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A comparison of D-Vac suction, fenced and unfenced pitfall trap sampling of epigeal arthropods in agro-ecosystems

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The aim of this study was to compare relative abundance of epigeal arthropods caught with either unfenced pitfall traps, traps within fences or D-Vac suction sampling in arable habitats (two fields and two meadows). From our results we conclude that short-term D-Vac suction sampling is not appropriate for the three taxa Carabidae, Staphylinidae, and Lycosidae because relatively large and heavy individuals are underestimated. Fenced and unfenced traps yielded different estimates of the relative abundance of Carabidae and Staphylinidae: unfenced traps overestimated the percentage of Carabidae present but underestimated the Staphylinidae. The dominance structure of the carabid assemblages at the sampling sites was more similar for the two trapping methods than for the four sites. In arable fields body size seemed to be the main factor in determining the catch, but in meadows the trapping efficiency was possibly influenced by other variables. Additional laboratory experiments were carried out to observe the influence of behaviour on pitfall trap efficiency. Species specific behaviour was shown to bias results even between species of the same genus (*Poecilus*). We suggest that in arable habitats, fenced pitfall traps should be used at least in addition to unfenced traps. The former allow the standardisation of data to a certain area, whereas the latter are needed to sample large species and to determine activity patterns.

1. Introduction

Methods commonly used when studying epigeal arthropods in the field include unfenced pitfall traps, fenced pitfall traps, and D-Vac suction sampling (Sunderland *et al*. 1995). The use of pitfall traps is the most widespread method for catching epigeal arthropods (e.g. Spence & Niemelä 1994). Studies concerning the various factors which influence the efficiency of these traps have been listed by Adis (1979) and Sunderland *et al*. (1995). According to these authors the use of unfenced pitfall traps is only advisable in intensive, long-term studies on the population dynamics of epigeal arthropods and in determining their relative abundances. Furthermore, the results might only be comparable within species (Baars 1979), within habitats (e.g. Loreau 1992) and between habitats of similar structure and history (e.g. Luff *et al*. 1992). However, short term studies have also been shown to yield representative results (Niemelä *et al*. 1990), when interpreted with care (Maelfait & Desender 1990). Until now research on the methodological problems of the above sampling methods has been carried out mainly in grassland or forests. Hence, we do not know whether the conclusions described above are also valid for more ephemeral and disturbed habitats such as arable fields (Topping & Sunderland 1992).

For more detailed studies on epigeal arthropods the use of fenced traps, photoeclectors or D-Vac suction samples has been recommended (Sunderland *et al*. 1995 and references therein), as the area sampled is standardised. However, constructing enclosures, such as photoeclectors or fenced traps, is very laborious and time consuming. D-Vac suction sampling is judged to be suitable for quick and representative collection of many arthropod taxa living in the vegetation layer (Duffey 1974); but it is not adequate for the collection of heavy insects or species which are able to burrow into the ground. This problem can be overcome by clipping vegetation, searching the ground and taking additional litter and soil samples (e.g. Sunderland *et al*. 1987, Dinter 1995), however, in many cases such a destruction of the habitat might not be acceptable. Therefore, the decision as to which methods are appropriate depends strongly on both the objective and the type of the study. In general, comparative data on the efficiency of different methods used for the estimation of density or abundance of invertebrate predators are still lacking (Sunderland *et al*. 1995).

We have been confronted with the sampling problem during our studies on an agricultural area, where we collect data on epigeal invertebrate predators (Mommertz *et al*. 1995). Data must be obtained as quickly and cheaply as possible, and habitat disturbance must be kept to a minimum. Therefore, we use pitfall traps. To gain more information on the reliability of our pitfall catches we carried out field experiments to evaluate and compare the trapping efficiency of short D-Vac suction samples (without destroying the habitat), and fenced and unfenced traps with regard to the relative abundances of Carabidae, Staphylinidae, and Lycosidae. Since additional studies of species specific behaviour towards traps are necessary to interpret catches (e.g. Greenslade 1964, Luff 1975, Halsall & Wratten 1988, Topping 1993), a laboratory experiment was conducted to determine the trapping efficiency of pitfall traps with respect to two carabid species.

