A Comparison of Pitfall Traps with Bait Traps for Studying Leaf Litter Ant Communities

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ABSTRACT A comparison of pitfall traps with bait traps for sampling leaf litter ants was studied in oak-dominated mixed forests during 1995–1997. A total of 31,732 ants were collected from pitfall traps and 54,694 ants were collected from bait traps. They belonged to four subfamilies, 17 genera, and 32 species. Bait traps caught 29 species, whereas pitfall traps caught 31 species. Bait traps attracted one species not found in pitfall traps, but missed three of the species collected with pitfall traps. Collections from the two sampling methods showed differences in species richness, relative abundance, diversity, and species accumulation curves. Pitfall traps caught significantly more ant species per plot than did bait traps. The ant species diversity obtained from pitfall traps was higher than that from bait traps. Bait traps took a much longer time to complete an estimate of species richness than did pitfall traps. Little information was added to pitfall trapping results by the bait trapping method. The results suggested that the pitfall trapping method is superior to the bait trapping method for leaf litter ant studies. Species accumulation curves showed that sampling of 2,192 ± 532 ants from six plots by pitfall traps provided a good estimation of ant species richness under the conditions of this study.

KEY WORDS Ants, Formicidae, pitfall traps, bait traps, forest

IN MEASURING AND monitoring biodiversity and conducting inventory of arthropods, one important aspect is to establish standard sampling methods that can obtain unbiased results that are comparable to other studies. Ants have been the subject of numerous ecological studies and have been sampled by various methods including pitfall traps, bait traps, litter sampling, fogging, beating, sweeping, and hand picking (Andersen 1991, Majer 1997, Olson 1991, Romero and Jaffe 1989). Each of these studies addressed specific objectives or focused on target groups of ants. The purposes of the studies typically fall into two major categories: the ant community characteristics and inventory. To obtain an inventory of ant species is relatively easy since the number of ants is not considered. However, the study of community characteristics requires more than just a species list, and involves data on relative abundance and distribution patterns. All of the existing ant sampling methods have their advantages as well as disadvantages in terms of cost, convenience, quality of samples, representation of the ant species richness, relative abundance, and repeatability.

Leaf litter ants are commonly sampled by pitfall and bait traps. Pitfall traps are easy to use and can be operated continuously during day and night over extended periods of time with little attention required. Numerous studies on ant communities have used the pitfall trapping method. It provides a reasonably good estimation of species richness and relative abundance, but has potential defects. Olson (1991) found pitfall trapping is less appropriate for sampling litter ants than litter sifting because it underestimates the proportion of small species. Litter sifting is less convenient, however, and can seriously distort the ant relative abundance if ant nests are near some of the traps. The size of foraging ant populations, the dispersion of colonies, and levels of ant activity influence the number of ants obtained from pitfall traps. This problem can be avoided by considering species frequency of occurrence, rather than total abundance in samples (Greenslade and Thompson 1981, Fox and Fox 1982, Greenslade and Halliday 1983), but this in turn introduces other errors. For example, single individuals recorded in 10 samples would be considered to be more abundant than another species occurring in nine samples, but averaging more individuals (Andersen 1991). By integrating the various attributes of species, pitfall traps are of potential value as an index of a species' relative abundance.

Bait trapping has been used to determine frequencies and territories of ants (Brian et al. 1966), and their distributions (Cherry and Nuessly 1992, Majer and Delabie 1994). Bait traps are easier to operate and obtain much cleaner samples than pitfall traps, but have several serious disadvantages. Baits are selective, being influenced by feeding preferences of the ant species. Also, time of day and transient changes in weather influence the number and species of ants

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visiting baits. In a comparison experiment, Greenslade and Greenslade (1971) found both beer-syrup and alcohol-syrup traps caught more ants than pitfall traps, but the same range and number of species were represented in all the trapping methods. The only difference was an apparent under-representation of *Camponotus* species in the pitfall traps.

In this study, we compared the effectiveness of pitfall trapping and bait trapping methods for ground foraging ants. Our main purposes were: 1) to estimate total richness with species accumulation curves over sampling periods and sampling plots and 2) to compare ant species diversity, richness, and species relative abundance obtained from pitfall trapping and bait trapping methods.

