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The effects of pitfall trap diameter on ant species richness (Hymenoptera: Formicidae) and species composition of the catch in a semi-arid eucalypt woodland

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Abstract Ants play an important role in Australian biodiversity and environmental impact assessments, with pitfall-trapping being the principal sampling method. However, the relationship between trap diameter and ant species catch has not been investigated in the context of survey design. Using four different trap diameters, each at a density of one trap per 100 m^2, the present study asks three questions: (i) given an equal number of traps, do traps with larger diameters catch more species than smaller-diameter traps?; (ii) do traps with small diameters bias against large or rare species?; (iii) for equal area of the trap mouth, do small but more numerous traps catch more species than fewer but large traps? A total of 84 species were sampled within the 1600 m^2 study site, with numbers of species for trap diameters of: 18 mm (46 species), 42 mm (56 species), 86 mm (62 species) and 135 mm (64 species). At equal trap density, 18 mm traps caught significantly fewer species than larger traps. Traps of 86 mm and 135 mm were no more efficient than 42 mm traps. Only 86 mm and 135 mm traps caught all species > 10 mm in length (6 species). For equal area of the trap mouth, small traps were more efficient than large traps. Differences in the catch of the different-sized traps were due primarily to different capture rates of the rare species (40 species): 18 mm traps caught 25% of rare species, 42 mm caught 41%, 86 mm caught 44% and 135 mm caught 52%. The role of rare ant species in environmental impact studies is discussed.

Key words: ants, body size, pitfall traps, rare species, sampling effort, species richness, trap area, trap diameter.

INTRODUCTION

Considerable efforts are currently being aimed at measuring global biodiversity, as well as at monitoring biodiversity in response to environmental change, particularly the highly diverse terrestrial arthropods (Noss 1990; Kremen *et al.* 1993). Among Australia's terrestrial arthropods, ants are used most commonly as indicators of ecosystem change (Majer 1983; Greenslade & Greenslade 1984; Andersen 1990). One of the principal methods of measuring ant community parameters is pitfall-trapping (Greenslade 1973; Majer 1978; Andersen 1991; Lobry de Bruyn 1993), often in combination with hand-collections or, less frequently, with baits or quadrats (e.g. Andersen 1983; Majer *et al.* 1984; Greenslade 1985). Factors that influence the efficiency of trapping a representative sample of the ant fauna have been reviewed by Adis (1979) and Luff (1975). One important factor is trap diameter.

For Australia, many different trap diameters have been used to sample ants, ranging from 18 mm test-tubes to 220 mm containers (Greenslade & Greenslade 1971; Yeatman & Greenslade 1977; Fox & Fox 1982; Rossbach & Majer 1983; Majer 1985; Abensperg-Traun 1988; Andersen 1991; Arnold *et al.* 1993; Lobry de Bruyn 1993; Scougall *et al.* 1993). Traps of 18 mm and 42 mm diameter appear to be used most frequently. Although selection of trap diameter is often influenced by whether arthropods other than ants also need to be sampled (e.g. Arnold *et al.* 1993), the relationship between trap diameter and ant species catch in the context of survey design is not well known (Yen 1993). Only Greenslade and Greenslade (1971) measured the effects of trap diameter on ant catch, but compared ant abundance only, while Andersen (1991) compared pitfall catches with quadrat counts. The present study, conducted in a gimlet *Eucal-*

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yptus salubris woodland in a semi-arid part of the Western Australian wheatbelt, asks three questions: (i) given an equal number of pitfall-traps, do traps with larger diameters catch more species than small-diameter traps?; (ii) do traps with small diameters bias against large or rare species?; and (iii) for equal area of the trap mouth, do small but more numerous traps catch more species than fewer but larger traps?

METHODS

Study area and study site

The physical and biological characteristics of the study area in the central wheatbelt of Western Australia, approximately 200 km east of Perth, are fully described by Saunders *et al.* (1993). In brief, the study area lies within a wheat- and sheep-farming district with a Mediterranean-type climate, with mild wet winters and hot dry summers. Average annual precipitation is approximately 330 mm (Beard 1980).

