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Sampling epigeal arthropods: an evaluation of fenced pitfall traps using mark-release-recapture and comparisons to unfenced pitfall traps in arable crops

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Abstract

The efficiency of fenced pitfall traps for estimating the density of commonly occurring epigeal predatory beetles was examined using mark-release-recapture. Most beetles of those recovered were recaptured within one week of their release. For seven of the ten species tested recapture rates were over 70%, with higher rates for the larger species. The predatory arthropod species composition captured using fenced pitfall traps was compared to unfenced pitfall traps in winter wheat, spring barley and winter oilseed rape. Compositional analysis revealed that the dominance structure of seven carabid beetle (Coleoptera: Carabidae) taxa differed between the trap types and month of sampling in winter wheat and spring barley, but differences were small with the exception of a few taxa. Linear relationships between the two techniques were found for some carabid and rove beetles (Coleoptera: Staphylinidae). The dominance structure of seven linyphiid spider (Araneae: Linyphiidae) taxa differed between the two trap types in wheat but not barley, although large differences were restricted to two taxa. No linear relationships between the two techniques were found for any of the Linyphiidae examined. Rove beetles were more effectively sampled using the fenced compared to unfenced pitfall traps.

Introduction

Obtaining reliable data on the density of invertebrates in agroecosystems is essential if their ecology, their importance as biocontrol agents and the impact of agricultural practices is to be accurately determined. However, because of the limitations in the most commonly used sampling methods such density estimates are often difficult to obtain. A variety of sampling techniques exist for epigeal invertebrates but these vary considerably in their effectiveness at trapping each species and so the proportion of the population sampled may differ between techniques. The range of species sampled also differs between techniques. Many of the techniques for sampling invertebrate predators in agroecosystems were recently reviewed by Sunderland et al. (1995) and these authors concluded that good data were lacking on the proportion of the population sampled using these methods. Techniques which reliably provide a measure of population density were identified as being the most useful and these included suction sampling and fenced pitfall traps. However, the most widely used method is unfenced pitfall trapping, a technique which is known to be affected by a wide range of factors and in particular activity of the animals being trapped (Luff, 1975; Adis, 1979; Halsall & Wratten, 1988; Sunderland et al., 1995). Comparisons between different methods are also rare but such information would be useful when trying to select the appropriate technique for the species under investigation. In addition, if reliable correlations can be found between techniques it may be possible to compare results between studies where different techniques were used.

Fenced pitfall traps, which consist of a pitfall trap surrounded by an enclosure of between 0.25–1.0 m^2 have been shown to be suitable for estimating the density of ground-active invertebrates, notably Carabidae (Coleoptera). These traps also act as emergence traps (Helenius, 1995). The enclosures have been constructed of wood (e.g., Dennison & Hodkinson, 1984) or metal (e.g., Bonkowska & Ryszkowski, 1975) with the tops of the enclosures covered with a fine mesh. Ensuring that the traps are completely sealed is essential to prevent ingress or egress. The proportion of the population sampled using fenced pitfall traps have been evaluated for some species using mark-recapture in pasture (Desender et al., 1985), woodland (Dennison & Hodkinson, 1984) and rye and potato crops (Bonkowska & Ryszkowski, 1975). These studies revealed that recapture efficiency was high, up to 96%, especially for the larger species. The technique therefore appears to be accurate for some species (Sunderland et al., 1995) with estimates being similar to those from soil sampling (Desender & Maelfait, 1983). The technique has mostly been used to estimate densities of Carabidae (Basedow, 1973; Bonkowska & Ryszkowski, 1975; Baars, 1979; Dennison & Hodkinson, 1984; Desender & Maelfait, 1986; Helenius, 1995; Ulber & Wolf-Schwerin, 1995) but relatively little information exists for other taxa. Fenced pitfall traps were also used to measure densities of some Araneae and Staphylinidae (Coleoptera) (Basedow & Rzehak, 1988) and non-predatory invertebrates (Gist & Crossley, 1973).

Fenced pitfall traps are relatively fast and easy to establish and consequently are less time-consuming compared to other density estimation techniques such as soil flooding (Desender & Segers, 1985), microhabitat removal (Edwards & Fletcher, 1971) or the combination of suction sampling, ground searching, isolating and removing trapping used by Sunderland et al. (1987). Fewer species may be collected in fenced pitfall traps compared to photoeclectors (Funke, 1971); the latter are comprised of a similar sized enclosure fitted with a pitfall trap and a light trap. However, fenced pitfall traps are cheaper to construct and consequently suitable for more extensive studies. Suction sampling is the only widely adopted method used to provide an estimate of invertebrate density. The efficiency of this technique has been evaluated for a range of invertebrate taxa (Duffey, 1980; Bayon et al., 1983; Hand, 1986; Sunderland & Topping, 1995) and has been found to have a number of limitations. The suction power limits the technique to smaller species (Bayon et al., 1983) and is also affected by the vegetation cover (Hand, 1986) and the species' vertical stratification (Topping & Sunderland, 1994; Sunderland & Topping, 1995). Some of these limitations can be overcome by using a combination of suction sampling and surface searching which has been shown to provide accurate estimates of spider densities (Sunderland & Topping, 1995). Alternatively, repeated sampling within a frame using the stronger suction of a narrower nozzle can be used to collect larger species but sample sorting times are high at up to one hour per sample (Dinter, 1995). Suction sampling, however, unless repeated many times still only provides a snapshot in time of the species present. Furthermore, because it cannot be used when foliage is wet and is often limited to daylight, it may underestimate nocturnal species, which include most of the Carabidae found in agricultural habitats (Thiele, 1977). Thus fenced pitfall traps, although more laborious to set up than suction sampling, overcome many of the limitations outlined above and provide cleaner samples that are quicker to sort and identify.