Materials and Methods

The study was carried out in the George Washington National Forest (GWNF) in Augusta Co., VA, and in the Monongahela National Forest (MNF) in Pocahontas Co., WV. The two forests are ≈80 km from each other. In each forest, nine plots were delineated, with distances between adjacent plots ranging from 1–8 km. The plots in the GWNF were similar to each other in vegetation. One plot in the MNF varied greatly from other plots. The GWNF plots were at 635 ± 24 m (mean ± SE) elevation, and MNF plots were at 946 ± 54 m elevation. All plots were dominated by oaks (*Quercus* spp.) with an average of 86% in canopy coverage. Detailed descriptions of the study plots can be found in Wang et al. (2000).

In each plot, a low site (valley) and a high site (ridge) were selected to set up pitfall traps. The elevation differences between the two sites at each plot were 39 ± 28 m. At each site in 1995, a set of nine pitfall traps was installed one m apart in a 3 × 3 grid pattern. The design was changed to six traps arranged in a circle of 15 m diameter (7.9 m between adjacent traps) in 1996 and 1997. This change was intended to collect more diverse ants through a larger sampling area than that in 1995. The pitfall traps were composed of an inner cup, a funnel, and an outer cup. The outer cup had a diameter of 58 mm. The inner cup was half filled with propylene glycol as a killing agent and preservative. Detailed description of the traps was presented in Wang et al. (2000). Pitfall traps were emptied every Monday for 15 wk from early May to mid-August each year for a total of 45 wk during the 3 yr. For each site, ants from a set of traps (9 in 1995, six in 1996–1997) were combined. So there were two pitfall samples per plot each week, one from the high site, and one from the low site.

The bait traps were 100 × 15 mm disposable polystyrene petri dishes. A central hole of 5 mm in diameter was drilled to secure the dish to the ground with a metal skewer. Four 5 mm diameter holes were drilled on the sides of the bottom half of the dish to allow ants to enter. Each dish was baited with 0.4 ml honey and 0.5 ml peanut butter. Most ants are attracted to one or both of these two baits. Three parallel 80 m ant sampling transects were marked out 20 m apart in each plot (Majer and Delabie 1994), adjacent to high pitfall trap sites. Nine dishes were placed at 10 m intervals on one of the three transects on Monday and collected on Tuesday morning of each week from early May to mid-August from 1996 to 1997. In 1995, sampling began 3 wk later than in 1996 and 1997, so that there were only 12 weekly bait trap samples in that year. A total of 42 weekly samples were taken during 1995–1997. Each dish was placed in a Ziploc plastic bag when collected. They were then returned to the laboratory and stored in a freezer for later examination. Traps were placed on the other two transects over the next two weeks, so that each transect was sampled once every three weeks in 1996 and 1997. In 1995, the placement was different in that the first four weekly samples were done on one transect, and alternation with the other two transects was conducted during the remaining 8 wk.

All ants were identified to species using Creighton (1950), Lynch (1987), and Wilson (1955). Species richness, abundance, and diversity (Shannon's H′) (Shannon and Weaver 1949) of each plot were summarized or calculated. Voucher specimens from the study were deposited in the Natural History Museum of Los Angeles County, Los Angeles, CA, and the West Virginia University Arthropod Collection, Morgantown, WV.

Ant species richness from pitfall traps between forests and sampling years were analyzed by two-way analysis of variance (ANOVA). Means of species richness in different years were separated by least significant difference (LSD) after ANOVA (SAS Institute 1999). Ant diversity index (H′) between forests and sampling methods were also analyzed by two-way ANOVA. For comparison of ant species richness between sampling methods, only the high site pitfall traps and six bait traps from each plot during 1996–1997 sampling period were considered. This will ensure the same number of pitfall and bait traps per plot and the same operating period. The pitfall traps deployed at low sites were not considered in this comparison because they were further away from the bait traps and were usually in a very different microhabitat. The 10 most abundant ant species from the total of the two sampling methods were listed. Correlation analysis was used to compare their relative abundance between sampling methods. The relative abundance was defined as the number of a species caught in a trap type divided by the total of ants caught in that trap type. Analyses were performed using SAS software (SAS Institute 1999).