The 1600 m^2 study site (40 × 40 m) was situated within the 174 ha North Baandee Nature Reserve (117°56′E, 31°22′S). It consisted of a pure stand of mature gimlet *E. salubris* woodland on a duplex soil with an understorey of predominantly *Acacia* species and abundant leaf and woody litter (soil litter cover ~40%), interspersed with sizable areas of bare ground known to favour ant foraging (Andersen 1983). Site location was chosen to optimize spatial homogeneity of plant and litter cover within the site. The reserve has no known history of livestock-grazing, is thus relatively undisturbed and supports a diverse ant fauna (Arnold *et al.* 1993).

Experimental design and sampling methods

Four circular trap sizes were used, with internal diameters (at the mouth) of 18 mm (Pyrex glass test-tubes), 42 mm, 86 mm and 135 mm (plastic) traps; all are referred to as 'traps' hereafter. With the exception of the largest trap diameter, all other trap diameters have been used in previous Australian ant studies. Sixteen replicates of each trap diameter (16 × 4 = 64 traps) were installed on eight gridlines, with 5 m intervals between gridlines and traps, giving a trap-density of one trap per 100 m^2 for each trap diameter. The positions of the different-sized traps on the gridlines were randomly assigned to the whole study site. Traps were sunk into the soil early in January 1994, their openings flush with the soil surface, and left closed for seven consecutive days to avoid digging-in effects (Greenslade 1973). Traps were filled with propylene glycol, which is not known to significantly attract or repel ants (Adis 1979), and opened for seven consecutive days in mid-summer (January) when activity of surface-foraging ants in the study area is at its annual peak (Abensperg-Traun 1992). Ambient temperatures in the shade during the sampling period ranged from approximately 15°C to about 40°C. While restriction of sampling to mid-summer is likely to underestimate total species richness of surface-foraging ants for the site, the high site richness and its coincidence with annual peak activity of the ants provides adequate data to examine differences of the catch due to trap diameter. Also, a previous study of ants in 29 gimlet *E. salubris* sites of the study area, sampled both in summer and winter, indicated that winter sampling only added a total of five ant species across all sites, and all of these were rare (Arnold *et al.* 1993). Voucher specimens of ants trapped are held at CSIRO, Division of Wildlife and Ecology, Perth, Western Australia.

Data analysis

Species richness was calculated by identifying all specimens to 'morphotype' and then to species level using the authors' reference collection for the study area (Arnold *et al.* 1993). For polymorphic species of *Melophorus* and *Camponotus*, effective separation of species in the laboratory is often difficult, and sometimes impossible. At completion of pitfall-trapping, we therefore excavated colonies of such species within the study site and collected the range of morphotypes for matching with the pitfall catch. Ants were placed into size-classes (total body length in mm) and numbers of species calculated for <5 mm, 5–10 mm and >10 mm ants. For species with a range of worker sizes, the species was categorized on the basis of the size of its most abundant workers in the traps. Species classified as 'rare' used the classification of Arnold *et al.* (1993) on the ants of gimlet woodlands in the study area (29 study sites); it defined rare species as having occurred in $<10\%$ of these 29 sites, and with a total abundance of <5 workers in sites where the species did occur. Differences in ant species richness across the four trap diameters were analysed using one-way analysis of variance. Scheffe's F-test was used for multiple pairwise comparisons of these ant variables across the trap diameters. All data were transformed prior to analysis using methods that best normalized the data: square-root (numbers of species) and $\log(x)$ (percentages).

To test whether, for equal area of the trap mouth (henceforth referred to as trap-area), small but more numerous traps catch more species than fewer but large traps, the following calculations were made. Trap-area was calculated as radius^2 × 3.14 (pi), giving 254 mm^2 (18 mm), 1385 mm^2 (42 mm), 5806 mm^2 (86 mm) and 14 307 mm^2 (135 mm). If, for instance, a set of 18 mm traps was as efficient as 42 mm traps at catching ant species, given equal trap-area and a homogeneous distribution of ant species, then a randomly chosen set of five traps (numbers of required traps were rounded-off to the nearest whole number) of 18 mm diameter should, on average, catch a similar number of ant species as a single 42 mm trap. Due to the constraint of trap replicates, four tests only were possible: 18 mm *vs* 42 mm, 42 mm *vs* 86 mm, 42 mm *vs* 135 mm and 86 mm *vs* 135 mm traps (a comparison between 18 mm and 86 mm traps would require 23 test-tubes, 5806/254 = 23, and 56 test-tubes would be needed for a comparison between 18 mm and 135 mm traps). For each of the pairs, 10 values (total numbers of species) were calculated, selecting traps at random using a random numbers table, giving mean numbers of species (± SD) for each of the paired comparisons.

