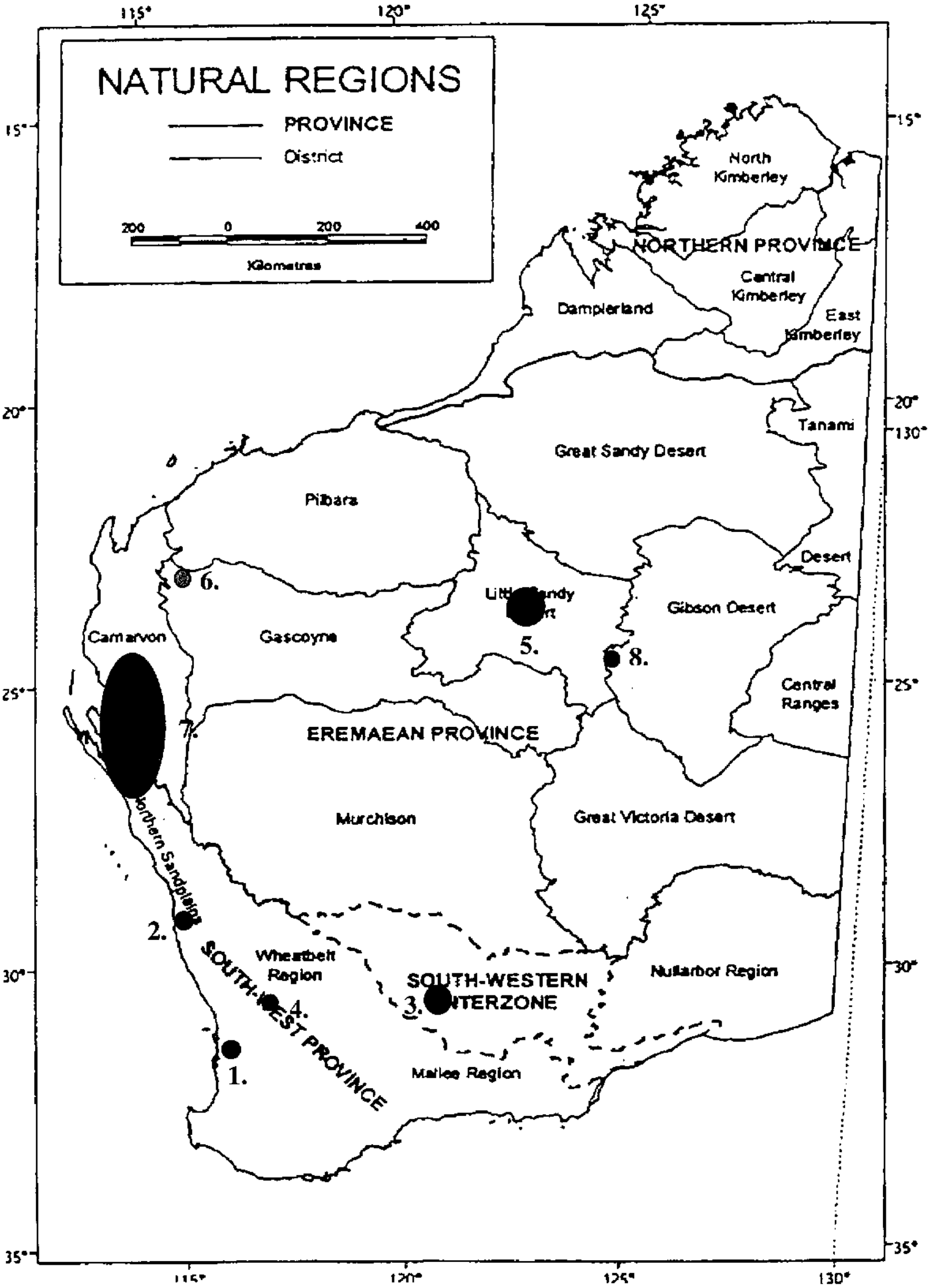

Figure 2 Map of Western Australia, displaying the locations of the eight studies detailed in Table 1 (modified from Beard, 2002). The relative size of the bubbles indicates the relative sampling area covered by each individual study.