Pitfall trapping is the most commonly used epigeal invertebrate sampling method. This is because it is cheap and quick, allowing many samples to be taken. The technique provides some estimation of diversity for Carabidae (Ulber & Wolf-Schwerin, 1995) and wandering spiders (Uetz & Unzicker, 1976). Only in specific circumstances can they be used for estimating abundance and for a limited number of species. The disadvantages of pitfall traps are numerous because capture efficiency is affected by many factors and therefore their capture rate is a result of abundance, activity and species trappability (Adis, 1979; Sunderland et al., 1995).

In this study, mark-release-recapture was used to investigate the efficiency of fenced pitfall traps for ten predator beetle taxa in a spring barley crop. Beetle activity as a result of intra-species and inter-species interaction may influence capture rate and efficiency, therefore different densities of beetles were released in our experiments. The composition of species captured using fenced pitfall traps was then compared to unfenced pitfall traps. This was carried out as part of the LINK Integrated Farming Systems Project in which beneficial arthropods are monitored as bioindicators of farming practice (Holland et al., 1994). Sampling using these two methods was carried out at the same time and analysed to compare the relative efficiency of each method for a range of Carabidae, Staphylinidae and Araneae commonly found in agricultural ecosystems.

Materials and methods

Evaluation of fenced pitfall traps using mark-release-recapture (MRR). In 1995 three experiments (1-3) were carried out using wooden fenced pitfall traps. Each trap consisted of a square wooden enclosure (0.5 m × 0.5 m) with a height of 0.24 m, which could be collapsed for ease of transport. The top was covered with muslin secured using a band of tight elastic. The enclosure was secured into the ground to a depth of 12–25 mm. A single pitfall trap (9.5 cm diam.) was located in the middle of one edge of each enclosure. The crop within the enclosures was cut to a height of 10 cm to allow the tops to be fitted.

Two 6 × 4 grids of 24 fenced pitfalls with traps spaced at 2-m intervals were set up in a field of spring barley, one on 20 July 1995 and one on 24 July 1995. The pitfall traps, containing a water solution (4% formaldehyde and 0.05% detergent), were left open for two weeks prior to the start of the mark-release-recapture to remove natural populations of beetles which otherwise may have influenced the activity of the marked invertebrates. During this two week period in each set of grids 1.1 and 1.7 unmarked carabids of the species used in the MRR study were captured per fenced pitfall trap. Experiments 1 and 3 were carried out in the grid established on 20 July 1995 and experiment 2 used the grid set up on 24 July 1995. In 1996 one experiment was carried out using 0.25 m^2 fenced pitfall traps constructed of aluminium, riveted at the corners with the top covered by a fine insect proof mesh, attached to a wooden frame. A 6 × 4 grid of 24 fenced pitfalls with traps spaced at 2-m intervals was set up in rough grassland on 21 May. As in the previous experiments the pitfall traps were left open for two weeks prior to the start of the mark-release-recapture study to reduce invertebrate numbers within the enclosures. In each experiment there were four insect species each at three densities (4, 8 or 12 except in experiment 3 where there were 2, 4 or 8) with two replicates of each density. Each treatment was randomly distributed in the traps for each experiment. *Pterostichus melanarius* Illiger (Coleoptera: Carabidae) was used in each experiment to act as a standard against which the other species could be compared.

Beetles for mark-release-recapture were collected from the surrounding habitat and stored at 4 °C with abundant food. Each individual was marked, using typeface correction fluid 'Tippex' which was shown to be non-toxic, with a unique code so that any escapees who found their way into another enclosure could be identified. After marking, the beetles were held until the evening to ensure mortality did not occur. They were then released into the enclosures with the pitfall traps covered to allow a settling in period. The following day the pitfall trap covers were removed and capture of marked and unmarked beetles was then monitored on a daily basis for two weeks in 1995, by which time capture of marked beetles had ceased. Traps were assessed every two days for a total of 10 days after release in 1996. Captured insects were identified and sexed according to Holliday (1977). Minimum and maximum temperature, rainfall and humidity were recorded daily within and outside the enclosures because invertebrate activity can be effected by these factors (Luff, 1987). Crop density may also affect activity (Honek, 1988) and was therefore measured in each enclosure by counting the number of individual plants.

Data analysis. The capture efficiency (CE) of the traps for each beetle species and density in each experiment was calculated by dividing the total number of marked beetles recaptured by the total number of marked beetles released. The CE data for each experiment was analysed separately using two-way factorial ANOVA with beetle species and density as factors.

Comparison of fenced pitfall traps and pitfall traps. During 1995 and 1996 pitfall traps and fenced pitfall traps were used to monitor invertebrates at the LINK Integrated Farming Systems Project site in Hampshire, UK. At this site there are nine pairs of plots in which integrated and conventional farming systems are compared through a five-course rotation of cereals and break crops. Each plot was a minimum of four ha and had a minimum width of 100 m. Within each plot a transect of four pitfall traps (9.5 cm diam.), 10 m apart, starting 30 m from the field boundary and extending into the field were used. Each pitfall trap was partly filled with water and detergent and left open for five days. At the same time an adjacent transect of four fenced pitfall traps was established 10–20 m from the pitfall traps with the same distance between traps as for the pitfall traps. The wooden fenced pitfall traps were of the same design as those described above but with the addition of a high guiding plate (0.45 m length × 0.2 m high) which was placed over the pitfall trap thereby dividing the enclosure in half to increase capture in the pitfall trap. As needed the crop within the enclosures was cut to a height of 10 cm to allow the tops to be fitted. The traps were operated for two weeks each month from April to June relocating them each time. A range of Carabidae, Staphylinidae, Linyphiidae and Lycosidae were identified to species, genus or family providing 23 different taxa.

