COMMUNITY ECOLOGY 9(2): 247-254, 2008
1585-8553/$20.00 © Akadémiai Kiadó, Budapest
DOI: 10.1556/ComEc.9.2008.2.14

Management effects on carabid beetles and spiders in Central Hungarian grasslands and cereal fields

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Keywords: Abundance, Fertiliser, Grazing, Landscape scale effects, Local scale effects, Species composition, Species richness.

Abstract: Modern agriculture is one of the main anthropogenic threats to biodiversity. To explore the effects of agricultural intensification we investigated carabids and spiders in two studies; in 2003 in grasslands and two years later in cereal fields in the same region. Both aimed to study the effect of management on arthropod diversity and composition at local and landscape scales. In 2003, we used a paired design for grasslands (extensively *vs.* intensively grazed). In 2005, a gradient design was applied with a total of seven land-use intensity categories. In both studies, sampling was carried out using funnel traps with the same sampling effort. Linear mixed models showed that high grazing intensity in grasslands had a positive effect on carabid species richness and abundance, but no effect on spiders. Landscape diversity had a positive effect only on carabid abundance. In the case of cereal fields, the management intensity (nitrogen fertiliser kg/ha) had a negative effect on spider richness and no effect on carabids. After variance partitioning, both local and landscape characteristics seem to be important for both cereal and grassland arthropod communities. Based on our results, we think that current and future agri-environmental schemes should be concentrated on cropland extensification. Low intensity croplands could act as a buffer zone around the semi-natural grasslands, at least in this biogeographic region.

Abbreviations: DCA – Detrended Correspondence Analysis, GLM – General linear model, RDA – Redundancy Analysis.

Introduction

Since the first appearance of agricultural cultivation systems around eight thousand years ago, huge areas of Europe have been transformed into cultivated fields and grasslands, with only few natural refuges remaining (Duelli and Obrist 2003). The flora and fauna of historical open areas colonised extensively-used agricultural land in relatively high species numbers and abundance (Sutherland 2002). However, in the second part of the 20th century agricultural intensification increased, with serious adverse effects on biodiversity (Krebs et al. 1999, Tilman et al. 2002). Increased use of chemicals and landscape homogenisation, mainly in the western and northern parts of Europe, reduced the habitats of once common animal and plant species that eventually have become endangered or have gone extinct (Tilman et al. 2002, Roschewitz et al. 2005, Holzschuh et al. 2008). The degree of intensification in the Central and Eastern European countries was lower, both before and after the collapse of communist regimes, and a rich flora and fauna can still be encountered in these regions (Báldi and Faragó 2007).

Effects of agricultural management on arthropod communities occur on two spatial scales, i.e., the local and the landscape scales (Tscharntke et al. 2005a). Local scale effects on arthropod communities resulting from application of chemicals and physical disturbance of croplands and grasslands are typical for intensive agriculture (Oliver et al. 2005). These practices also have indirect effects, such as the simplification of vertical structure in cereal fields after herbicide use, which impoverish arthropod communities, including spiders (Baines et al. 1998). Previous studies have addressed the deleterious effects of intensive grazing and mowing systems on grassland arthropods (Kruess and Tscharntke 2002, Knop et al. 2006). For example, Woodcock et al. (2005) suggested that with increasing management intensity, plant species diversity decreases and simplified vegetation structure results in lower carabid diversity. Furthermore, not only grazing intensity but also time of the first grazing or mowing, duration of grazing and the species of grazing animal have important effect on carabid life cycles (Grandchamp et al. 2005, Woodcock et al. 2005). Arthropods comprise a highly diverse taxonomic group, therefore the responses of different taxa are likely to be extremely variable. For example, Gibson et al. (1992) found that vegetation structure is more important for spiders than vegetation composition, in contrast to trends in other invertebrate assemblages.

Arable fields are among the most disturbed landscapes on earth. Yearly ploughing together with management practices results in high mechanical disturbance, whilst the increased use of pesticides and fertilisers results in a wide range of effects, including low weed species richness and cover, habitat-loss, decreased food supply, microclimate changes and direct and indirect toxicity effects on spiders and carabids (Basedow 1990, Wilson et al. 1999, Weibull and Östman 2003, Orlowski 2006).