RESULTS

Effects of trap diameter on total ant species richness of the catch

A total of 84 species was caught within the study site. At equal trap densities, traps with large diameters caught more species than smaller traps (Fig. 1), with totals of: 46 species for 18 mm traps, 56 species for 42 mm traps, 62 species for 86 mm traps and 64 species for 135 mm traps (Table 1). One-way ANOVA showed significant differences between means ($F = 20.37$, d.f. 3, 63, $P < 0.001$), and multiple comparisons using Scheffe's F-test ($\alpha = 0.05$) indicated that 18 mm traps caught significantly fewer species than all other trap sizes. Scheffe's test did not detect differences in numbers of species caught by the three larger trap diameters.

Figure 2 gives species accumulation curves against cumulative numbers of traps. The curves indicate a similar trend for all trap sizes and suggest that trap diameter is the controlling factor for any given number of traps.

Effects of trap diameter on ant species composition

Members of certain dolichoderine and formicine genera, particularly the species-rich *Iridomyrmex*, *Camponotus* and *Stigmacros* and, to a lesser extent *Monomorium*, showed the most marked increase in species richness with trap diameter (Table 1).

When species were classified by size, distribution for all species was: <5 mm, 46 species; 5–10 mm, 32 species; and >10 mm, 6 species. At equal trap densities, traps with large diameters caught more species in the <5 mm and 5–10 mm size categories; one-way ANOVA showed a significant difference between means (Table 2). Large traps did not catch significantly more large species (>10 mm) than small traps (Table 2). However, only 86 mm and 135 mm traps caught all of the largest species (of the genera *Myrmecia*, *Bothroponera*, *Rhytidoponera* and *Camponotus*).

Forty species, or 48% of the total catch, were rare. At equal trap densities, the efficiency of trapping rare species

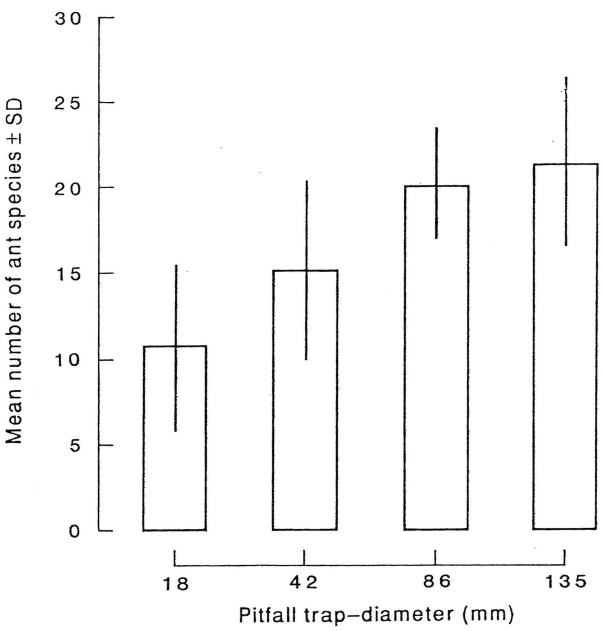

Fig. 1. Mean number of ant species (± SD) for pitfall traps with different internal diameters but at equal trap density (1 trap/100 m²for each trap diameter).