Data analysis. The total number of taxa and their number per pitfall trap per day or fenced pitfall traps per m^2 were calculated using data from both years. A more detailed analysis of the Carabidae and Linyphiidae, both of which are predominantly ground-active, was carried out to determine if the proportion of each taxon differed between the two trap types and whether month of sampling was important. The proportions of each taxa sum to one for each trap type (unit-sum constraint) and so exhibit linear dependence. To overcome this limitation, compositional analysis (Aitchison, 1986; Aebischer et al., 1993) was used, the principles of which are as follows. In a data set with D taxa, let us take x_i as the proportion of a taxon x caught in a trap i. We have $x_1 + ... + x_D = 1$. For any one taxon j, the logratio transformation $y_i = \ln(x_i/x_j)$ $i = 1...D$, $i \neq j$) renders the y_i linearly independent (Aitchison, 1986). The logratios y_i are unconstrained and suitable for multivariate analysis of variance and covariance (Aitchison, 1986). Hypotheses can be tested using the likelihood ratio (Wilk's λ). Data were analysed from: 16 plots per month for April to June in winter wheat; eight plots per month for May to June in spring barley and 12 plots for April in winter oilseed rape. The extensive growth of oilseed rape prevented sampling with fenced pitfall traps beyond this date. Because of the replication available only seven of the most frequently caught carabid and linyphiid taxa were selected for analysis. A multivariate analysis of variance was performed on the transformed data to examine the effect of trap type, month of sampling and interaction effects. The relationship between numbers captured using the two techniques for all crops and months was also examined for each taxon using linear regression after $\log_{10}(x + 1)$ transformation.

The number of carabid and linyphiid taxa was compared between the two trap types for each month and crop using t-tests with Bonferroni adjustment. Data for Staphylinidae are given but few species in this family are ground active and pitfall traps are thought therefore an inappropriate method (Sunderland et al., 1995). To determine whether carabid beetle size effected the likelihood of capture in either trap, average carabid beetle size for each species obtained from (Harde, 1984) was compared using regression analysis to the abundance and the proportion of the total traps in which the species was captured. The likelihood of capture in the fenced compared to unfenced pitfall traps may have differed according to the relative abundance of each taxon, therefore, the proportion of the total traps in which a taxon was captured was compared for each trap type using paired t-test and their linear relationship examined. The analysis was carried out for taxa from the Carabidae, Staphylinidae and Araneae.

Results

Evaluation of fenced pitfall traps. In each of the first three experiments in 1995 marked beetles were only captured for up to nine days after release with the majority being captured in the first day. The CE only differed significantly for species in experiment 2 ($F_{3,12} = 54.0$, $P<0.001$) and experiment 4 ($F_{3,12} = 8.4$, $P<0.01$). There were no significant effects for density and neither were there any interaction effects. In experiment 2 the CE for *Bembidion obtusum* Serville was significantly lower than the other three species (Tukey, $P<0.05$) and in experiment 4 the CE for *Bembidion lampros* Herbst differed significantly (Tukey, $P<0.05$) from that for *P. melanarius* and *Harpalus rufipes* DeGeer. There was some variation in the rate of capture between species and between experiments for *P. melanarius* (Table 1). In experiment 3 few insects were recaptured and this was attributed to the extremely hot, dry conditions. The maximum temperature and minimum humidity within the enclosures in experiment 3 was 39.7 °C and 34% r.h. respectively compared to 32.5 °C and 51.5% r.h. in experiment 1.

The CE was high (>80%) for the larger species (*P. melanarius*, *H. rufipes*, *Nebria brevicollis* Fabricius and *Amara familiaris* Duftschmid) and declined considerably (<60%) for the third experiment (Table 1). Multiple regression analysis showed there was no relationship between capture efficiency and crop density or proportion of males:females caught.

A number of unmarked invertebrates were also captured within the fenced pitfall traps. In the four experiments there were an average of only 0.4 unmarked Carabidae per trap, comprising mainly of *Bembidion* spp., compared to three Staphylinidae per trap of which 50% were Aleocharinae and two Linyphiidae per trap.

Comparison of pitfall and fenced pitfall traps. The compositional analysis revealed that the relative proportions of different carabid taxa sampled in wheat

Table 1. Mean capture efficiency (CE) for each species in the fenced pitfall traps from experiments 1–4

Species	Mean CE	Stdev of CE	Max CE	Min CE
Experiment 1				
Pterostichus melanarius	0.85	0.12	1	0.75
Bembidion lampros	0.72	0.17	1	0.5
Harpalus rufipes	0.96	0.10	1	0.75
Nebria brevicollis	0.81	0.15	1	0.63
Experiment 2				
Pterostichus melanarius	0.94	0.10	1	0.75
Bembidion obtusum	0.14	0.24	0.63	0
Coccinella 7-punctata	0.76	0.15	0.92	0.5
Amara familiaris	0.96	0.07	1	0.83
Experiment 3				
Pterostichus melanarius	0.35	0.39	1	0
Notiophilus biguttatus	0.58	0.34	0.75	0
Agonum dorsale	0.33	0.38	0.38	0
Loricera pilicornis	0.29	0.33	0.75	0
Experiment 4				
Pterostichus melanarius	0.91	0.09	1	0.75
Bembidion lampros	0.33	0.29	0.75	0
Harpalus rufipes	0.81	0.10	1	0.75
Amara spp.	0.63	0.30	1	0.25

and barley differed between the two trap types and this varied with the month, but there was no interaction effect (Table 2). Overall for the majority of carabid taxa the relative differences between the trap types were small ($<$10%) (Figures 1a and b). Some taxa were consistently caught more by one trap type than the other in the cereal crops: the proportion of *Bembidion* spp. and *Trechus* spp., two small beetles, were greater in the fenced pitfall traps whilst *N. brevicollis*, *Amara* spp. and *Pterostichus* spp., three larger beetles, predominated in the unfenced pitfall traps. *Bembidion* spp. were the most abundant taxa in barley (Figure 1b) and in the early wheat samples (Figure 1a). Considering the relative proportions of linyphiids in wheat and barley there was a significant interaction between trap type and month for both crops (Table 2). The pitfall traps contained a higher proportion of *Erigone* spp. during April and May but not in June. In oilseed rape there was no significant difference between the trap types for Carabidae or Linyphiidae (Table 2). The most frequently captured taxa were similar for each crop type (Table 3).