Results and Discussion

Thirty-two species of ants were collected during 1995–1997, 31 from pitfall traps and 29 from bait traps. Bait traps added only one ant species to those caught by pitfall traps. The extra species collected from bait traps, *Apahaenogaster tennesseensis* (Mayr), was found only on one date (with 33 workers in the trap) during three sampling years, which indicated it was a very uncommon species. Three species not present in bait

Table 1. Comparison of total ant species richness between sampling methods and forests from 1996–1997 samples

Sampling method	Forest			
	GWNF		MNF	
	n	No. of species	n	No. of species
Bait	9	14.1 ± 0.5Aa	9	8.6 ± 0.6Ba
Pitfall	9	20.4 ± 0.5Ab	7[a]	12.7 ± 0.9Bb

Mean ± SE of total weekly catches per plot based on ants from the high site pitfall traps and six bait traps per plot; means within the same row followed by different upper case letters are significantly different ($P < 0.05$; 2-way ANOVA); means within the same column followed by different lower case letters are significantly different ($P < 0.05$; 2-way ANOVA). GWNF, George Washington National Forest; MNF, Monongahela National Forest.

[a] Two plots were deleted from analysis because of disturbance by animals and unusual low number of ants (<90 per plot) collected.

traps were found in pitfall traps: *Camponotus nearcticus* Emery, *Formica rubicunda* Emery, and *Leptothorax shaumi* Roger. *Camponotus nearcticus* was a common species, which was caught 175 times by pitfall traps from 13 plots with a total of 332 individuals. Ant species sampled by the two methods in 1996 and 1997 showed that bait traps collected significantly fewer species from each plot compared with pitfall traps ($F = 71.7$; df = 1, 30; $P < 0.01$) (Table 1). There were also significantly fewer ant species in MNF plots than in GWNF plots ($F = 114.9$; df = 1, 30; $P < 0.01$). There was no significant interaction effect between forest and sampling method ($F = 3.1$; df = 1, 30; $P = 0.09$). Therefore, in these habitats, bait traps were not as effective as pitfall traps in obtaining an inventory of ant fauna.

A total of 31,732 ants were collected from pitfall traps and 54,694 ants were collected from bait traps. The ten most abundant ant species collected from the two methods comprised 80.6% of the pitfall samples and 97.4% of the bait trap samples (Table 2). We found no correlation between the pitfall and bait trap samples in the relative abundance of these ten ant species (R = 0.13; $F = 0.1$; df = 1, 8; $P = 0.72$). The most

Table 2. Percentage abundances for the 10 most abundant ant species from pitfall and bait traps during 1995–1997

Ant species	Relative abundance by sampling method, %	
	Pitfall	Bait
Aphaenogaster rudis (Emery)	13.6	49.9
Camponotus pennsylvanicus (De Geer)	23.3	1.5
Monomorium minimum (Buckley)	0.5	10.7
Myrmica punctiventris Roger	10.3	3.7
Tapinoma sessile (Say)	4.2	8.3
Formica neogagates Emery	11.5	3.0
Prenolepis imparis (Say)	4.2	6.5
Myrmica n. sp. 1	8.4	3.0
Lasius alienus (Foerster)	4.1	5.0
Crematogaster lineolata (Say)	0.5	5.8
Total percentage	80.6	97.4

Species are ordered from most abundant to least abundant according to total abundance from both sampling methods.

Table 3. Comparison of ant species diversity (H′) between sampling methods and forests (mean ± SE)

Sampling method	Forest			
	GWNF		MNF	
	n	Diversity index (H′)	n	Diversity index (H′)
Bait	9	0.73 ± 0.04Aa	9	0.37 ± 0.07Ba
Pitfall	9	1.02 ± 0.03Ab	9	0.72 ± 0.03Bb

Means within the same row followed by different upper case letters are significantly different ($P < 0.05$; 2-way ANOVA); means within the same column followed by different lower case letters are significantly different ($P < 0.05$; 2-way ANOVA). GWNF, George Washington National Forest; MNF, Monongahela National Forest.

distinct differences between the sampling methods were shown for *Aphaenogaster rudis* (Emery), *Camponotus pennsylvanicus* (De Geer), and *Monomorium minimum* (Buckley) (Table 2). Both *A. rudis* and *M. minimum* have efficient communication systems to recruit foragers to food and were attracted to bait traps in large numbers. The largest numbers of the two species collected from individual bait traps were 290 for *A. rudis* and 522 for *M. minimum.* Hence, bait traps may over represent the proportion of those species because the recruitment behavior draws in large number of foragers. In contrast to *A. rudis* and *M. minimum*, *C. pennsylvanicus* does not have a strong recruitment behavior to food sources (Fowler 1986). The maximum number of *C. pennsylvanicus* collected from a bait trap was only 21. This is the largest species sampled in the plots (6–13 mm long). The small size of the bait traps might also have limited the maximum number of *C. pennsylvanicus* that were captured.