Table 1 Summary information regarding the locality and sampling procedures of the eight different studies across WA.

Location in WA (see Figure 1)	**Vegetation type**	**Collection method**	**Duration and time of sampling**	**Intensity of sampling**	**Total no. of species collected**	**Reference**
1. Dwellingup (32°43'S, 116°04'E) and **Jarrahdale** (32°20'S, 116°07'E)	*Eucalyptus* mixed species woodland	Pitfall traps	7-day sample every month 1976-1977 then four times a year till 1989	12 traps per site at 7 sites	63 spp. 24 genera	Majer and Nichols, (1998)
2. Eneabba (29°53' – 29°57'S, 115°15' – 115°18'E)	Kwongan heathland	Pitfall traps, litter and soil sampling (Tullgren funnels), hand collection, sweeping and tree beating	7-day sample in 1980 and April 1997	20 traps per site at 10 sites	96 spp. 30 genera	Bisevac and Majer, (1999)
3. Kambalda (31°13' - 31°12'S, 121°38' – 121°40'E)	Kwongan heathland	Pitfall traps and hand collection	7-day sample in December 1992, February and July 1993	10 traps per site at 15 sites	93 spp. 24 genera	Wallis *et al.*, (2001)
4. Wheatbelt (~31°25'S, 117°26'E)	Gimlet (*Eucalyptus salubris*) woodland and shrubland	Pitfall traps and hand collection	7-day samples from 1991 - 1994	16 traps per site at 56 sites	141 spp. 39 genera	Abensperg-Traun *et al.*, (1997)
5. Little Sandy Desert (24°25'S, 120°20'E)	*Acacia* woodland and hummock grassland	Pitfall traps	Traps open for 22 months, from 1995-1997 cleared 4 times	3 traps per site at 30 sites	152 spp. 32 genera	Stephen van Leeuwen CALM
6. Barlee Range Nature Reserve (23°09'S, 115°53'E)	*Acacia* woodland and hummock grassland	Pitfall traps	4-day samples on 3 occasions, from 1993-1995	12 traps per site at 12 sites	53 spp. 15 genera	Stephen van Leeuwen CALM

Table 1 (cont.)

7. Southern Carnarvon Basin (23°00'S – 28°30'S, 112°30'E – 115°30'E)	Hummock and tussock grassland, samphire bushland, *Acacia* woodland, and *Eucalyptus* mixed species woodland	Dry and wet pitfall traps	Traps open for 1 year from 1994 to1995 and cleared 4 times	5 traps per site at 61 sites	243 spp. in 35 genera	This paper
8. Gibson Desert Nature Reserve (24°42' – 24°45'S, 124°46' – 124°48'E)	*Acacia* woodland and hummock grassland	Pitfall traps	5-day sample in August 2002	10 traps per site at 12 sites	71 spp in 19 genera	This paper

COMPARISON OF COMMUNITIES

The eight studies span very different areas within WA (see Figure 2), and each study varied greatly in scope. Some covered 14 years of sampling while others were conducted over one season. Pitfall traps of different sizes were used in each study, and studies included other methods such as litter sampling and opportunistic collection. The details of each study are displayed in see Table 1.

Although these are considerations, the ant species collected still generated a list of 463 species that are present across this area. The data for each study were then entered into a similarity matrix where each survey's ant community was compared to every other survey. This was generated using the statistical package PRIMER v5 using presence/absence of each species across each study (Clarke and Gorley, 2001). The data were then displayed using a complete linkage dendrogram, which linked the most similar sites together in terms of ant community composition (see Figure 3).