Significantly ($P<0.001$) fewer carabid and linyphiid taxa were captured using the fenced pitfall compared to the unfenced pitfall traps during April in all three crops but this difference decreased in the following months (Table 4). It was those taxa caught less frequently in the pitfall traps, for example *Asaphidion flavipes* Linnaeus and *Loricera pilicornis* Fabricius, that were not captured using the fenced pitfall traps, indicating that they were present at too low a density (Table 3).

For six of the ten beetle taxa tested there was a significant linear relationship between the two techniques (Table 5) although most of these exhibited relatively high variability. No significant relationships were found for any of the Linyphiidae. The fenced pitfalls captured over twice the proportion of Staphylinidae in wheat and oilseed rape and for most of the taxa, whilst Linyphiidae were captured in approximately equal proportions (Table 3).

There were no significant relationships between carabid beetle size and abundance or the proportion of the total traps in which the species was captured. There was a significant difference between the trap

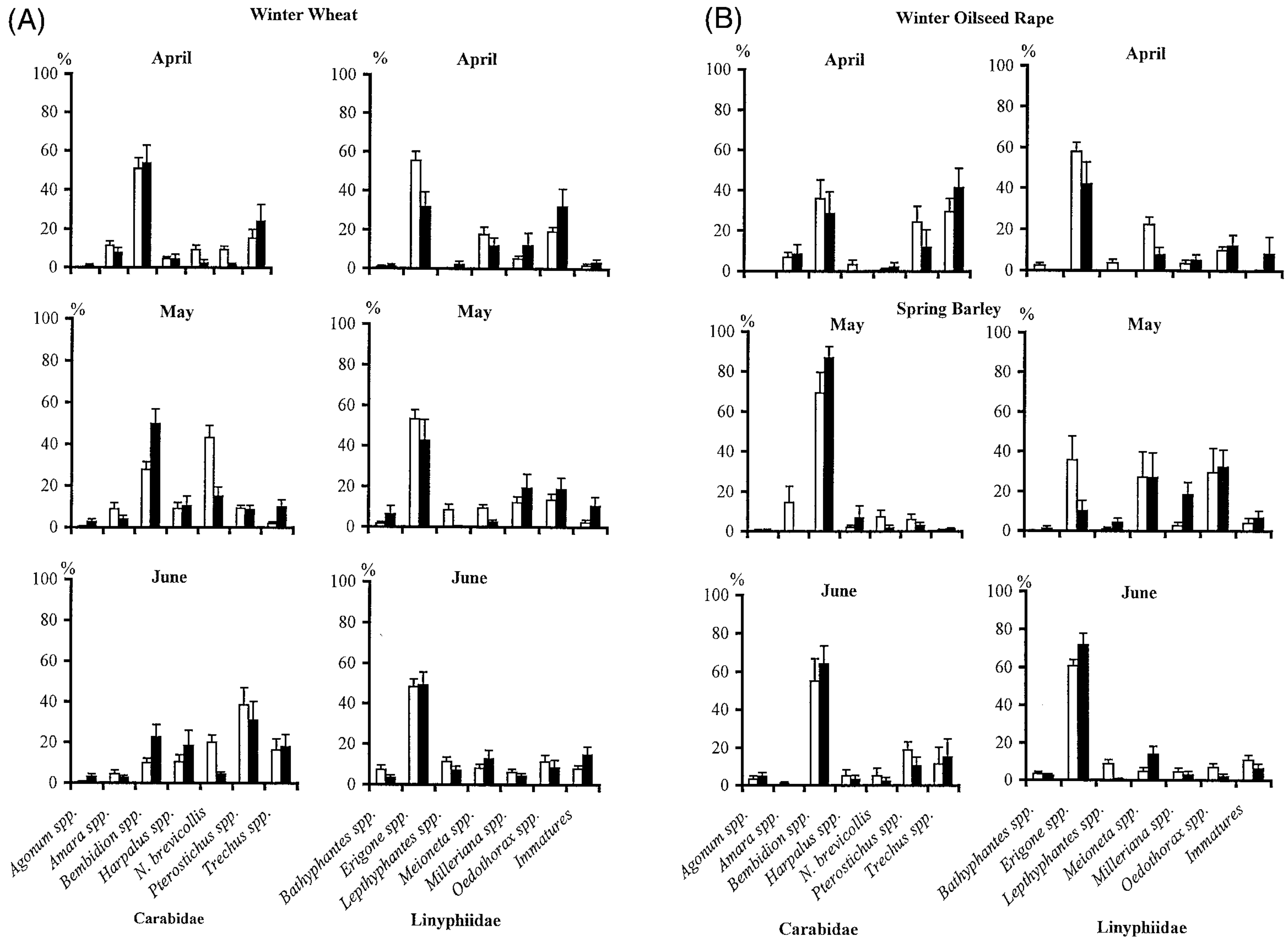

Figure 1. (A) Percentage carabid and linyphiid composition for the fenced and unfenced pitfall traps in winter wheat during April, May and June. (□ unfenced pitfall traps, ■ fenced pitfall traps). (B) Percentage carabid and linyphiid composition for the fenced and unfenced pitfall traps in spring barley during May and June and winter oilseed rape during April. (□ unfenced pitfall traps, ■ fenced pitfall traps).