The length of hedgerows in agricultural landscape continues to decrease, despite evidence suggesting their vital role for spiders and carabids (Thomas et al. 2001, Clough et al. 2005). Hedgerows are potential overwintering habitats and source habitats for colonisation of cultivated fields in spring or following disturbance (Magura 2002). Moreover because of their position between different habitats, there is often an overlap in arthropod communities in these small semi-natural areas, resulting in higher local species richness and abundance, and greater potential for migration into cultivated fields (Samu et al. 1999, Schmidt and Tscharntke 2005). The positive effects of landscape heterogeneity and semi-natural areas on arthropods have been shown in many studies (e.g., Burel et al. 1998, Benton et al. 2003, Jeanneret et al. 2003a).

Most previous studies have investigated the effects of agriculture management with respect to grasslands or cereal fields in the same region. These model studies ignore the fact that these land-use types occur in many cases side by side, possibly mutually influencing the biodiversity of both (Tscharntke et al. 2005a). In 2003, we compared the carabid beetle and spider fauna of semi-natural grasslands with low and high grazing pressure. Two years later, the experiment was repeated on a gradient of increasing management in cereal fields in the same biogeographical region. We expected in both cases that landscape diversity would have a positive effect on the population density and species richness of the investigated taxa, while increasing management intensity would have a negative effect. The two studies were not pooled in a common analysis, due to the different years of the studies. The main aim of the present work is therefore to see if we can find similar patterns in the responses of carabids and spiders of the two studies analysed separately, since both investigated the effects of local and landscape scale management.

The present analyses used a subset of data from two wider studies that investigated the relationships between birds, several arthropod taxa and vegetation diversity and management and landscape variables in Hungarian grasslands and cereal fields (Báldi et al. 2005, Báldi et al. 2007, Batáry et al. 2007a,b,c, Batáry et al. 2008, Kovács et al. 2007).

Materials and methods

Study areas

In 2003, extensively and intensively grazed grasslands were compared in three different biogeographical regions of the Hungarian Great Plain. In the current study, we analyse only one region (middle third former flood area of the Danube, Kiskunság NP, Báldi et al. 2005), where two years later a study in cereal fields was performed (Kovács et al. 2007, Fig. 1). The whole region, the so-called Upper-Kiskunság Plain, is a part of the vast alkali lowland plain of the Great Hungarian Plain. The most important parts of the region from a nature conservation point of view are the large grasslands (up to many hundreds of hectares), termed as "puszta", where

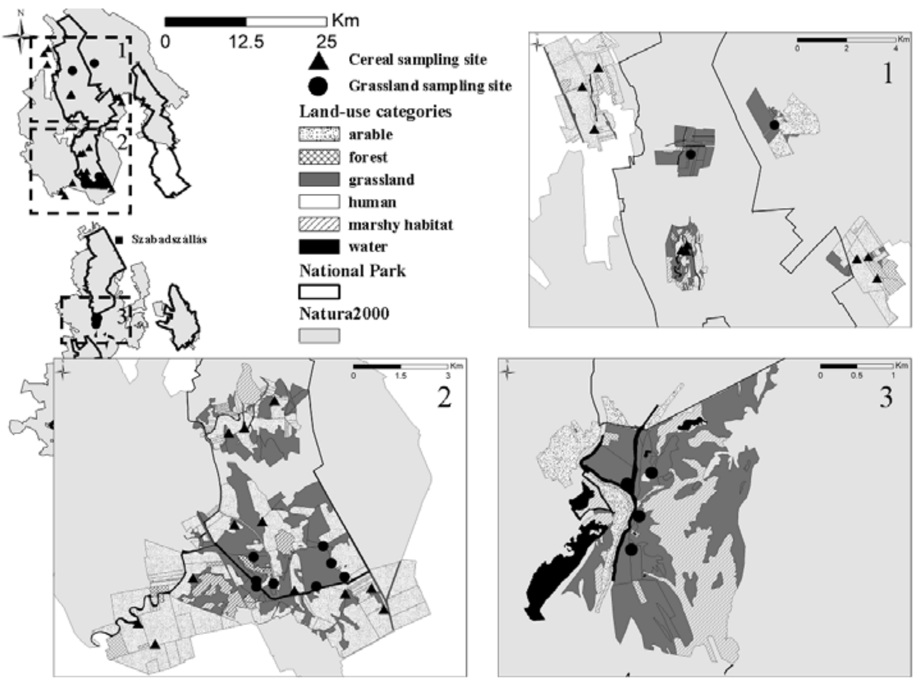

Figure 1. Map of the study areas showing the sampling sites of the grassland and cereal field studies, land-use types, National Park and Natura2000 borders.

traditional grazing methods still persist. The "puszta" habitat is characterised by common grass species like the false sheep's fescue (*Festuca pseudovina* Hack. ex Wiesb.) and bermudagrass (*Cynodon dactylon* (L.) Pers.), and is scattered with large croplands (up to many tens of hectares), roads, canals and built-up areas, resulting in a large-scale habitat mosaic.