The aims of this study were: first, to compare estimates of the relative abundances of taxa within epigeal arthropod communities which were obtained by either fenced pitfall trapping, unfenced pitfall trapping or non-destructive D-Vac sampling, and second, to find out whether there are species-specific differences in trapping efficiency which can be explained by laboratory observations of behaviour.

2. Materials and methods

2.1. Field experiment

The studies were carried out within the FAM research network (Forschungsverbund Agrarökosysteme München). This project is a long-term (15 years) study aimed at the registration, prognosis and evaluation of environmental changes in agroecosytems caused by different management practices (Beese *et al*. 1996). Four sites — two meadows and two cereal fields — were chosen at the FAM experimental farm in Bavaria about 40 km north of Munich. Soil properties, management and vegetation cover varied among the sites (Table 1). The distance between each of the sites averaged 600 m.

Sampling by unfenced pitfall traps, fenced traps and D-Vac suction was carried out in June 1992, October 1992 and April 1993. At each sampling date and site 5 replication units were taken. A replication unit was arranged in form of an equilateral triangle with 3 m long sides. At the corner points of a replicate triangle the three different sampling methods were carried out. The positions of the replicate triangles were chosen at random on a 20 × 25 m plot in the centre of each site, and the distance between each replicate triangle was at least 5 m. The pitfall traps consisted of plastic funnels (8 cm in diameter) with a plastic bottle containing ethylene glycol and detergent, fixed at the bottom. Traps were covered with a tin roof (10 × 10 cm) to protect them from rainfall. For fenced trap sampling a single trap was surrounded by a plastic ring (25 cm high, buried 5 cm in the soil, covering 0.25 m^2). A tent-like cover made of grey non-transparent cloth prevented immigration and emigration. Daylight entered via an opening at the top (7.5 cm in diameter) covered with a transparent plastic lid. A one week sampling time was chosen for unfenced traps, as this is the standard length of monitoring period used in our project. Two weeks were chosen for fenced traps, as this was judged to be necessary to empty the trapping area (personal observations and Bonkowska & Ryszkowski 1975).

The D-Vac suction apparatus had a 2.2 kW motor and a nozzle with a diameter of 35 cm, which was held in contact with the soil surface during sampling. Plastic rings, as described above, enclosed each of the sample areas and sampling lasted for 90 seconds. This sampling time was chosen because destruction of sites had to be kept to a minimum and longer suction times would have been too time consuming for the routine monitoring used in our project. For the same reasons there was no additional sampling of vegetation or ground in conjunction with the D-Vac samples.

The body lengths of Staphylinidae, Lycosidae and Carabidae were measured to estimate biomass (mg dry weight) from regression equations given in the literature (Rogers *et al*. 1976 for Staphylinidae, Breymeyer 1967 for Lycosidae, and Jarosik 1989 for Carabidae). Carabid beetles were identified to species after Freude *et al*. (1965). Statistical analysis of the data was carried out using SPSS for Windows (Norusis Inc., Version 6.01). Since the population density was low for most taxa during autumn 1992 and spring 1993, only summer data (June 1992) have been taken into account, unless otherwise indicated.

2.2. Laboratory experiment

The behaviour of *Poecilus versicolor* and *P. cupreus* (Carabidae) towards pitfall traps was studied. Both species are common in our study area and are mainly active during the daytime (personal observations and Kegel 1990). A plastic box with an area of 60 × 40 cm served as an "arena" for the observations. It was filled with soil (sieved to 2 mm) and planted with tussocks of winter wheat taken from the field. The winter wheat was planted in 4 rows parallel to the short sides of the box with a separation of one cm between tussocks and 15 cm between rows. It was clipped to a height of 20 cm to facilitate observation. 8 pitfall traps (as described for the field experiment, but without trapping fluid) were buried in the boxes in two rows parallel to the long sides of the box. Traps were placed at equal distances from each other and at similar distances from the sides of the box between the plant rows. The animals were kept at 20°C with a natural light–dark cycle and a constant food supply before experiments. Each animal was placed in a metal ring in the middle of the arena. The ring was removed after 3 minutes, when the animal had overcome the disturbance caused by transferring it to the arena. Only one animal was observed at a time. "Survival time" (i.e. duration until a specimen was caught in a trap) and "number of traps touched" were recorded. If the animal was not caught within 15 minutes, the experiment was terminated at that point.