Table 2. Compositional analysis results comparing trap type and month of sampling for seven carabid and linyphiid taxon in winter wheat, spring barley and winter oilseed rape

Crop	Test	Carabidae		Linyphiidae	
	Test	Wilk's λ	F-statistic	Wilk's λ	F-statistic
Wheat	Trap	0.73	$F_{6,85} = 5.2^{***}$	0.82	$F_{6,85} = 3.2^{**}$
	Month	0.33	$F_{12,170} = 10.6^{***}$	0.55	$F_{12,170} = 4.8^{***}$
	trap*month	0.88	$F_{12,170} = 0.9$	0.70	$F_{12,170} = 2.8^{**}$
Barley	Trap	0.50	$F_{6,23} = 3.8^{**}$	0.77	$F_{6,23} = 1.1$
	Month	0.31	$F_{6,23} = 8.6^{***}$	0.37	$F_{6,23} = 6.6^{***}$
	trap*month	0.70	$F_{6,23} = 1.6$	0.44	$F_{6,23} = 4.9^{**}$
WOSR	Trap	0.93	$F_{3,20} = 0.5$	0.63	$F_{6,17} = 1.6$

(P<0.001=***, P<0.01=**, P<0.05=*).

types in the proportion of traps from which each taxon was captured. For the Carabidae ($t = 3.5$, $n = 13$, P<0.01) and Araneae ($t = 4.3$, $n = 9$, P<0.01) each taxon was more likely to be captured in the unfenced pitfall traps, whereas Staphylinidae ($t = -2.6$, $n = 6$, P<0.05) were more likely in the fenced pitfall traps (Figure 2). The slope for Carabidae and Araneae was also shallower indicating that for the more widespread taxa capture in the unfenced pitfall trap was more likely compared to the fenced pitfall trap. The slope for Staphylinidae was near to 1.0 indicating that capture was equally likely in either trap regardless of numbers caught.

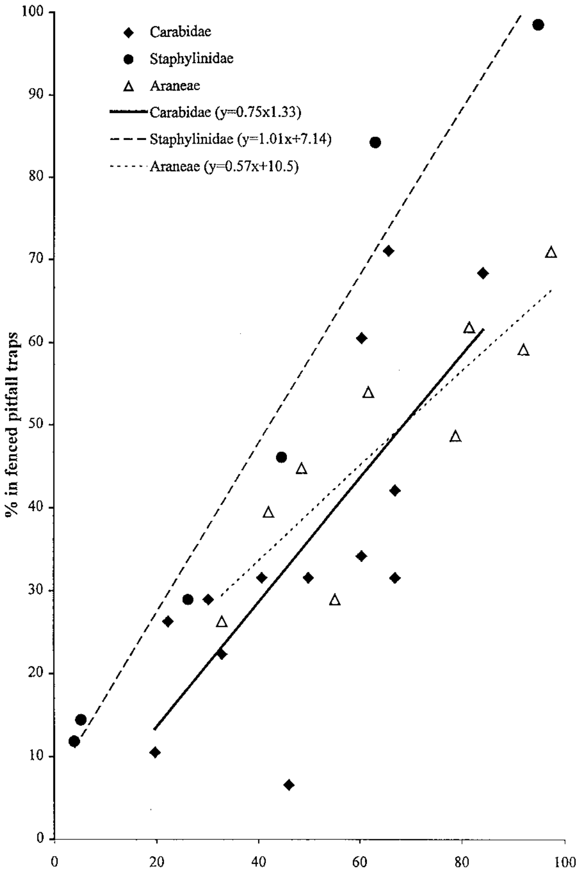

Figure 2. Proportion of fenced compared to unfenced pitfall traps in which each taxon was recorded.

Discussion

Many of the methods used for estimating invertebrate abundance have been only poorly evaluated (Sunderland et al., 1995). The mark-release-recapture study demonstrated the potential efficiency of fenced pitfall traps, with the majority of known invertebrates present within enclosures being recaptured. Recovery rates were similar to those found in previous studies where these were 95% for *P. melanarius* in pasture (Desender et al., 1985), 66–100% for *Pterostichus* spp., *Abax* spp. and *Nebria* spp. in woodland (Dennison & Hodkinson, 1984) and 96% for carabids in rye and potato crops (Bonkowska & Ryszkowski, 1975). The poor capture rates in experiment 3 were most likely a result of changes in the insects behaviour, as shown by the lower capture rate for *P. melanarius*, and were not because the traps were less efficient for these species. High temperatures and low humidity are known to induce diapause in Carabidae (Forsythe, 1987). Mortality may also have occurred although no dead beetles

Table 3. Total proportion of each taxa captured per crop in the pitfall and fenced pitfall traps