Diversity of ants measured by diversity index (H′) from 1995–1997 pitfall samples was significantly higher than that from bait traps (Table 3) ($F = 42.7$; df = 1, 32; $P < 0.01$). The diversity index was significantly higher in GWNF than in MNF ($F = 45.4$; df = 1, 32; $P < 0.01$). There was no significant interaction effect between forest and sampling method ($F = 0.4$; df = 1, 32; $P = 0.52$).

Species accumulation curves over sampling weeks from the 18 study plots indicated that in each year, pitfall traps caught more species than bait traps and most species were captured after 5.3 ± 1.3 and 9.7 ± 0.9 wk of pitfall trapping or bait trapping, respectively (Fig. 1). The pitfall trapping was consistently faster than bait trapping in accumulating more species during the three sampling years. The 1997 pitfall samples showed a much slower species turnover than 1995 and 1996 samples. This was caused by the much lower number of ants collected from each week of sampling in 1997 than in 1996 and 1997. The average number of ants collected each week from the 18 plots by pitfall traps were 865 ± 46, 789 ± 88, and 462 ± 65 for 1995–1997, respectively. Comparison of species accumulation curves by pitfall traps over number of plots and sampling periods revealed that the minimum number of plots needed to capture most of the ants species was 8, 7, and five for 1995–1997, respectively (Fig. 2). The minimum sampling periods needed were 4, 4, and 8 wk for 1995–1997, respectively (Fig. 2).

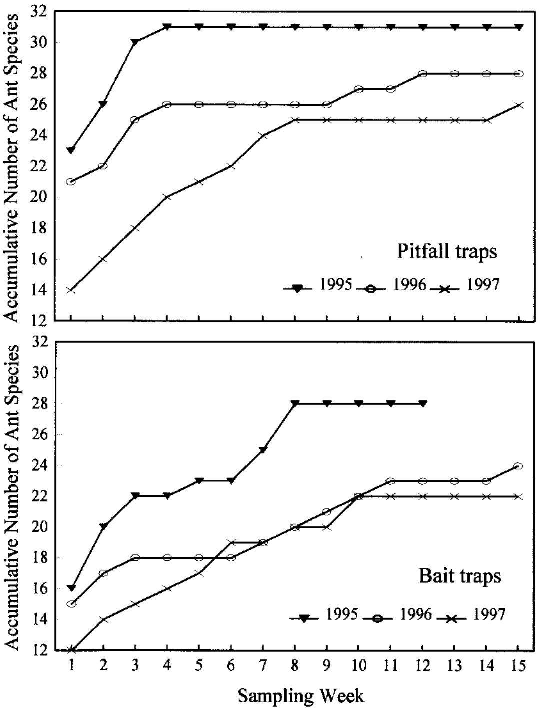

Fig. 1. Ant species accumulation curves over sampling periods from pitfall and bait traps.

Considering that the number of ants captured will vary with weather conditions and trap sizes, using the number of ants might be most appropriate in estimating how long the sampling period should continue to sample the majority of the ant species in a habitat. The minimum number of collected ants needed to represent the most ant species for 1995–1997 was 2,863, 2,569, and 1,140, respectively (mean ± SE: 2,191 ± 532). The much lower number of ants needed to catch the most ant species in 1997 might be related with the repeated sampling at the same spot over past two years.

The change in arrangement of pitfall traps from 3 × 3 m grids in 1995 to circles of 15 m diameter in 1996 was intended to catch more ant species. The average number of ant species per plot from pitfall traps was significantly different between years ($F = 16.6$; df = 2, 8; $P < 0.01$) and between forests ($F = 142.1$; df = 1, 14; $P < 0.01$) (Table 4). Significantly fewer species were caught per plot in 1996 than in 1995 in each of the two forests. The number of species caught per plot in 1997 was significantly less than in 1995 and 1996 in George Washington National Forest plots. The decrease in number of species caught per plot might be caused by repeated sampling at same locations. No additional ant species were captured in pitfall traps in 1996 compared with 1995. This indicated that the 1995 data did not miss much information about ant species richness due to the close layout of the pitfall traps and the increased disturbance in vicinity of traps.