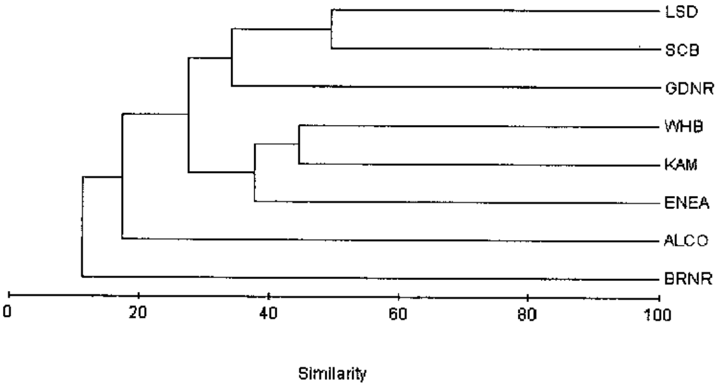

Figure 3 Dendrogram displaying the similarity of ant species communities; **LSD**- Little Sandy Desert, **SCB**- Southern Carnarvon Basin, **GDNR**- Gibson Desert Nature Reserve, **WHB**- wheatbelt, **KAM**- Kambalda, **ENEA**- Eneabba, **ALCO**- Dwellingup and Jarrahdale, **BRNR**- Barlee Range Nature Reserve

The linkage shows 4 groupings of the three arid sites (LSD, SCB and GDNR), the three southern sites (WHB, KAM and ENEA), the southern forest site (ALCO) and the northern arid site BRNR. At a higher similarity cut-off, ENEA and GDNR separate out from their respective groups.

DISCUSSION

Sampling intensity

The studies displayed in Table 1 demonstrate how trapping intensity (number of traps and sites) can make a large difference to the number of species collected. The Southern Carnarvon Basin (SCB) study yielded the greatest number of species (91 species more than the next most speciose study). It was also the most wide-ranging study including a major crossover zone between the arid Eremaean Province and the wetter South-west Province. This is followed closely by the Little Sandy Desert (LSD) collection, which was conducted over a smaller area but over a longer period of time.

The arid zone Gibson Desert (GDNR) collection falls out of the dendrogram branch that places the SCB and the LSD together. This may be a result of the low sampling intensity of the study and the shortness of the collection period. Taking into account these facts, the species collected in GDNR nevertheless did not contain many arid zone specialists. Perhaps the low species richness is a reflection of the homogeneity of the GDNR study area as compared to the two larger studies. This is perhaps the reason for its placement closer to the more mesic collections in the lower part of the dendrogram.

The Wheatbelt (WHB) collection had the highest number of species and genera of the four southern surveys. This is perhaps due to the time frame (4 years) over which the study occurred. The two studies in heathland or shrubland, Eneabba (ENEA) and Kambalda (KAM), yielded a relatively low number of species in relation to the arid surveys, but the genus numbers are very comparable. The outliers in this case are ALCO, the southern forest sites at Dwellingup and Jarrahdale and BRNR, the northern arid zone site. The ant species numbers are low for both these studies. The ALCO study was a long-term project, but once again the low sampling intensity and vegetation changes may have had an effect on the variety of ants inhabiting the area.

The Barlee Range collection was unique compared to all other studies. Many of the ant species in this collection were widespread generalists, as was the case for the collection from the Gibson Desert. The BRNR is a long unburnt pristine area that has never been exposed to grazing with the closest townships about 180km from the Reserve. A potential explanation for the low species richness in this undisturbed area, apart from shortness of trapping duration, is the drought conditions that the area had been experiencing during the sampling period (Stephen van Leeuwen, pers. comm.). The fact that this collection was so dissimilar to the other arid zone collections strengthens the need for more research to be carried out in the northern portion of the arid zone.

Species diversity

A comparison of the ratio of species to genera in each study also differentiated the southern sites from the arid sites to a fair degree. The ratio of species to genus at LSD and SCB were 1.3 to 2 times higher than the southern sites. The exceptions were GDNR and BRNR, which had a similar ratio to the southern sites. This means that the arid fauna in these areas are more speciose than the south-west fauna, which is in keeping with other arid and semi-arid studies in Australia (Andersen, 1993). The GDNR and the BRNR surveys pose many questions, as they are the northernmost sites within this study and yet their fauna do not conform with the other arid zone surveys nor with eachother.

The Kambalda survey had the highest species to genus ratio among the southern sites. This is most likely explained by its location in the South-western Interzone (see Figure 2), The transitional nature of this region could support the incursion of more arid zone characteristics into this southern area. It is of interest that the KAM fauna is more similar to the WHB fauna. KAM and ENEA share the same vegetation type. It is possible that the differences between inland and coastal climatic variables, such as increased precipitation along the coast, are contributing to the separation of these two Kwongan heathland sites.