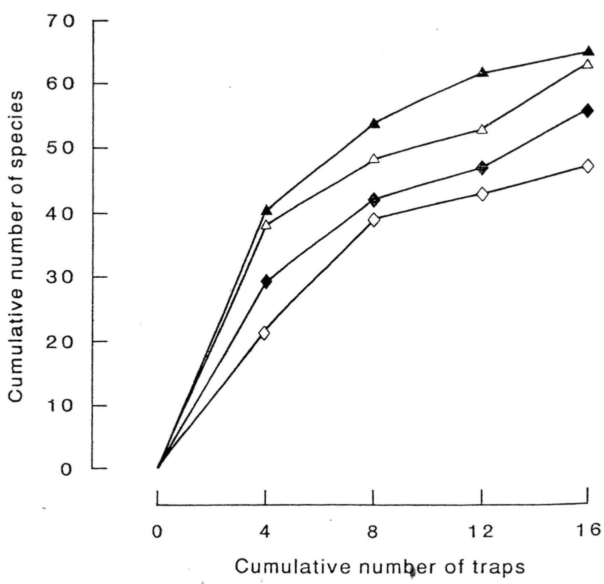

Fig. 2. Ant species accumulation curves for cumulative numbers of pitfall-traps across the four trap diameters: 18 mm (◇); 42 mm (◆); 86 mm (△) and 135 mm (▲).

Table 1. Total ant species richness (number of species) and species richness of ant genera for traps with different internal diameters

Ant taxon	No. ant species for pitfall-trap diameters 18 mm	42 mm	86 mm	135 mm
All ants (84)	46	56	62	64
Myrmeciinae				
Myrmecia (2)	—	—	2	2
Ponerinae				
Anochetus (1)	1	1	1	—
Bothroponera (1)	1	—	—	—
Cerapachys (2)	—	1	—	1
Odontomachus (1)	—	1	1	1
Rhytidoponera (4)	4	3	4	3
Sub-total Ponerinae	6	6	6	5
Myrmicinae				
Crematogaster (4)	2	3	4	3
Meranoplus (7)	3	5	3	5
Monomorium (13)	9	10	8	11
Pheidole (1)	1	1	1	1
Podomyrma (1)	—	—	1	1
Tetramorium (2)	1	1	2	1
Sub-total Myrmicinae	16	20	19	22
Dolichoderinae				
Dolichoderus (1)	1	—	—	—
Iridomyrmex (7)	3	5	5	6
Tapinoma (1)	1	1	1	1
Sub-total Dolichoderinae	5	6	6	7
Formicinae				
Acropyga (1)	1	—	—	—
Camponotus (12)	6	9	11	10
Melophorus (14)	9	9	11	11
Opisthopsis (1)	—	1	1	1
Stigmacros (8)	3	5	6	6
Sub-total Formicinae	19	24	29	28

Total site richness appears in parentheses.

Table 2. Relative differences in numbers of different-sized ant species in traps with different internal diameters (mean ± SD)

Ant size category	No. ant species for pitfall-trap diameters 18 mm	42 mm	86 mm	135 mm	F-value	P
<5 mm (46 spp.)	8.81 ± 2.78	11.00 ± 3.03	13.14 ± 2.28	13.56 ± 3.07	9.12	*
5–10 mm (32 spp.)	3.06 ± 1.56	5.35 ± 1.94	7.07 ± 1.81	8.12 ± 2.06	23.52	*
>10 mm (6 spp.)	1.18 ± 0.54	1.25 ± 0.44	1.87 ± 0.88	1.68 ± 0.60	1.41	NS

Site totals for numbers of species are given in parentheses; NS, not statistically significant at $P<0.05$; *$P<0.001$. Significance tests were performed on transformed values.

was a function of trap diameter: 18 mm traps caught 25% of rare species, 42 mm caught 41%, 86 mm caught 44% and 135 mm caught 52%. The size profile of these rare species was: <3 mm, 44% of species; 3–5 mm, 22%; 5–10 mm, 25%; and >10 mm, 9%.

Sampling efficiency after compensation for trap-area

For equal trap-area, smaller but more numerous traps caught significantly more ant species than fewer but large traps (from 1.4 to 2.1 times more species; Table 3).

Table 3. Numbers of ant species (±SD) for pairs of trap diameters with the smaller traps of the pairs adjusted to approximately equal the surface area at the mouth of one larger trap (see Methods)

Paired comparisons	No ant species Small traps	Large traps
18 mm (5) *vs* 42 mm	29.50±2.50	16.80±4.31
42 mm (4) *vs* 86 mm	35.70±3.30	20.40±2.63
42 mm (10) *vs* 135 mm	46.80±2.65	21.90±2.46
86 mm (2) *vs* 135 mm	30.20±3.29	21.90±2.46

Numbers of required (smaller) traps for comparison with single larger traps in parentheses.