Sampling design

In the grassland study, seven pairs of extensively (max. 0.5 cows/ha) and intensively (min. 1 cow/ha) grazed grasslands were compared in a paired design. None of the grasslands were fertilised, sprayed or reseeded. Both 'intensive' and 'extensive' grassland types are managed at a relatively low intensity level compared to Western European standards, where the stocking rates even on extensive sites exceed 1 cow/ha (e.g., Kruess and Tscharntke 2002, Grandchamp et al. 2005). Carabids and spiders were sampled using funnel traps opened for three 2-week collecting periods during spring and early summer in 2003 (for trapping method, see Obrist and Duelli 1996, Batáry et al. 2007b). On each field, samples were taken with two traps: one at the edge (but within the grassland) and the other 50 m away in the interior (altogether 7 pairs × 2 fields × 2 traps× 3 periods = 84 trap samples). For all analyses, in-field (edge and interior) traps were pooled.

In the cereal field study in 2005, we used a gradient design. Seven land-use intensity categories within five farms were chosen. The farmers were asked to fill out a questionnaire about the use of fertilisers (nitrogen input in kg/ha/year with seven intensity options: 0, 34, 68, 92, 100, 113 and 270) and pesticides (no insecticide was used before the field sampling). In all intensity categories, we chose three autumn-sown cereal fields, with the exception of two categories, in which samples were taken from only one (0 N kg/ha/year) or two (113 N kg/ha/year) fields, due to the limited number of the available fields. In both cases, the same number of traps as in the other studies was used (the minimum distance between pairs of traps was 200 m). On each field, samples were taken with two funnel traps using the same procedure as for the grassland study, with two 2-week collecting periods (altogether 7 intensities × 3 fields × 2 traps × 2 periods = 84 trap samples). For all analyses, in-field traps were pooled. In both studies, adult carabids and spiders were identified to species level (Heimer and Nentwig 1991, Ádám 1996).

Local and landscape parameters

In both studies, five local factors were measured along 95 m long transects (Báldi et al. 2007, Kovács et al. 2007). All fields had one transect in the edge and one 50 m away from the edge. In each transect, ten 1 × 5 m^2 plots were established at 5 m intervals. In June 2003 and June 2005, we estimated the cover of each plant species (in the analyses total plant cover, total weed cover and species richness were used), bare ground (%), and height of vegetation (cm). In the cereal field study, the weed plus wheat cover was measured, and in the grassland study the plant litter cover (%) (Table 1).

Eighteen landscape parameters were measured within 500 m circles around every field based on aerial photographs (for more details, see Batáry et al. 2007c). Six land-use types were considered: arable field, grassland, forest, marshland, built-up area and open water. On the landscape scale, we distinguished parameters according to landscape composition and configuration as in other studies (Batáry et al. 2008, Concepción et al. 2008). Landscape composition variables describe the actual amount of each land use type within the landscape, without being spatially explicit. The landscape configuration shows the geographical distribution or spatial character of patches within the landscape (Concepción et al. 2008). Percentage area and Shannon diversity of these land-use types were defined as landscape composition metrics (Table 1). The number of patches of the above mentioned land-use types, mean area of arable, forest, grassland and marshland and total length of boundaries were grouped as landscape configuration metrics.

Statistics

To analyse the species richness and abundance of the two taxa, general linear mixed models were applied, using similar models for both studies. From the local scale variables, grazing intensity (extensive *vs*. intensive) was used as a fixed factor in the grassland study, and N input (kg/ha/year) as a fixed covariate in the arable land study. From the landscape scale variables, land-use diversity was used as a fixed covariate. In both studies, we applied a nested design. In the grassland study, the trapping period was the first random factor and field pair was the second. In the case of the cereal field study, we used the random factors of period/farmer/field. The normality of the distribution of the model residuals was assessed using normal quantile plots, and raw data were log-transformed when necessary (see Kéry and Hatfield 2003). The calculations were made using R (version 2.2.1; R Development Core Team 2006) and the *nlme* package for R (version 3.1; Pinheiro et al. 2007).