The ratio of "core species" (*Iridomyrmex, Camponotus* and *Melophorus* species) to all other species is a commonly used analysis, as the species from these genera are often found to influence the presence of other species (Greenslade and Greenslade, 1989; Andersen, 1995). In this case, the ratios do not appear to follow any particular trend between the southern sites and the arid sites; GDNR and BRNR fauna stand out in that 51% and 43% respectively of their ant fauna is comprised of species from this core group.

The comparison of these studies distributed across the southern half of the State has shown that the ant communities are highly diverse and can be classified into the broad geographical regions in the same manner as vegetation. Considerations have to be made, with regard to sampling intensity when comparing surveys, although even small studies, such as the GDNR and BRNR studies, contribute to an overall awareness of the ant species that occur in an area.

Further long-term research would be necessary to fully understand why these areas in the arid interior have ant communities not dissimilar to those found in southern forest sites. As this region has been so little studied, the findings for the GDNR and the BRNR study reinforces the fact that assumptions cannot be made about ant species and their distribution across the arid zone. Greater importance is placed upon the need for individual species groups to be studied and their geographic ranges plotted. Without an understanding of the biology of these species, it is difficult to explain their presence in any particular area.

Species taxonomy for Australia continues to improve and evolve but, until species names are established, future research in WA should attempt to utilise the same species codes so that comparisons of ant fauna can still be made. As the species diversity of these important members of the ecosystem is continually studied, a greater appreciation will be placed upon all invertebrates and their roles in the maintenance of biodiversity in terrestrial environments.

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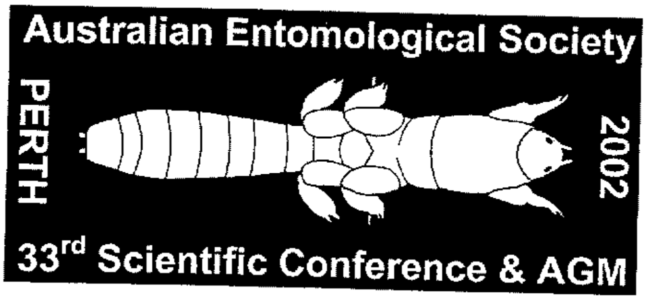
APPENDIX

AUSTRALIAN ENTOMOLOGICAL SOCIETY

33rd AGM & Scientific Conference

PROGRAM & ABSTRACTS



Esplanade Hotel
Fremantle, WA
22-27 September, 2002

ANTS SPECIES ASSOCIATIONS IN BANKSIA WOODLANDS OF WESTERN AUSTRALIA; AN INVESTIGATION INTO ANT SPECIES COEXISTENCE

Nihara Gunawardene

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Australia is well known for its abundance of ant species. As a result of this wealth of species, it is of interest to see how these different species interact with each other within particular areas. Studies of ant ecology in Australia and other countries, have found that partitioning of space and time has enabled large numbers of ant species to coexist. This study attempts to determine whether species composition is based upon seasonal partitioning of activity, diurnal activity partitioning, or food preference.

Research was conducted at Jandakot Regional Park in Western Australia. Results yielded 44 species present in an area of roughly 200m by 400m. The total number of species collected in winter was 22, but only five species had abundances greater than 10 individuals. The summer collection yielded 34 species, of which 11 were considered abundant. Most of the abundant winter species were not abundant in summer, prompting the possibility of some climate specialisation for these species.

The ant species *Iridomyrmex conifer* appeared to be the most abundant species in both winter and in summer. It was positively correlated with a number of other species in summer, but not in winter. This was most likely due to decreased numbers of ants in winter, and the absence of direct competitor species.

An ordination of the more common ant species from both seasons, in terms of structure and habitat requirements, showed that there was a general separation of niches in terms of ant size and food preference. Most of the large carnivorous ants had separate niches from the generalised opportunists that were ubiquitous throughout the site.

Overall, partitioning of space and time appeared to be determined by temperature adaptation (to season and diurnal fluctuations), and food preference (which is related to body size and mandible type), rather than direct competition from other species. Further studies would be useful in order to acquire information on the ant species that were not abundant in order to investigate whether their comparatively low abundances are related to competitive interactions with the more abundant ants.

