Composition and diversity of spring-active carabid beetle assemblages in relation to soil management in organic wheat fields in Denmark

Gabor L. Lövei[1], Søren Toft[2] & Jørgen A. Axelsen[3]

[1]Danish Institute of Agricultural Sciences
Department of Crop Protection
Research Centre Flakkebjerg
DK-4200 Slagelse
Denmark
E-mail: gabor.lovei[a]agrsci.dk

[2]Institute of Biological Sciences
University of Aarhus
Bldg. 135
DK-8000 Århus C
Denmark

[3]Department of Terrestrial Ecology
National Environment Research Institute
Vejlsøvej 25
DK-8600 Silkeborg
Denmark

Abstract

Patterns in spring-active carabid beetle assemblages were described in relation to four organic soil management regimes (no soil nutrient addition, undersowing, animal manure, undersowing + manure) in two areas of Denmark by means of pitfall trapping. On the island of Zealand, the Flakkebjerg study area had 22 species, 3-10 species/trap, and the species rank of these was the same for all treatments. The dominant species were *Pterostichus melanarius, Agonum dorsale, Harpalus rufipes* and *Calathus fuscipes*. At Foulum, Jutland, there were 46 species, 12-15 species/ trap, dominated by *P. versicolor, P. melanarius, A. dorsale* and *Nebria brevicollis.* Their rank, however, was not the same for all treatments. There were remarkable differences in the carabid assemblages of the two sites, and manure addition modified the assemblages, more pronouncedly so in the poorer-soil Flakkebjerg site. However, we did not detect clear effects of the treatments on carabid species richness, overall abundance or on *Pterostichus melanarius* alone.

Key words: Soil fertilisation, undersowing, manure, assemblage composition, carabids, diversity scaling

Introduction

Polyphagous predators can survive on many different types of prey and this enables them to persist in habitats that experience fluctuations in prey availability (Symondson *et al.,* 2002). In seasonal climates, however, this fluctuation can result in a complete lack of food, and a subsequent dormancy (not necessarily caused by the lack of food but climatic constraints). A critical period for polyphagous predators is when activity in the spring resumes. At this time, activity can be fuelled by reserves built up before the onset of winter, but this is not usually sufficient. Especially for invertebrate predators, prey availability early in the season is critical, and is often critically low (Toft & Bilde, 2002).

Ground beetles (Coleoptera: Carabidae) are among the dominant soil-surface active arthropods in northern temperate ecosystems (Lövei & Sunderland, 1996). Many species of ground beetles occur in cultivated areas, and many of these are obligate or facultative predators. For this reason, ground beetles are usually considered beneficial in agricultural habitats (Lövei & Sunderland, 1996). Carabids also eat soil-born organisms (Hengeveld, 1980), that can, especially in early spring, be an important food source (Toft & Bilde, 2002).

Increased soil nutrient content can support a more rich soil fauna (Wardle, 2002) and it can also subsidise the above-ground food chain. Several examples of soil subsidies to the above-ground food webs are documented, but the potential effect on above-ground predators remains unexplored (Wardle, 2002).

As carabids are prominent predators active on the ground but spend an unknown part of their activity in the soil (Lövei & Sunderland, 1996), it is plausible to assume that soil food webs can subsidise above-ground food webs, specifically ground-active predators, by providing food for them during times of food shortage. If this occurs, we can expect a change in ground beetle assemblage composition, diversity, density, satiation level, or any combination of the above as a result of different soil management practices. We investigated whether ground beetle assemblages responded to different methods of soil nutrient management in an organic crop rotation. At two different locations in Denmark, we found that soil manipulation influenced the ground beetle assemblage in several ways, but undersowing was less influential than fertilising by animal manure on spring-active ground beetle assemblages.

Study area, material and methods

In order to sample carabids, we used selected plots in a long-term organic crop rotation experiment. This experiment has 10 x 10 m treatment plots as base units in a randomised block design, and is repeated exactly at four Danish locations. We selected two of these: at Flakkebjerg (55^{o}19' N, 11 ^{o}23' E), on the island of Zealand and in Foulum (56 ^{o}30' N, 9 ^{o}34' E), on the peninsula of Jutland, Denmark. The individual plots were separated from each other by grass strips, 5 m within rows and 10 m between rows. We selected plots that had first-year wheat crop in the crop rotation sequence. There were four treatments: unfertilised control, undersowing with legumes, fertilising with animal manure and undersowing + manure. Each treatment had four replicate plots per location, giving us a total of sixteen 10 x 10 m sample plots at each location. Full details of the soil manipulation experiment are in Djurhuus & Olesen (2000).