To measure the influence of environmental variables on different farmland beetle and spider species composition constrained ordinations were performed. We conducted separate analyses for the two taxa and for the two studies. Only those species which occurred in more than five traps from the total 42 traps were included in the analyses. Abundance data were log-transformed prior to analysis to improve normality of response variables. We conducted separate DCA (Detrended Correspondence Analyses) for all four species dataset to decide which constrained ordination model should be applied (Lepš and Šmilauer 2003). In all cases, redundancy analysis (RDA) proved to be the appropriate method.

In all four indirect gradient analyses (grassland beetles, grassland spiders, cereal field beetles, cereal field spiders), we performed separate analyses to eliminate those environmental variables that do not explain variation (based on

Table 1. Environmental variables at local and landscape scales used as explanatory variables in the analyses on biodiversity. Landscape scale variables were grouped according to landscape composition and landscape configuration.

Group of variables	Variable	Description
Local	Plant species richness	Species richness of plants in grassland study
		Species richness of weeds in cereal field study
	Cover	Cover of plants, bare ground and litter in grassland study
		Cover of vegetation (weed+wheat), weeds and bare ground in cereal field study
	Vegetation height	Mean grass height in grassland study
		Mean vegetation height in cereal field study
	Management	Grazing intensity (extensive/intensive) in grassland study
		Fertiliser amount in cereal field study
Landscape composition	% of land-use types	% of arable, built-up area, forest, grassland, marshland and open water
	Diversity of land-use types	Shannon diversity of land-use types
Landscape configuration	Patch density of land-use types	No. of arable, built-up area, forest, grassland, marshland and open water
	Mean area of land-use types	Mean area of arable, forest, grassland and marshland
	Length of boundaries	Total length of all boundaries

Table 2. Mean ± SE of species richness and abundance per field of carabids and spiders detected in the grassland and cereal field studies in the Kiskunság Plain, Hungary.

	Species richness		Abundance	
	Grassland study	Cereal field study	Grassland study	Cereal field study
Carabids	6.48 ± 0.47	9.50 ± 0.64	20.67 ± 2.50	33.45 ± 4.89
Spiders	10.07 ± 0.56	13.26 ± 0.68	58.52 ± 4.99	34.38 ± 2.52

Table 3. General linear mixed models on the effects of management intensity (extensive or intensive grazing regime in the grassland study and fertiliser use (kg N/ha/year) in the cereal field study) and landscape (land-use diversity) of Hungarian grasslands and autumn-sown cereal fields. Type: direction of the significant effect. df: denominator degrees of freedom.

	Management				Landscape			
	F	*df*	*p*	type	*F*	*df*	*p*	type
Species richness								
Grassland carabids	64.868	19	< 0.001	+	1.957	19	0.178	
Grassland spiders	0.343	19	0.565		0.800	19	0.382	
Cereal field carabids	1.197	25	0.284		0.021	5	0.891	
Cereal field spiders	4.442	25	0.045	–	1.036	5	0.355	
Abundance								
Grassland carabids	5.834	19	0.026	+	19.426	19	< 0.001	+
Grassland spiders	1.511	19	0.234		0.053	19	0.820	
Cereal field carabids	3.273	25	0.083		0.359	5	0.575	
Cereal field spiders	2.877	25	0.102		0.065	5	0.809	

Monte Carlo permutation tests with 999 permutations; Jeanneret et al. 2003a,b, Aviron et al. 2005). Separate analyses were done for local variables, for landscape composition variables and for landscape configuration variables. Variables that contributed significantly ($p < 0.05$) to the pattern of species composition were included in the global ordination. From the used variables which showed strong correlation ($r > 0.7$) with each other, only those which had the highest correlation values with RDA axes were selected for partial RDA. Finally, in the partial RDA, the variance explained by each variable and its significance (Monte Carlo permutation tests with 999 permutations) was obtained after eliminating the variance explained other variables, which were used as co-variables (partial variables). Since differences in species composition caused by different sampling periods were not the focus of this study, sampling periods were used as dummy co-variables. DCA and RDA were performed using Canoco 4.54 (ter Braak & Šmilauer 2002).