ANT SPECIES ASSOCIATIONS IN *BANKSIA* WOODLANDS OF WESTERN AUSTRALIA: AN INVESTIGATION IN TO COEXISTENCE

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Abstract

Australia is well known for its abundance of ant species. As a result of this diversity, it is of interest to see how these different species interact with each other within particular areas. Studies of ant ecology in Australia and other countries, have found that partitioning of space and time has enabled large numbers of ant species to coexist. This study attempts to determine whether species composition is based upon seasonal partitioning of activity, diurnal activity partitioning, or food preference.Research was conducted at Jandakot Regional Park in Western Australia. Results yielded 44 species present in an area of roughly 200m by 400m. The total number of species collected in winter was 22, but only five species had abundances greater than 10 individuals. The summer collection yielded 34 species, of which 11 were considered abundant. The species considered abundant in winter did not coincide with those in summer, prompting the possibility of some climate specialisation for these species. The ant species *Iridomyrmex conifer* appeared to be the most prolific species in both winter and in summer. It was positively correlated with a number of other species in summer, but not in winter. This was most likely due to decreased numbers of ants in winter, andthe absence of direct competitor species.An ordination of the more common ant species from both seasons, in terms of structure and habitat requirements, showed that there was a general separation of niches in terms of ant size and food preference. Most ofthe large carnivorous ants had separate niches from the generalised opportunists that were ubiquitous throughout the site. Overall, partitioning of space and time appeared to be determined by temperature adaptation (to season and diurnal fluctuations), and food preference (which is related to body size and mandible type), rather than direct competition from other species. Further studies would be useful in order to acquire information on the ant species that were not abundant in order to investigate whether their comparatively low abundances are due to competitive interactions with the more abundant ants.

Introduction

The ways in which ant species co-exist are numerous, and are usually founded on the principle of resource availability. If an ant species can establish a colony in the area, its success will depend on the resources available to it. These resources will change according to vegetation, season, and the presence or absence of competing species. In areas where ant diversity is low, ants are less constrained by competition with other species, and can concentrate on optimising foraging schedules. In areas where species diversity is high, ants can reduce competitive interactions by changing their foraging spatially or temporally, or by switching to other food sources. This study was aimed at identifying ant species inhabiting *Banksia* woodland and inferring some aspects of their species associations to glean a better understanding of why they are able to coexist.

Section 6 of the Jandakot Regional Reserve is an enclosed section of relatively undisturbed *Banksia* woodland surrounded by pastureland. Transect 1 and 2 were placed 100m apart and run parallel to each other through fairly homogenous vegetation.

Methodology

Sampling was carried out using two methods, pitfall trapping and food baiting. An area (200m x 400m) within the Jandakot Regional Reserve was sampled along two parallel 150m transects. The section of the Regional Park is located on the outskirts of the Perth metropolitan area.

- **Seasonality**

Sixty pitfall traps were deployed for three days in winter (August) and three days in summer (January).

- **Diurnal Activity**

Traps were set out again in the same positions during summer for five 5 hour intervals over a 25 hour period (Time period A: 1030h-1530h; Time period B: 1530h- 2030h; Time period C: 2030h-0130h; Time period D: 0130h- 0630h; Time period E: 0630h- 1130h).

- **Food preference**

Three food types, (a. canned tuna, b. honey, and c. cracked wheat) were equidistantly placed around every alternate trap along the two transects, and the ants attending each bait were hand collected over a two hour period during mid morning in summer.

- **Physical characteristics**

Ten individuals from each species were measured for body length and categorised by mandible type.

- **Vegetation cover**

Six vegetation variables were measured in a 1 metre quadrat around each pitfall trap. These variables were % tree cover, % shrub cover, % grass cover, % litter cover, % bare ground, and litter depth (mm). Vegetation was sampled in both winter and summer seasons.

Results

Altogether, 44 species of ants were recorded for the site; 22 in winter and 36 in summer, with an overlap of only 14 species across seasons. There were two species that were solely caught in the 5 hour trapping sessions and two species that were hand collected from the food trials that had not been caught in the pitfall traps.