3. Results

3.1. Field experiment

The absolute numbers of individuals caught by all methods are shown in Table 2. Unfenced traps generally yielded higher numbers of carabid beetles and lower numbers of staphylinid beetles than fenced traps. Due to low numbers of individuals in the fields it was not possible to judge differences in sampling efficiency for lycosid spiders. In most cases D-Vac samples contained lower numbers of all taxa than the fenced traps placed in an area of the same size. Only small numbers of carabids were caught by D-Vac suction samples. At all sites fenced pitfall traps

Table 1. Vegetation cover and management of sampling sites.

	June 1992	October 1992	April 1993
Field S (sandy), Size: 3.2 ha			
% Vegetation Cover	67	0	15
Crop	summer barley	none	winter wheat
Management	recently sprayed	ploughed with herbicide	none
Field L (loamy), 6.5 ha			
% Vegetation Cover	53	0	20
Crop	spring barley	none	spring wheat
Management	recently sprayed	ploughed with herbicide	none
Meadow G (gravely), 0.5 ha			
% Vegetation Cover	90	90	90
Management	recently mown	none	none
Meadow L (loamy), 1.5 ha			
% Vegetation Cover	100	100	100
Management	recently mown	none	none

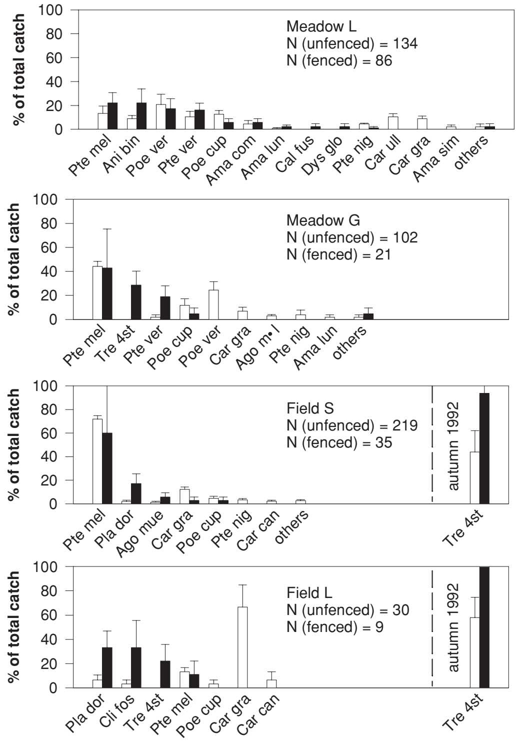

Fig. 1. Dominance structure of Carabidae in pitfall traps in June 1992 (unfenced = open bars, fenced = black bars). Error bars are standard errors. For the fields, autumn data of *Trechus quadristriatus* are shown additionally (sum of individuals: Field S: *N* unfenced = 7, *N* fenced = 32; Field L: *N* unfenced = 12, *N* fenced = 36). Abbreviations: Ama com – *Amara communis*, Ama lun – *A. lunicollis*, Ama sim – *A. similata*, Ani bin – *Anisodactylus binotatus*, Ago mül – *Agonum mülleri*, Cal fus – *Calathus fuscipes*, Car can – *Carabus cancellatus*, Car gra – *Carabus granulatus*, Car ull – *Carabus ullrichi*, Cli fos – *Clivina fossor*, Dys glo – *Dyschirius globosus*, Not big – *Notiophilus biguttatus*, Pla dor – *Platynus dorsalis*, Poe cup – *Poecilus cupreus*, Poe ver – *P. versicolor*, Pte mel – *Pterostichus melanarius*, Pte nig – *P. niger*, Pte ver – *P. vernalis*, Tre 4st – *Trechus quadristriatus*.

and D-Vac samples were dominated by staphylinid beetles. Unfenced pitfall traps were dominated by carabid beetles at three of the four sites.