Results

Spider and carabid species richness was higher in the cereal fields than in the grasslands (Table 2, for complete species list see Appendix). Abundance of carabids was also higher in the cereal fields, whilst spider abundance trapped was higher in the grasslands.

In the grassland study, the higher grazing pressure had a significant positive effect on species richness and abundance of carabids (Table 3). Further, the increasing land-use diversity had a significant positive effect on the abundance of carabids (Fig. 2). Spider abundance and diversity in the grassland study was neither affected by management nor by land-use diversity. The same was true for the spider abundance in the cereal field study, although here the increased fertiliser had a significant negative effect on species richness (Fig. 3).

After variance partitioning with partial RDA for the grassland carabids, one landscape configuration variable

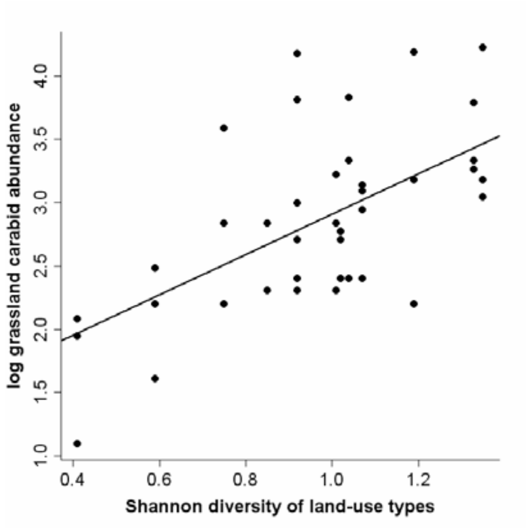

Figure 2. Fitted regression line of general linear model on the relationship of land-use diversity within 500 m buffer area of grassland study sites and grassland carabid abundance on logarithmic scale (Y = 1.32 + 1.59 * Lg(X), $F_{1,19}$ = 19.426, p = 0.0003, n = 42).

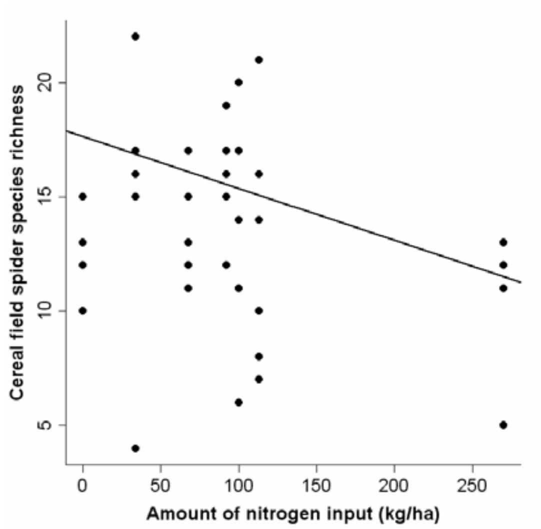

Figure 3. Fitted regression line of general linear model on the relationship of fertiliser use (kg N/ha/year) and cereal field spider species richness on autumn-sown cereal fields (Y = 17.65 – 0.02 * X, $F_{1,25}$ = 4.442, p = 0.0453, n = 42).