We sampled ground beetles with pitfall traps, setting one trap near the centre of each of the 32 plots selected. Traps were 10 cm diameter plastic cups, containing ca. 200 ml of 70% ethylene glycol and a drop of detergent. In order to protect the catch from rain and scavenging as well as to prevent accidental killing of frogs and small mammals, we used a 25 cm x 25 cm metal cover, secured ca. 5 cm above the trap. Traps were set at the time of aphid immigration, and were checked fortnightly until aphids emigrated from the crop. In Flakkebjerg, this covered the period of 6 June - 18 July 2002 (3 fortnightly samples), and in Foulum, 17 May - 12 July 2002 (4 samples). The catches were sieved on site, and stored in vials with 70% ethyl alcohol until sorting and identification in the laboratory. For identification, keys by Lindroth (1985, 1986) and Hůrka (1996) were used. Nomenclature follows Lindroth (1985, 1986). Voucher specimens are deposited at the Department of Crop Protection, DIAS Flakkebjerg Research Centre, Denmark.

To evaluate diversity, the generalised Rényi entropy equation was used (Tóthmérész, 1995; Lövei *et al*., 2002). Rényi diversity, $HR(a)$, is calculated as follows:

$$HR(a) = \frac{1}{1-a} \log \sum_{i=1}^{S} p_i^a \quad ,$$

where p_i is the relative abundance of the i-th species, and S is the number of species; a is a so-called scale parameter. The equation is interpreted for the range $a \geq 0$, with the restriction that $\alpha \neq 1$. The results are graphically presented as a 'diversity profile'. The diversity profiles were generated by the DivOrd program package (Tóthmérész, 1993). For multivariate analysis (PCA), the NuCoSa program package (Tóthmérész, 1996) was used. For the PCA, no species were excluded, the Matsusita index was used, and the analysis was centered on samples. A repeated measures ANOVA (Sokal & Rohlf, 1995) was used to test for differences in the number of beetles between study areas, treatments and sampling occasions.

Results

Assemblage composition

In Foulum, 46 species were captured (Table 1) with 12-15 species/trap. The most common species were *Pterostichus versicolor, P. melanarius, Agonum dorsale* and *Nebria brevicollis.* Their rank, however, was not the same for all treatments.

Table 1. The total list of the ground beetles captured in pitfall traps in the different soil fertility treatments. Foulum, Jutland, and Flakkebjerg, Zealand, during 2002.

	Total number of beetles captured in the treatment									
	Foulum					Flakkebjerg				
Species	**Control**	**Under-sowing**	**Manure**	**Ma + Us***	**Total**	**Control**	**Under-sowing**	**Manure**	**Ma + Us**	**Total**
Pterostichus versicolor	503	535	185	179	1402	1	6	2	10	19
Pterostichus melanarius	324	399	300	265	1288	1033	965	1380	1363	4741
Agonum dorsale	136	116	126	131	509	130	239	306	434	1109
Nebria brevicollis	134	135	63	137	469	11	10	17	29	67
Bembidion tetracolum	78	43	97	47	265	-	-	-	-	0
Amara plebeja	62	64	39	90	255	-	-	-	-	0
Clivina fossor	44	44	63	39	190	-	-	-	-	0
Harpalus rufipes	66	33	57	33	189	117	86	146	243	592
Harpalus tardus	38	33	38	42	151	-	-	1	-	1
Loricera pilicornis	43	39	38	29	149	1	2	5	3	11
Harpalus affinis	42	36	30	17	125	11	9	12	23	55
Bembidion lampros	44	25	26	18	113	1	1	1	-	3
Amara familiaris	15	11	44	36	106	1	2	2	-	5
Amara aenea	29	9	7	4	49	-	-	-	-	0
Pterostichus niger	7	8	2	17	34	-	-	-	-	0
Synuchus vivalis	5	7	7	6	25	-	-	-	-	0
Trechus obtusus	4	8	4	3	19	-	-	-	-	0
Trechus quadristriatus	9	3	1	2	15	-	-	1	-	1
Calathus cinctus	7	2	2	2	13	-	-	-	-	0
Agonum muelleri	5	2	4	-	11	-	2	-	1	3
Bembidion obtusum	2	4	3	2	11	-	-	-	-	0
Borscus cephalotes	3	3	4	1	11	-	-	-	-	0
Calathus fuscipes	5	5	1	-	11	19	31	27	17	94
Carabus nemoralis	2	2	5	1	10	1	1	1	-	3
Demetrias atricapillus	-	-	-	-	0	-	-	3	7	10
Amara similata	2	1	5	1	9	-	-	-	-	0
Bembidion properans	4	-	3	-	7	-	-	-	-	0