Iridomyrmex conifer was the most abundant species in winter and in summer, although its distribution across the site was considerably limited in summer (see Figures 1 and 2). Out of the winter sample, only five species of ants had more than 10 individuals trapped, whereas summer had 11 ants that were considered to be abundant (>10 individuals).

Diurnal activity sampling showed that the early evening (1530h – 2030h) revealed the highest number of ant species (14 out of 27) whereas the hottest part of the day (1030h – 1530) yielded the lowest number of ant species (6 out of 27). *Melophorus insularis*, although, was one species that was collected only during he hottest part of the day (See Figure 2). There were only two species of ants that were present throughout the diurnal sampling period, namely *Monomorium sydneyense* and *Rhytidoponera inornata* (see Figure 3).

The food trials demonstrated that most of the ant species were omnivorous. Only four species of the 13 species collected were found feeding solely on the tuna. This coincides with the body length and mandible type measurements, which showed that most of the species of ants collected were medium sized (2.1mm–6.0mm), generalist (triangular mandibles) feeders.

Niche analysis carried out on the 28 species, which were represented in the majority of the measurement variables, showed that size and feeding preference largely influenced their placement in the ordination diagram (see Figure 4).

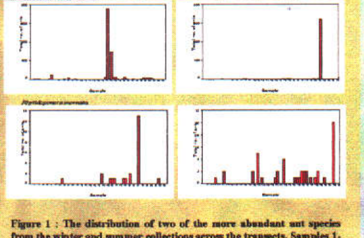

Figure 1 : The distribution of two of the more abundant ant species from the winter and summer collections across the transects. Samples 1-30 correspond to Transect 1, and sample 31-60 to Transect 2. Note that the vertical axes for each species is different

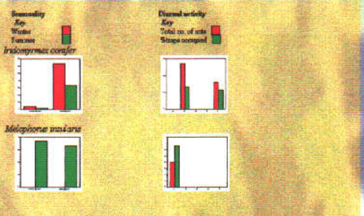

Figure 2: Graphs showing the seasonal activity and diurnal activity of two abundant species. I. *conifer* is active in both summer and winter, whereas *Melophorus insularis* was found only in the summer. This seasonal preference is also reflected in the diurnal activity, as *M. insularis* appears to prefer only the hottest part of the day.

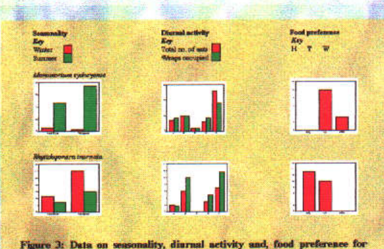

Figure 3: Data on seasonality, diurnal activity and, food preference for selected species sampled along the two transects.

Seasonality graphs show the percentage traps occupied by each species and the total number of ants collected during the winter and summer 3-day collection periods. Diurnal Activity graphs show the total number of ants per species and the percentage traps occupied throughout the site during the five 5-hour collection periods (A: 1030h-1530h, B:1530h-2030h, C:2030h-0130h, D: 0130h-0630h, E: 0630h-1130h).Food preference graphs display the attendance of species at three food baits: Honey (H); Tuna (T); and Wheat (W).

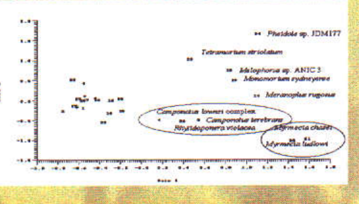

Figure 4: Ordination of the most common ant species for which sufficient ecological data were available to show their proximity to each other in terms of niche relationships.

Discussion

Increased food availability and warmer temperatures in summer can account for the increased number of ant species during this period. This can be supported by the distribution of *I. conifer*, which was more widespread in winter and very limited in summer. This could be a function of increased food supply in closer vicinity to the nest which may reduce the need to forage widely, or increased competition from other species which may reduce the foraging capabilities of the species. A combination of seasonality (and consequently food availability) and diurnal activity appear to influence the presence or absence of the ant species described, as well as to determine whether certain species can coexist together in a certain area. As there were a number of species that were in too low a density to be statistically analysed, future research projects would most likely benefit from a more intensive and longer-term study.