Because of the low individual numbers in the D-Vac samples, a more detailed analysis was carried out with just the pitfall data: a description of relative abundances of Staphylinidae, Carabidae, and Lycosidae in fenced and unfenced traps is given in Table 3. A χ^2-test revealed significant differences between the methods with respect to numbers and biomass at three of the four sites ($p < 0.001$).

The degree of deviation between observed and expected values in the calculation of the χ^2-test was high for Carabidae and Staphylinidae, and low for Lycosidae. This indicated that the contribution of the first two groups to the significant difference was higher than that of the latter. The difference between the methods was greater in terms of biomass than in individual numbers, this was because the mean body size of Staphylinidae was smaller (6.1 ± 2.5 mm) than that of Carabidae (12.3 ± 5.5 mm).

At all four sites, unfenced traps yielded more carabid species than fenced traps (Fig. 1). For example, all three *Carabus* species occurring in the study area could only be detected when using unfenced traps. Other species generally caught in higher percentages in unfenced traps compared to fenced traps were both *Poecilus* species, *Pterostichus niger*, and *P. melanarius* (only in the field). For *T. quadristriatus* data from autumn 1992 are also shown as it had its activity maximum during this time of year.

A cluster analysis of the dominance structures for each site and each method revealed that differences between the collection methods were always smaller than between the sites (Fig. 2). Fenced as well as unfenced traps alone would have led to the same conclusion: Field S and Meadow G are most similar to each other (caused by a dominance of *P. melanarius* at both sites), whereas

Table 2. Summary of catches (number of individuals) of Carabidae (Car), Staphylinidae (Sta), and Lycosidae (Lyc) in fenced and unfenced traps and in D-Vac samples at the four sites and the three sampling dates.

Site Method	Taxon Car	 Sta	 Lyc	Sum
Meadow L				
unfenced	151	80	52	283
fenced	91	142	66	299
D-Vac	2	54	44	100
Meadow G				
unfenced	108	36	54	198
fenced	23	27	15	65
D-Vac	3	32	5	40
Field S				
unfenced	229	53	6	288
fenced	68	95	0	163
D-Vac	5	39	0	44
Field L				
unfenced	43	108	7	158
fenced	47	349	0	396
D-Vac	8	32	3	43

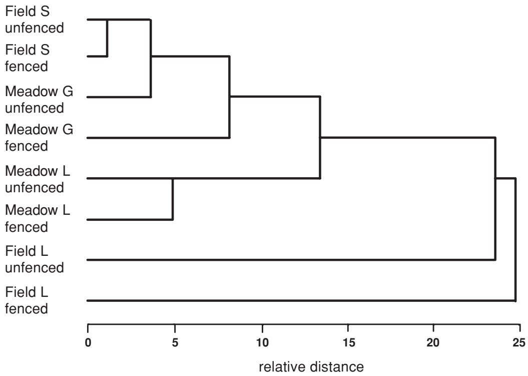

Fig. 2. Comparison of relative abundances of carabid species by cluster analysis based on cosine coefficients of similarity for summer 1992. The dendrogram was built using complete linkage.

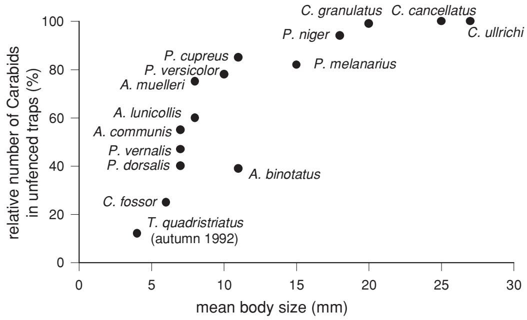

Fig. 3. The effect of body size on the efficiency of fenced and unfenced traps. Data from all sites and both methods have been pooled, and for each species the percentage of individuals in unfenced traps was calculated and plotted against mean body size.

Field L with the smallest number of species is the least similar.