Species	Total number of beetles captured in the treatment									
	Foulum					Flakkebjerg				
	Control	Under-sowing	Manure	Ma + Us*	Total	Control	Under-sowing	Manure	Ma + Us	Total
Calathus melanocephalus	2	4	1	-	7	-	2	1	-	3
Asaphidion flavipes	4	-	-	2	6	-	-	-	-	0
Pterostichus niger	-	-	-	-	0	-	3	2	1	6
Amara bifrons	2	1	1	1	5	-	-	-	-	0
Pterostichus strenuus	-	-	-	5	5	-	-	-	-	0
Stomis pumicatus	1	1	-	2	4	-	-	-	-	0
Amara communis	3	-	-	-	3	-	-	-	-	0
Amara consularis	2	-	1	-	3	-	-	-	-	0
Amara fulva	1	1	1	-	3	-	-	-	-	0
Amara lunicollis	-	2	1	-	3	-	-	-	-	0
Calathus erratus	1	-	1	-	2	-	3	1	1	5
Harpalus rubripes	-	-	2	-	2	-	-	-	-	0
Notiophilus palustris	-	1	1	-	2	-	-	-	-	0
Notiophilus pusillus	2	-	-	-	2	-	-	-	-	0
Pterostichus cupreus		2	-	-	2	-	-	-	-	0
Amara aulica	-	-	-	-	0	-	2	-	-	2
Amara apricaria	1	-	-	-	1	-	-	-	-	0
Anisodactylus binotatus	1	-	-	-	1	-	-	-	-	0
Notiophilus aquaticus	1	-	-	-	1	-	-	-	-	0
Harpalus rufibarbis	-	1	-	-	1	-	-	-	-	0
Trechus micros	1	-	-	-	1	-	-	-	-	0
Amara ovata	-	-	-	-	0	1	-	-	-	1
Notiophilus aquaticus	-	-	-	-	0	1	-	-	-	1
Notiophilus pusillus	-	-	-	-	0	1	-	-	-	1
Total number of individuals	1636	1581	1163	1114	5494	1329	1364	1908	2132	6733
Total numbers of species	40	34	34	28	46	14	16	17	12	22