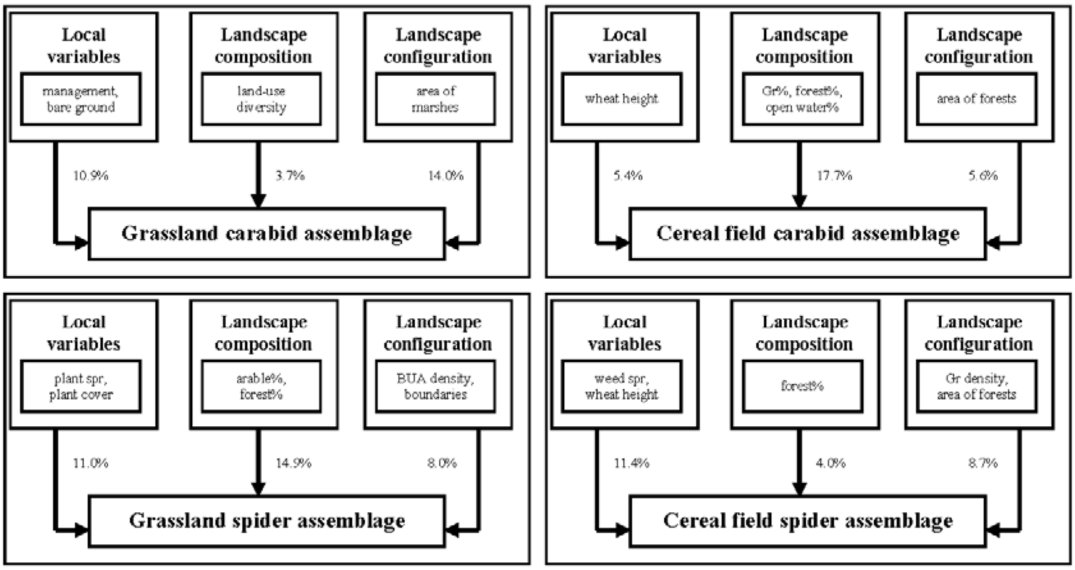

Figure 4. Four synthetic models of correlative relations between environmental variables and carabid and spider assemblages of grasslands and cereal fields, based on partial RDA. Abbreviations: Gr: grassland; spr: species richness; BUA: built-up area.

(mean area of marshlands) and two local variables (management and bare ground cover) explained the greatest part of variation (Fig. 4). Among the landscape composition variables, the only significant variable was land-use diversity. Contrary to the grassland carabids, in grassland spider communities the landscape composition variables (% arable and % forest) were the most important. However, local variables (plant species richness and plant cover) and landscape configuration variables (built-up area density and total length of boundaries) also explained a significant part of variation. In the case of cereal field carabid communities, landscape composition variables (% grassland, % forest and % open water) also explained most of the variation, but the local variable wheat height and the landscape configuration variable mean area of forests also had significant effects. Finally, the cereal field spider communities were affected mostly by local variables (weed species richness and wheat height). Two landscape configuration (grassland density and area of forests) and one landscape composition (% forest) variables also had significant effects.

Discussion

In the present study, we analysed the effects of land-use intensification at local and landscape scales on the carabid and spider fauna of Central Hungarian farmlands. In 2003, grassland sampling with paired fields was performed in which we found effects on species richness and abundance of carabids, but not on spiders at either scales (Batáry et al. 2007b, Batáry et al. 2008). Direct gradient analyses showed the importance of environmental variables at both scales on both taxa. The latter situation was true for the cereal field study performed two years later in the same biogeographical region with the same sampling effort, but with a gradient design. However, analyses on species richness and abundance in the cereal field study showed changes only for spiders at the local scale.

Looking at our GLM results in more detail, the interesting positive effect of higher grazing pressure found on carabid species richness and abundance could most probably be explained by the very small difference in grazing intensity between the intensive (min. 1 cow/ha) and extensive (~0.5 cow/ha) paired fields compared to Western European standards. In a study by Kruess and Tscharntke (2002), the grazing intensity in Germany defined intensive as 5.5 cows/ha and extensive as 1.4 cows/ha, whilst average grazing intensity in a study by Grandchamp et al. (2005) comparing mown vs. grazed plots in the Swiss Pre-Alps, was deemed to be 1.4 cows/ha. In contrast to these, all of the grasslands investigated in this study were pesticide and fertiliser free, i.e., can be termed as "semi-natural" habitats. Analysing all three regions together, we found no management effects either on specialist or generalist carabids (Batáry et al. 2007b), therefore the positive effect found in this study is region specific. These grasslands probably require this level of grazing disturbance to attain such an elevated level of species richness and abundance. Similar to the present result, Grandchamp et al. (2005) showed that cattle density was positively related to the number of carabid species in grazed montane meadows in the Pre-Alps.

The absence of management and landscape scale effects on cereal field carabids is intriguing, especially taking that into account that there was a relatively large variation in the amount of fertiliser applied and a similar range in land-use diversity to the grassland study. The most probable explanation is that the studied cereal fields surround the above mentioned semi-natural grasslands, from where strong immigration is presumed, i.e., mass and spillover effect (Shmida and Wilson 1985, Zonneveld 1995, Tscharntke et al. 2005b). Considering the spillover of predator arthropods from grasslands to cereal fields we would suspect that with increasing landscape diversity this spillover effect would intensify. We could not demonstrate this intensification of spillover effect at landscape scale; however, at a finer edge scale we found significantly higher species richness and higher abundance of both taxa in the cereal field edges than in the interiors (Kovács et al. 2007).