Furthermore, we examined the relationship between body size and trapping method (Fig. 3). When comparing fenced with unfenced traps, the larger the species the higher the proportion caught by unfenced traps (Spearman´s rank correlation coefficient = 0.91, $p < 0.001$). For example, the large *Carabus* species were found almost exclusively in unfenced traps, whereas *T. quadristriatus*, the smallest species, occurred most frequently in fenced traps. When the correlation between body size and trapping efficiency was recalculated for each site separately (including the autumn data of *Trechus quadristriatus*) the resulting coefficients were significant for the fields (0.93 for Field S, 0.99 for Field L, $p < 0.001$ in both cases) but not for the meadows (0.51 for Meadow G, 0.49 for Meadow L).

3.2. Laboratory experiment

In an artificial winter wheat field *P. cupreus* touched seven times more traps per second than *P. versicolor* and was trapped within almost half the time ($p < 0.05$, Table 4). This shows that differences in activity and trapability occur even within the same genus in beetles of similar body size.

4. Discussion

There were pronounced differences in the results derived from each sampling method. In the two arable fields with their low ground cover we would have expected relative abundances, estimated by D-Vac suction samples, similar to those derived from fenced traps. However, our results show that a non-destructive sampling of 90 s is not appropriate for collecting ground dwelling beetles (Carabidae and Staphylinidae), as the relatively larger and heavier individuals are not captured. A more intensive sampling of the area is necessary to detect Carabidae and Staphylinidae hiding under plants and litter or buried in the ground (Sunderland *et al*. 1987). For spiders D-Vac suction sampling has been reported to be more effective than pitfall trapping, except for Lycosidae (Merret & Snazell 1983, Dinter 1995).

Table 3. Relative abundances of individuals and biomass of Carabidae (Car), Staphylinidae (Sta), and Lycosidae (Lyc) in fenced and unfenced traps at the four sites in summer 1992. Differences between methods have been tested with χ^2-tests.

Site	Method						
	unfenced traps			fenced traps			
	Car	Sta	Lyc	Car	Sta	Lyc	$p <$
Meadow L							
% Individuals	53	30	17	33	49	18	0.001
% Biomass	93	4	3	64	33	3	0.001
Meadow G							
% Individuals	58	15	27	52	39	9	
% Biomass	87	5	8	88	9	3	
Field S							
% Individuals	88	10	2	56	44	0	0.001
% Biomass	98	1	1	85	15	0	0.001
Field L							
% Individuals	65	26	9	12	88	0	0.001
% Biomass	96	3	1	19	81	0	0.001

This is confirmed by our study, where pitfall traps caught higher numbers of Lycosidae than D-Vac samples. We therefore conclude that D-Vac suction sampling is not appropriate for the three taxa Carabidae, Staphylinidae, and Lycosidae, if used for short sample times similar to those in our study.

Fenced and unfenced traps produced contradictory results for individual numbers and biomass of Carabidae and Staphylinidae in three of the four sites under investigation. Carabidae dominated the group of predatory arthropods by number and biomass in unfenced traps, while Staphylinidae was the most important group in fenced traps. This is probably caused by the fact that inside the fence the trap encounter rate is generally increased. Results for Lycosidae are difficult to interpret because of their low individual numbers in fenced traps. Cluster analysis of similarity coefficients obtained for the relative abundances of carabid species revealed that the differences between the collection methods were always smaller than those between the sites. Two interpretations could explain this pattern: first, both methods reflect the "real" dominance structure and, therefore, give similar results. Second, both methods sampled relative abundances on the microhabitat scale (separation between types of trap = 3 m compared to distance between sites = 600 m) with equal effectivity, i.e. the coefficients of similarity reflect only spatial distances between the samples. However, as we were mainly interested in the comparison of the methods, the conclusion that both methods would have provided us with similar results with respect to dominance structure is sufficient for our purpose.

The low densities of Lycosidae and Carabidae in fenced traps might be partially a consequence of individuals escaping before the fences were built — at least in the fields (Dinter 1995). However in both fields the number of Lycosidae in the unfenced traps was also low indicating that they were in fact present only in low numbers. In the meadows, vegetation on the ground should have been dense enough to prevent the escape of spiders, and therefore the data probably reflect the differences between real densities and activity densities. However, for Carabidae, escaping has to be taken into account at the field sites, especially because of the small size of the enclosures. The major difference between methods revealed by the cluster analysis of Field L might be such an artifact, as this difference is mainly caused by the absence of the large *C. granulatus* in the fenced traps.