*** Ma + Us: manure + undersowing**

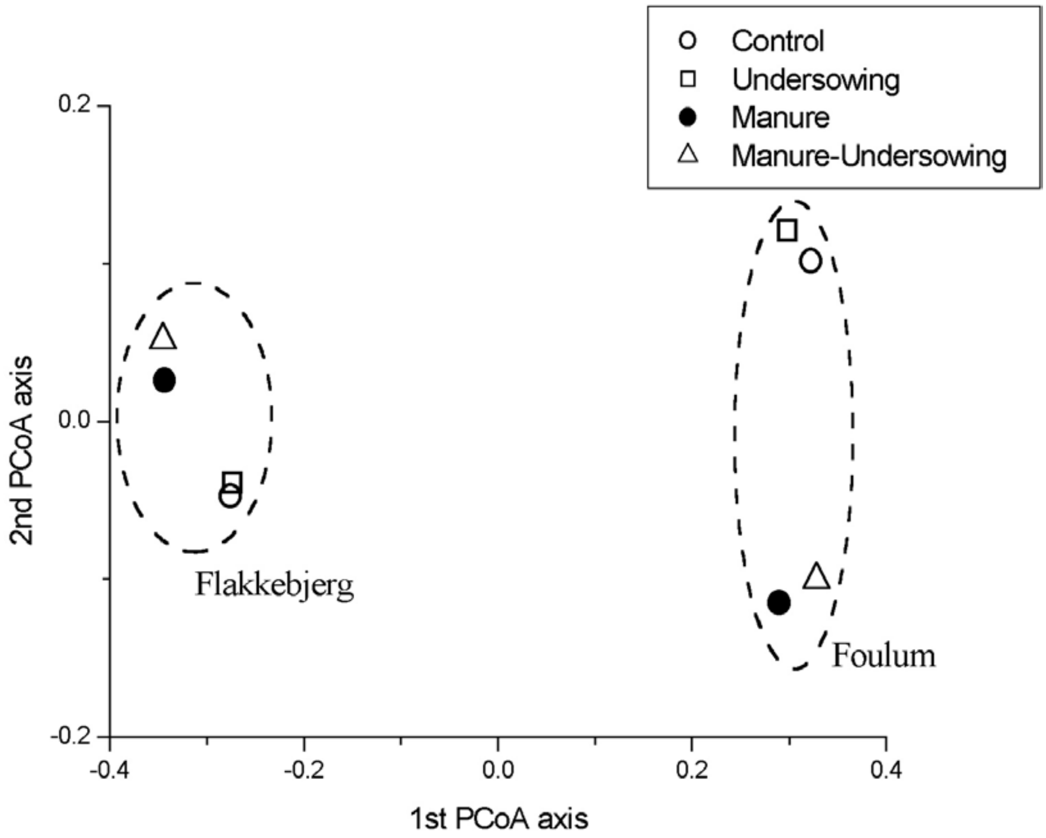
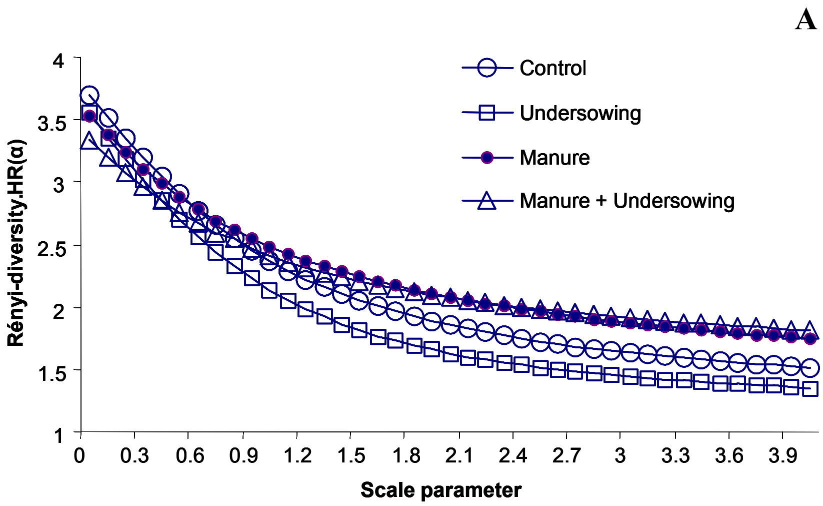


Figure 1. Multivariate analysis (Principal Component Analysis) of the ground beetle assemblages of the soil fertility treatments (4 replicates/treatment combined) at Flakkebjerg (to the left) and Foulum (right). The first two axes explain 93.5% of the variation in the data.

In Flakkebjerg, only 22 species were captured, and the species number / trap was also lower (3-10 species / trap). The most numerous species were *P. melanarius, A. dorsale, Harpalus rufipes* and *Calathus fuscipes*. Their ranks were the same in all treatments (Table 1).

Diversity
The PCA clearly separated the ground beetle assemblages at the two locations (Fig. 1). The first two axes explained 93.5% of the variation in the data. Manure had a larger impact on the assemblage composition than undersowing at both locations.

The Rényi-diversity profiles at Foulum (Fig. 2A) indicated that the combined assemblage of the undersown patches was unequivocally less diverse than the control, and the manure-treated areas. Compared to the manure + undersowing treatment (M+U), it was more diverse only at small values of the scale parameter, sensitive to species richness. From scale parameter α= 0.5 upwards, the undersown plots fell below the profiles of all other treatments (Fig. 2A). The manure or manure + undersowing treatments could not be unequivocally ordered, as the profiles cross each other at different values of the scale parameter. The