Taxa identified	Winter wheat (April–June)		Spring barley (May–June		WOSR (April)	
	Pitfall	Fenced pitfall	Pitfall	Fenced pitfall	Pitfall	Fenced pitfall
Agonum dorsale	0.2	0.6	0.7	1.1	0.0	0.0
Amara spp.	3.3	1.5	3.0	0.1	1.8	1.6
Asaphidion flavipes	0.6	0.1	0.3	0.0	4.7	2.6
Bembidion lampros	10.8	8.0	25.7	15.3	3.1	6.4
B. obtusum	3.2	7.2	8.3	22.2	7.0	3.6
Harpalus affinus	1.0	0.6	0.7	0.2	0.9	0.0
H. rufipes	2.8	2.1	0.6	0.8	0.0	0.0
Loricera pilicornis	1.5	0.1	0.3	0.0	2.6	0.0
Nebria brevicollis	11.9	2.6	2.5	0.7	0.3	0.3
Notiophilus biguttatus	1.7	0.7	1.6	0.8	8.1	1.0
Pterostichus melanarius	7.3	4.2	4.2	2.3	0.0	0.0
P. madidus	0.7	1.1	2.2	1.8	1.0	0.0
Trechus quadristriatus	4.3	4.9	1.0	2.2	8.2	8.4
Total Carabidae	49.4	33.6	51.1	47.4	37.6	23.8
Aleocharinae	7.5	16.4	11.7	13.1	12.8	30.8
Anotylus spp.	4.2	4.5	1.2	3.2	0.3	4.1
Philonthus cognatus	1.0	1.8	2.7	2.0	1.3	0.1
Philonthus spp.	0.1	0.5	0.4	0.1	0.0	0.2
Tachyporus spp.	3.2	9.9	3.9	6.7	0.8	10.8
Xantholinus glabratus	0.0	1.0	0.0	0.4	0.0	0.0
Total Staphylinidae	16.1	34.0	20.0	25.5	15.3	46.0
Bathyphantes spp.	0.9	0.9	0.5	0.5	1.3	0.0
Erigone spp.	16.5	11.9	14.6	12.4	25.3	15.3
Lepthyphantes spp.	1.7	0.7	1.5	0.4	1.9	0.0
Meioneta spp.	3.4	3.8	3.1	4.9	9.3	3.6
Milleriana spp.	1.8	1.6	1.3	1.6	1.5	1.8
Oedothorax spp.	5.0	6.5	4.2	3.9	3.9	3.4
Savigna frontata	2.3	2.1	0.2	1.0	1.8	3.4
Other linyphiids	1.1	3.0	2.8	1.9	0.1	0.6
Immature Linyphiidae	1.8	1.8	0.7	0.5	2.0	2.1
Total Linyphiidae	34.5	32.3	28.9	27.1	47.1	30.2

were found on the soil surface. The time required to recapture all the marked beetles was relatively short with most being caught within the first two days, therefore an operating period of one week would be sufficient if the aim was to estimate numbers of active beetles. Traps operating in the same position for longer would then also act as emergence traps, as used by Helenius (1995).

No marked invertebrates were found transferring between traps during the course of these experiments, however, some small unmarked invertebrates, notably Aleocharinae, and Linyphiidae, were captured during the course of each experiment indicating that either immigration was occurring, the initial trapping out was not completely effective or emergence within the traps had occurred. It may also be possible for burrowing species to enter the enclosures but may be balanced by an equal amount of migration.

The comparison of the two trapping techniques revealed that there were some differences in the relative proportions of each Carabidae and Linyphiidae taxa which were caught. Furthermore, there was more

Table 4. Number of carabid and linyphiid taxa captured using the unfenced and fenced pitfall traps in three different crops during April to June and results of t-test comparing taxa captured using the two methods

Crop	Month	Carabidae					Linyphiidae				
		Pitfall		Fenced pitfall		t	Pitfall		Fenced pitfall		*t*
		Mean	SE	Mean	SE		Mean	SE	Mean	SE	
Wheat	April	6.8	0.6	2.7	0.4	7.0***	4.5	0.3	2.8	0.4	3.7***
(30 d.f.)	May	7.0	0.6	6.4	0.5	0.8	5.6	0.4	3.2	0.4	4.0***
	June	7.5	0.4	7.1	0.6	0.6	6.6	0.3	6.1	0.3	1.3
Barley	May	5.9	0.6	3.5	0.4	3.3**	2.8	0.5	3.6	0.7	1.0
(14 d.f.)	June	5.6	0.3	5.3	0.4	0.7	5.8	0.6	4.1	0.5	2.1
Oilseed rape	April	5.0	0.5	2.1	0.3	4.7***	5.1	0.2	2.6	0.5	0.4

(P<0.001=***, P<0.01=**, P<0.05=*).

Table 5. Significant relationships between invertebrate catch in fenced and unfenced pitfall traps

Genus	Relationship	r^2	Significance
Bembidion spp.	$y = 0.80x + 0.63$	0.24	P<0.001
Harpalus spp.	$y = 1.66x + 0.35$	0.41	P<0.001
Pterostichus spp.	$y = 0.93x + 0.51$	0.42	P<0.001
Trechus spp.	$y = 1.09x + 0.42$	0.33	P<0.001
Anotylus spp.	$y = 1.1x + 0.63$	0.36	P<0.001
Tachyporus spp.	$y = 1.32x + 0.49$	0.34	P<0.001

chance that taxa from these two groups would be captured in the unfenced pitfall traps regardless of their relative abundance. The differences between some of the taxa studied were, however, relatively small and this explains why there were some linear relationships between the two techniques. The Staphylinidae were more likely to be captured in the fenced pitfall traps. This was probably because enclosing them altered their behaviour. They may have spent more time on the ground searching for a way out of the enclosures and therefore increased their likelihood of encountering the pitfall trap. The differences between fenced and unfenced pitfall traps found by Mommertz et al. (1996) were attributed to beetle body size with more smaller carabid beetles and smaller staphylinid beetles being captured in the fenced pitfall traps. The smaller species were the most frequently caught in this study, but in both trap types. Crop type and date of sampling may affect the numbers captured using unfenced pitfall traps because they are, to some extent, activity dependant. Thus the relationship to the fenced traps may change through the season and is the likely explanation for the differences found here and between the cereal and grass meadows studied by Mommertz et al. (1996).

The relationship between the trapping techniques may also have varied through time because of differences in the activity of individual species. Increased activity can be caused by many factors such as hunger or breeding behaviour and this would increase their likelihood of capture in a pitfall trap (Adis, 1979). This can be overcome by taking samples using pitfall traps throughout the whole year and using the totals, thereby overcoming seasonal variation in activity occurring in response to environmental conditions. This method was used by Baars (1979) who found strong relationships between densities of beetles estimated by trapping within enclosures compared to unfenced pitfall traps. Our study also showed that unfenced pitfall traps, despite all their limitations, can provide some estimate of beetle density although the relationships found between beetle density and unfenced pitfall traps were weaker than those found by Baars. However, whole-year sampling is very labour intensive and not always possible within annual crops. Where a robust relationship between the two trap types has been shown then invertebrate densities could be estimated across a wider area in which only unfenced pitfall traps were present. It would, however, be prudent to confirm the relationship using some fenced pitfall traps operating alongside the unfenced traps.