It is well known that many factors affect pitfall catches (Sunderland *et al.* 1995 and references therein). They can be divided into three groups: trapping technique, structure of the habitat(s) to be sampled and specific characteristics of the animals to be caught. The first group includes the disturbance of the animals caused by digging the traps and depletion of the habitat if traps are placed too close (less than 10 m) together (Digweed *et al.* 1995). This was possibly valid for our own study, as the mean distance between replicate unfenced traps was only 5 m. However, since we assume that the area influenced by a trap varies with the type of vegetation, it is impossible for us to assess the amount of bias caused by the spatial arrangement of the traps in our study. This leads to the second group of factors influencing trapping results: the structure of the habitat, namely its vegetation and soil properties. From long-term studies it is known that differences in soil properties such as those between Field S and Field L may cause differences in the relative abundances of carabid species even if vegetation cover and crop management are the same (e.g. Thiele 1977 and references therein). Furthermore, species specific traits such as diurnal activity, body size and behaviour towards traps can influence the catches. Diurnal activity may bias the catches in two ways: first, it is possible that building fenced traps during daylight, as we did, leads to an underestimation of nocturnal species, which may not be present in the habitat during daytime. Second, species hunting during daylight are more mobile than nocturnal species and are therefore overestimated by unfenced traps (Desender & Maelfait 1986). In our study, however, there were no consistent differences between the methods in the relative abundances of day or night active carabid species.

Table 4. Species specific behaviour towards pitfall traps. Values are given as means ± standard error. Differences between species are significant with $p < 0.5$ (Mann-Whitney *U*-test).

	Species	
	P. cupreus	*P. versicolor*
number of individuals	14	16
Parameter		
survival time (sec)	395 ± 107	702 ± 88
number of traps touched per second	0.028 ± 0.011	0.004 ± 0.001

Body size seemed to be the main factor affecting differences in the number of species, species composition and relative abundances of carabid beetles between fenced and unfenced traps in our study. Larger species were caught more often in unfenced traps. This is in accordance with other authors who found that larger specimens tend to be overestimated by unfenced traps compared to litter samples (Franke *et al.* 1988, Spence & Niemelä 1994). In the two meadows other factors — as mentioned above — seem to be more important.

That species specific behaviour can lead to differences in trapability even between species which have approximately the same body size and are closely related, was shown in our laboratory experiment. The more active (as indicated by the higher trap encounter rate) *P. cupreus* was trapped significantly faster than *P. versicolor*. These and other observations (Lang *et al.* unpublished data) seem to corroborate and supplement the observations of Halsall & Wratten (1988) for Carabidae and of Topping (1993) for spiders, where large differences in trapability were detected even between species running with the same speed. Our data suggest that it is necessary to perform further laboratory experiments on species-specific behaviour towards traps under varying conditions. This is especially important for studies of predator-prey relationships since it is frequently discussed that numbers of epigeal predators obtained from unfenced traps should reflect encounter rates with prey, and hence results may directly represent the relative importance of the predators caught (Spence & Niemelä 1994).

We conclude that in most cases fenced traps should be preferred for the study of epigeal arthropods because they allow the standardisation of the catch to a certain area and reflect the relative abundances of species within the epigeal arthropod communities. Compared to unfenced traps they catch a greater proportion of Staphylinidae, a predator group which is very important in agro-ecosystems (Poehling *et al.* 1985). Moreover, most specimens present within the fence will be obtained irrespective of individual behaviour, this is not possible when using unfenced traps or D-Vac suction sampling. However, unfenced traps also have advantages: they are not only cheap and easy to establish, they also provide more information on the number of species present in a habitat, and possibly more closely reflect the encounter rates with prey specimens than other methods. Since fenced traps also have shortcomings, we suggest that for studies of epigeal arthropods in arable land a combination of both, fenced and unfenced traps should be used. For the reasons outlined above, epigeal arthropods will continue to be predominantly collected by unfenced pitfall traps alone. However, the mere fact of being commonly used does not mean that we have all the information for how to interpret data derived from this method.

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