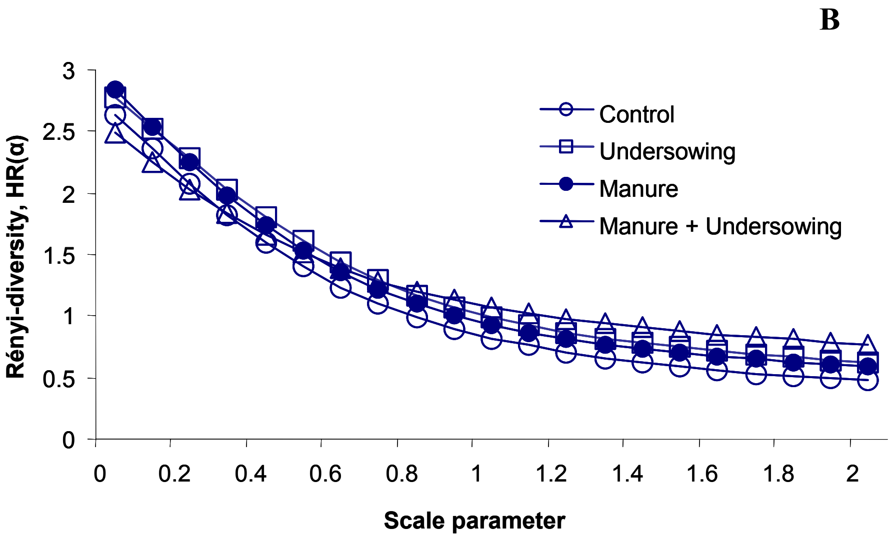


Figure 2. The Rényi diversity profiles of the four ground beetle assemblages studied at Foulum (A) and Flakkebjerg (B), spring 2002. The relative positions of the four profiles did not change at higher values of the scale parameter, so only the intervals α < 4 (a) and α < 2 are shown.

diversity relationship of the assemblages found in the plots that received animal manure and the manure + undersowing combined treatment is complex. The assemblage in manure treatment plots is more diverse when considering rare species (the curve runs above that of the M+U plots), but becomes less diverse (at scale parameters α>2.6, the curves cross, and the diversity of the assemblage in the M+U plots becomes more diverse, being less dominated by the common species) at higher values of the scale parameter (Fig. 2A).

The diversity profiles at Flakkebjerg (Fig. 2B) indicated a partially different situation. The control was unequivocally less diverse than manure or undersowing, but not their combination. However, the only difference was in the part of the curve where species richness has a large influence, at low values of the scale parameter. Near the value $\alpha = 0.3$, the diversity profile of the combination treatment crosses that of the control, and remains consistently above it. At the value of $\alpha \approx 1$, this curve indicates the highest diversity. The relationship between the effect on diversity of manure vs. undersowing is not as different as in Foulum, but the diversity profile for the undersown plots runs mostly above the equivalent curve for the manure-fertilised plots (Fig. 2B).

Carabid response to soil treatments
A repeated measures ANOVA on total number of beetles, and on common species indicated only a few significant relationships. There was a near-significant location * treatment interaction in the total number of beetles, mainly brought about by the significant difference in the number of individuals collected during the four sampling occasions. The only species with a significant treatment * sampling occasion effect on the number of individuals was *Pterostichus melanarius* (Table 2), again, mainly as a result of the different number of individuals collected during the sampling occasions.

Table 2. Analysis of variance on the total numbers of beetles captured, and on one of the common species, *Pterostichus melanarius*.

	numDF	denDF	F-value	Significance, *p*
Total number of beetles				
(Intercept)	1	68	275.44356	<0.0001
Location	1	27	2.47774	0.1271
Treatment	3	27	0.03254	0.9919
Sampling.occasion	3	68	6.24635	0.0008
Treatment*Sampling.occasion	9	68	1.85750	0.0736
Pterostichus melanarius				
(Intercept)	1	68	595.8805	<0.0001
Location	1	27	150.4353	<0.0001
Treatment	3	27	0.3976	0.7558
Sampling.occasion	3	68	40.2885	<0.0001
Treatment*Sampling.occasion	9	68	3.4687	0.0014

Discussion

The strongest impact in our studies was the regional difference in the species richness of the ground beetle assemblages. This probably reflected soil differences. For example, the humus content in the top 25 cm of the soil was nearly two times higher in Foulum than in Flakkebjerg (Djurhuus & Olesen, 2000). Other parameters also indicated a more nutrient-rich soil in Foulum than in Flakkebjerg. This, however, did not result in higher overall activity-density.

The diversity of the assemblages was influenced by the treatments, as well as by regional differences. The soil manipulations seem to have caused a larger effect in Flakkebjerg. This could be a consequence of the poorer soil at this site.

At the activity-density level, however, ground beetles did not show an overwhelming, consistent response to soil treatments. The spring distribution of ground beetles could be influenced by habitat features and the composition of the regional species pool more strongly than soil nutrient status in the local patch. An effect of patch size is also possible. However, this is contradicted by the results of the multivariate analysis: the carabid assemblages in the different treatments separated well from each other, at least in some cases. As the patches were randomly arranged, this seemed to indicate that patch size was not unrealistically small.

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