Among spiders, only the species richness was significantly negatively affected by management in the cereal field study. Clough et al. (2005) did not show management effect on spiders comparing organic and conventional wheat fields (despite the large difference in N fertilisation: organic: ~40 kg/ha and conventional: ~175 kg/ha; for fertiliser amount in Germany and other countries see Kleijn et al. 2006), but found a positive effect of non-crop area. Schmidt et al. (2008) also reported that local species richness was enhanced by non-crop habitats on a landscape scale. In our case, the absence of landscape scale effect in the cereal field study could be linked with the strong spillover effect from neighbouring grasslands. Considering the local scale management results of the current analyses, we found that in the grassland study the "increased" management intensity has neutral or positive effects on arthropod richness and abundance. Turning these grasslands into low intensity arable fields surrounded with semi-natural grassland could further increase these numbers up to a point, after which they will decrease. However, we have to emphasize that the land conversion from grassland to low intensity arable fields would probably result in a serious loss of stenotypic and specialist grassland fauna (Duelli and Obrist 2003, Tscharntke et al. 2005a, Batáry et al. 2007b).

The species richness, abundance and community composition of grassland carabid assemblages were affected by grazing management and land-use diversity. Aviron et al. (2005) investigating the carabid communities in different agricultural landscapes, found that landscape units (25 km^2 areas of contrasting landscape structure) and habitat types had higher effects on community composition than landscape composition, similar to our result. This was not the case in the cereal field study, where no effects were found on carabid species richness and abundance at either scales, however landscape composition scale variables were the most important factors influencing carabid community composition. Similarly to Aviron et al. (2005), Jeanneret et al. (2003a,b) found that habitat type is a very important explanatory factor of community composition for both beetles and spiders. The type of land-use in the surroundings also had significant effect, but only on carabids. Looking at the local variables of both cereal field taxa, we found that both plant and weed species richness are important factors, supporting the results of Jeanneret et al. (2003a). In our case, plant cover and wheat height were also significant. Dennis et al. (2001) also found that besides stocking rate and botanical composition, vegetation height determines the arachnid composition in Scotland. Finally, with exception of grassland beetle communities, in the other three cases the importance of forests is conspicuous. Öberg et al. (2007) argued that forests could serve as important source habitats for lycosid spiders in Swedish agroecosystems. Isaia et al. (2006) showed that landscape heterogeneity, mostly related to the presence of woods, seem to be the most important environmental factor for spider communities of Italian vineyards. Finally, we think that the similar environmental variables affecting the alkali grassland and cereal field arthropod communities could be connected with their common annual dynamics: both are productive in springtime, and both are disturbed until summer, either by harvest or by drying out (Samu and Szinetár 2002).

Summarizing our results, increasing management intensity affected the richness and the abundance of grassland carabids positively and the richness of cereal field spiders negatively. It also affected the species composition of grassland carabids. We consider that the recently introduced national agri-environmental schemes to be potential tools, which could contribute to the conservation of valuable fauna in this region. Although this is a correlative study, we think that current and future agri-environmental schemes should be concentrated on cereal field extensification to compose a buffer zone around the semi-natural grasslands, at least in this biogeographic region. Further, agri-environmental schemes should support the maintenance of extensive grazing. To conclude, we agree with Tscharntke et al. (2005a) that in diverse and complex landscapes (> 20% non-crop habitat) extensive farming appears to have a minimal or non-measurable enhancement effect on species diversity compared to intensive farming, therefore it should be implemented in more monotonous landscapes.

Acknowledgements: We would like to thank T. Szűts, B. Kancsal and A. Fanaczán for the identification of spiders, G. Szél and L. Somay for the identification of carabids, A. Holzschuh for valuable comments, P. Ódor for help with the CANOCO statistical software and L. Sutcliffe for linguistic revision. We are grateful to the Kiskunság National Park for permission, logistic help and for making available the aerial photographs and landowners for allowing us to work on their fields. The study was supported by an EU-funded project (QLK5-CT-2002-01495) and partly by a national project (NKFP 3B023-04). During the preparation of the paper P.B. was supported by the Alexander von Humboldt Foundation. A.B. was a Bolyai Research Fellow of the Hungarian Academy of Sciences.

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Received January 30, 2008
First revision June 23, 2008, second revision July 17, 2008
Accepted November 5, 2008

Appendix

Species list of carabids and spiders. It can be downloaded from the publisher's web site at www. akademiai.com