Fenced pitfall traps are more suitable than unfenced pitfall traps in studies where beetle activity may vary through the course of a study in response to experimental inputs. Insecticide trials, for example are typically monitored using pitfall traps but may give a misleading impression of the effect (Luff, 1987) because pesticides increase activity either through a direct stimulatory effect (Miller & Adams, 1982; Heneghan, 1992) or by increased hunger (Mols, 1987) and searching for a scarcer prey.

Comparative studies on the efficiency of pitfall and fenced pitfall traps have only rarely examined Araneae (Basedow & Rzehak, 1988) and only in detail for Lycosidae (Mommertz et al., 1996) although this family is highly unsuitable for assessment using fenced pitfall traps because they may move away as investigators approach (Uetz & Unzicker, 1976). The relative proportion of each linyphiid genus captured using unfenced and fenced pitfall traps was different in this study, although relatively small but no linear relationships between the two techniques were found confirming these differences. This would be expected given the inefficiency of pitfall traps for Linyphiidae (Topping & Sunderland, 1992). They, however, continue to be used because of their ease of use in extensive studies. Both techniques yielded very few immature Linyphiidae and were probably underestimating their densities given that over a season only 33% of those sampled were adult using a Dietrick Vacuum Sampler and surface searching (Topping & Sunderland, 1992). The linyphiids were not separated into different sexes although it is likely that the relationship between the two techniques may differ with sex because males are more active than females and therefore more frequently captured in unfenced pitfall traps.

The efficiency of the fenced pitfall traps may be improved by using more pitfall traps within each enclosure, although the 36 traps used by Ulber & Wolf-Schwerin (1995) increased the setting up period to two to three man hours per trap and thereby their usefulness for more extensive studies. These authors found that four traps per 0.5 m^2 enclosure only captured 73% of the carabids. In contrast one to three traps in conjunction with guiding plates have been used in fenced pitfall traps (Desender & Maelfait, 1986; Sunderland et al., 1987; Desender & Alderweireldt, 1988) and emergence traps (Kromp et al., 1995). The mark-release-recapture revealed that only one trap per enclosure was sufficient in most cases for this size of trap although reliability may be improved using a guiding plate. Surface searching within the enclosure at the end of the trapping period would make the technique more suitable for estimating the density of those species not readily caught using pitfall traps.

In conclusion, fenced pitfall traps appear to be suitable for estimating the density of some epigeal arthropod species. However, for the technique to be effective traps must be at sufficient density to be sampled within the relatively small sampling area possible. Capture efficiency is still dependent to some extent on activity and thus may be effected by environmental factors, such as temperature. These are overcome to some extent if the traps are in place for long enough. In this study most of the carabid species were captured within one week. They are advantageous compared to suction sampling because nocturnal species are also trapped and the density of vegetation is less influential. There is a need to standardise the enclosures construction and number of pitfall traps used to facilitate comparisons between studies.

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References

Adis, J., 1979. Problems of interpreting arthropod sampling with pitfall traps. Zoologischer Anzeiger Jena 202: 177–184.

Aebischer, N. J., P. A. Robertson & R. E. Kenward, 1993. Compositional analysis of habitat use from animal radio-tracking data. Ecology 74: 1313–1325.

Aitchison, J., 1986. The Statistical Analysis of Compositional Data. Chapman and Hall, London, UK.

Baars, M. A., 1979. Catches in pitfall traps in relation to mean densities of carabid beetles. Oecologia (Berl.) 41: 25–46.

Basedow, T., 1973. Der Einfluss epigäischer Raubarthropoden auf die Abundanz phytophager Insekten in der Agrarlandschaft. Pedobiologia 13: 410–422.

Basedow, T. & H. Rzehak, 1988. Abundanz und Aktivitätsdichte epigäischer Rauparthropoden auf Ackerflächen – ein Vergleich. Zoologische Jahrbuch Systematik 115: 495–508.

Bayon, F., A. Fougeroux, J. N. Reboulet & J. P. Ayrault, 1983. Utilisation et intérêt de l’aspirateur ‘D-vac’ pour la détection et le suivi des populations de ravageurs et d’auxiliaires sur blé au printemps. La Défense des Végétaux 223: 276–297.

Bonkowska, T. & L. Ryszkowski, 1975. Methods of density estimation of carabids in fields under cultivation. Polish Ecological Studies 1: 155–171.

Dennison, D. F. & I. D. Hodkinson, 1984. Structure of predatory beetle community in a woodland soil ecosystem. IV. Population densities and community composition. Pedobiologia 26: 157–170.

Desender, K. & M. Alderweireldt, 1988. Population dynamics of adult and larval carabid beetles in maize field and its boundaries. Journal of Applied Entomology 106: 13–19.

Desender, K. & J. P. Maelfait, 1983. Population restoration by means of dispersal, studied for different carabid beetles (Coleoptera, Carabidae) in a pasture ecosystem. In: P. Lebrun, H. M. Andre, A. De Medts, C. Gregoire-Wibo & G. Wauthy G. (eds), New Trends in Soil Biology. Dieu-Brichart, Ottignies-Louvain-la-Neuve, pp. 541–550.

Desender, K. & R. Segers, 1985. A simple device and technique for quantitative sampling of riparian beetle populations with some carabid and staphylinid abundance estimates on different riparian habitats (Coleoptera). Review d'Écologie et de Biologie du Sol 22: 497–506.