DISCUSSION

At a pitfall-trap density of one trap per 100 m^2, traps of 18 mm diameter, operational for one week, were less efficient at catching a representative sample of the ant fauna than larger traps. Traps of 86 mm and 135 mm diameter were no more efficient than 42 mm traps. However, given comparable trap-area, smaller but more numerous traps are more efficient than fewer, larger traps. This undoubtedly reflects the patchy distribution of the nests of ant species, and hence the foraging activity of their workers (Briese & Macauley 1977; Romero & Jaffe 1989). Using numerous small traps in preference to fewer large traps will achieve the dual purpose of high capture efficiency of rare species, and reduction of soil disturbance (and hence sample bias) associated with the establishment of large traps (Greenslade 1973; Majer 1978).

Luff (1975) demonstrated that beetles more effectively escaped from glass than plastic traps. The comparison of Pyrex (glass) test-tubes with plastic traps in the present study may thus have introduced a potential confounding factor into the experimental design. However, Luff (1975) used dry traps, contrasting with our study where escape from traps containing preserving fluid is unlikely to have significantly affected the results.

The trappability of any one species depends on several factors, the most important being population density, nest distribution, foraging strategy and body size. For instance, Greenslade (1973) and Andersen (1983) linked the rapid locomotory behaviour of many diurnal species, such as *Iridomyrmex* and *Melophorus* to proneness to capture by pitfall-traps. Conversely, larger diurnal species, such as the bull ants *Myrmecia*, tend to forage at much slower speeds and may not be trapped with comparable efficiency. Large ants also tend to have relatively small colonies, further reducing capture frequency. Trap diameter was a factor in the catch of large species because only the two largest trap diameters caught all large species. Not surprisingly, the largest species trapped, the bull ant, *Myrmecia* sp. 1 (length ~20 mm), was not sampled by 18 mm traps. Hand-collections, however, would easily account for such large species.

The optimal relationship between trap diameter and trap density is likely to be a compromise between capture efficiency, logistics and the use of complementary sampling methods. Few studies sample ants by supplementing pitfall catches with quadrat counts, baits or, much rarer still, leaf-litter extractions as in Burbidge *et al.* (1992). Most studies collect additional data via hand-collections only. However, the efficiency of hand-collections to account for rare ants, most of which are very small, cryptic species of the litter layer (Greenslade 1979; Greenslade & Thompson 1981), is poorly understood and needs to be tested. This uncertainty applies especially where trap density is low (e.g. Majer 1985) and is enhanced by the fact that the efficiency of hand-collecting very much depends on good vision and the willingness of the sampler to rigorously sample across the major ant-foraging substrates (e.g. bare ground, leaf litter etc.) and foraging periods (e.g. diurnal, crepuscular, nocturnal).

Ultimately, ant community studies have as one of their major aims a better understanding of the animals under investigation, which should include the rare species. Yet rare species are seldom addressed and are usually excluded from quantitative analyses and interpretation (e.g. Burbidge *et al.* 1992; Arnold *et al.* 1993). Their exclusion is generally justified given the limited aims of most studies. For environmental impact studies, however, it may well be that it is the rare, rather than the relatively common, ant species that are the more sensitive indicators of ecosystem change. Based on our data for the central wheatbelt of Western Australia, rare species, defined in terms of distribution and abundance, represent 40–50% of the total ant species pool, and significantly more if the criteria of Arnold *et al.* (1993) for rarity are only marginally broadened. Similar ant species frequency/abundance profiles were reported, among many others, by Rossbach and Majer (1983) for Mediterranean Western Australia, by Andersen (1993) for tropical northwest Queensland and by York (in press) for temperate eastern Australia. Given the important role of ants in environmental impact studies in Australia (Majer 1983; Greenslade & Greenslade 1984; Andersen 1990; Burbidge *et al.* 1992), we believe that the rare ant species deserve more attention than they have been given to date, especially in experimental design (capture efficiency) and analysis, despite the inherent analytical difficulties associated with small sample sizes.

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