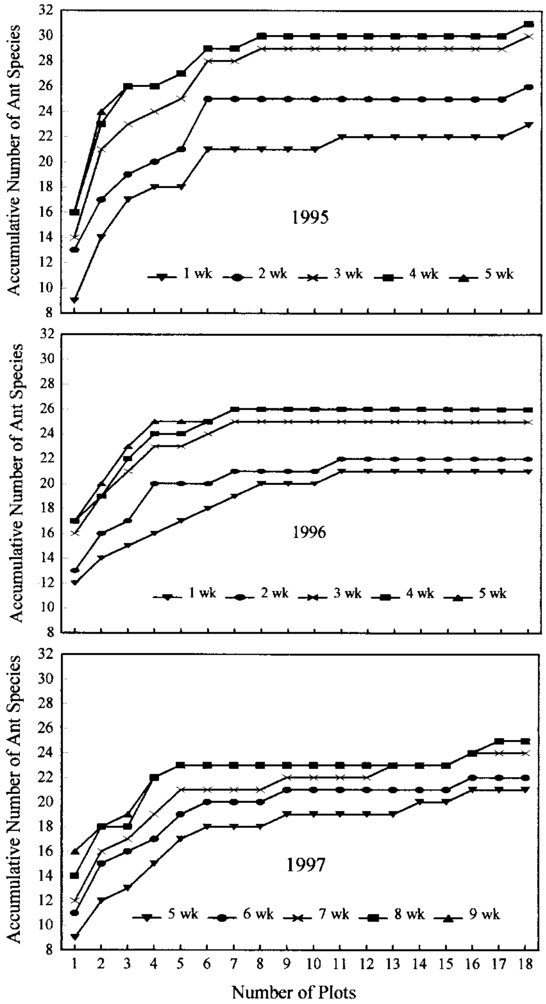

Fig. 2. Ant species accumulation curves over sampling plots from pitfall traps. The first nine plots are within George Washington National Forest. The second nine plots are within Monongahela National Forest.

In conclusion, this study showed pitfall trapping is superior to bait trapping in the characterization of relative species abundance, and capturing the most leaf litter ant species. The relative abundance of species was not correlated between pitfall traps and bait traps. It is necessary to sample sufficient numbers of ants from a number of plots to obtain the maximum number of ant species. A sampling of 2,191 ± 532 ants from six plots by pitfall traps is recommended for epigaeic ant community studies. This sampling scheme can vary with different regions and with the degree of homogeneity and complexity of the habitat. More plots may be needed in a more complex and heterogeneous habitat. If more traps were deployed per plot, the minimum number of plots needed for obtaining a good account of ant species may be reduced. The selection of the trap site will also affect the results. Various microhabitats should be considered when selecting trap locations.

Table 4. Comparison of ant species richness from pitfall traps between sampling years and forests (mean ± SE)

Sampling year	Forest			
	GWNF		MNF	
	n	Species richness	n^a	Species richness
1995	9	23.1 ± 0.5Aa	7	14.0 ± 0.7Ba
1996	9	20.9 ± 0.8Ab	7	11.6 ± 0.9Bb
1997	9	18.9 ± 0.4Ac	7	11.0 ± 1.0Bb

Means within the same row followed by different upper case letters are significantly different ($P < 0.05$; 2-way ANOVA); means within the same column followed by different lower case letters are significantly different ($P < 0.05$; 2-way ANOVA; means are separated by LSD). GWNF, George Washington National Forest; MNF, Monongahela National Forest.

[a] Two plots were deleted from analysis because of disturbance by animals and very low number of ants (<90 per plot) collected.

For a complete picture of ants composition in a habitat, a combination of pitfall traps with other methods, such as Winkler bags, direct counts, and hand searching might be needed to catch the rare species and species from other strata (Agosti and Alonso 2000). Winkler bags (or Winkler collector, Winkler extractor) are commonly used for sampling leaf litter ants (http://research.amnh.org/entomology/social insects/winkler demo.html). Litter sifting followed by extraction in Winkler bags records many species that do not turn up in pitfall traps (Olson 1991). Hand search and litter extraction can reveal those cryptic ants, and arboreal nesting species, and sparsely distributed species, which are likely undersampled by pitfall traps (Majer 1997).

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