Desender, K. & J. P. Maelfait, 1986. Pitfall trapping within enclosures: a method for estimating the relationship between the abundances of coexisting carabid species (Coleoptera, Carabidae). Holarctic Ecology 9: 245–250.

Desender, K., D. van den Broeck & J. P. Maelfait, 1985. Population biology and reproduction in *Pterostichus melanarius* Ill. (Coleoptera, Carabidae) from a heavily grazed pasture ecosystem. Mededelingen Fakulteit Landbouwwetenschappen Rijksuniversiteit Gent 50: 567–575.

Dinter, A., 1995. Estimation of epigeic spider population densities using an intensive D-vac sampling technique and comparison with pitfall trap catches in winter wheat. Acta Jutlandica 70: 23–32.

Duffey, E., 1980. The efficiency of Dietrick Vacuum Sampler (D-VAC) for invertebrate population studies in different types of grassland. Bulletin of Ecology 11: 421–431.

Edwards, C. A. & K. E. Fletcher, 1971. A comparison of extraction methods for terrestrial arthropods. In: J. Phillipson (ed.), Methods of Study in Quantitative Soil Ecology: Production and Energy Flow. JBP Handbooks, 18: 150–185.

Forsythe, T. G., 1987. Common Ground Beetles. Richmond Publishing Co., England.

Funke, W., 1971. Food and energy turnover of leaf-eating insects and their influence on primary production. Ecological Studies 2: 81–93.

Gist, C. S. & D. A. Crossley, 1973. A method of quantifying pitfall trapping. Environmental Entomology 2: 951–952.

Halsall, N. B. & S. D. Wratten, 1988. The efficiency of pitfall trapping for polyphagous predatory Carabidae. Ecological Entomology 13: 301–310.

Hand, S. C., 1986. The capture efficiency of the Dietrick vacuum insect net for aphids on grasses and cereals. Annals of Applied Biology 108: 233–241.

Harde, K. W., 1984. A Field Guide in Colour to Beetles. Octopus Books Ltd., London, UK.

Helenius, J., 1995. Use of emergence traps for estimating recruitment rates of teneral Carabidae in agricultural habitats. Acta Jutlandica 70: 101–112.

Heneghan, P. A., 1992. Assessing the effect of an insecticide on predatory ground beetles. Aspects of Applied Biology 31: 113–119.

Holland, J. M., M. V. Hewitt & A. D. Drysdale, 1994. Predator populations and the influence of crop type and preliminary impact of integrated farming systems. Aspects of Applied Biology 40: 217–224.

Holliday, N. J., 1977. Sex determination in living adult ground beetles (Coleoptera:Carabidae). Canadian Entomologist 109: 397–398.

Honek, A., 1988. The effect of crop density and microclimate on pitfall trap catches of Carabidae, Staphylinidae (Coleoptera), and Lycosidae (Araneae) in cereal fields. Pedobiologia 32: 233–242.

Kromp, B., Ch. Pflügl, R. Hradetzky & J. Idinger, 1995. Estimating beneficial arthropod densities using emergence traps, pitfall traps and the flooding method in organic fields (Vienna, Austria). Acta Jutlandica 70: 87–100.

Luff, M. L., 1975. Some features influencing the efficiency of pitfall traps. Oecologia 19: 345–357.

Luff, M. L., 1987. Biology of polyphagous ground beetles in agriculture. Agricultural Zoology Reviews 2: 237–278.

Miller, T. A. & M. E. Adams, 1982. Mode of action of pyrethroids. In: J. R. Coats (ed.), Insecticide Mode of Action. Academic Press, New York, pp. 3–27.

Mols, P. J. M., 1987. Hunger in relation to searching behaviour, predation and egg production of the carabid beetle *Pterostichus coerulescens* L.: results of simulation. Acta Phytopathologica et Entomologica Hungarica 22: 187–205.

Mommertz, S., C. Schauer, N. Kösters, A. Lang & J. Filser, 1996. A comparison of D-vac suction, fenced and unfenced pitfall trap sampling of epigeal arhtropods in agro-ecosystems. Annales Zoologici Fennici 33: 117–124.

Sunderland, K. D. & C. J. Topping, 1995. Estimating population densities of spiders in cereals. Acta Jutlandica 70: 13–22.

Sunderland, K. D., C. Hawkes, J. H. Stevenson, T. McBride, L. E. Smart, P. I. Sopp, W. Powell, R. J. Chambers & O. C. R. Carter, 1987. Accurate estimation of invertebrate density in cereals. Bulletin SROP/WPRS 1987/X/1: 71–81.

Sunderland, K. D., G. R. De Snoo, A. Dinter, T. Hance, J. Helenius, P. Jepson, B. Kromp, F. Samu, N. W. Sotherton, S. Toft & B. Ulber, 1995. Density estimation for invertebrate predators in agroecosystems. Acta Jutlandica 70: 133–164.

Thiele, H.-U., 1977. Carabid Beetles in their Environments. Springer-Verlag, Berlin.

Topping, C. J. & K. D. Sunderland, 1992. Limitations to the use of pitfall traps in ecological studies exemplified by a study of spiders in a field of winter wheat. Journal of Applied Ecology 29: 485–491.

Topping, C. J. & K. D. Sunderland, 1994. Methods for quantifying spider density and migration in cereal crops. Bulletin of the British Arachnological Society 9: 209–213.

Uetz, G. W. & J. D. Unzicker, 1976. Pitfall trapping in ecological studies of wandering spiders. Journal of Arachnology 3: 101–111.

Ulber, B. & G. Wolf-Schwerin, 1995. A comparison of pitfall trap catches and absolute density estimates of carabid beetles in oilseed rape fields. Acta Jutlandica 70: 77–86.