Carabid beetle (Coleoptera: Carabidae) diversity in agricultural and post-agricultural areas in relation to the surrounding habitats

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Carabid beetles were studied in eight study sites, representing differently treated agricultural and post-agricultural areas and their surrounding habitats. The study aimed to answer the questions (1) to what degree differently treated agricultural and post-agricultural areas differ with respect to stage of succession, species numbers and species composition, and (2) what is the impact of the different measures on the species diversity across a larger area (landscape).

Altogether, 933 individuals from 61 species were collected. The study sites differed with respect to the successional stages. Species numbers ranged from 8 to 25 species. High ß-diversity values did not always correspond with low Jaccard indices for the respective pairs of study sites. Special attention has to be drawn particularly to species, which are rare in the studied landscape, and to the respective habitats. A correspondence Analysis (CA) indicated that human management impact seems to be of special importance with respect to differentiation of the carabid coenoses.

The study indicates that the value of a single site with respect to biological diversity has to be assessed in the context of a larger area, in which it is embedded (landscape). It is necessary to identify those types of landscape elements, which are missing to exploit the full potential of the landscape. In this context not only the individual landscape elements but also the landscape structure is of importance.

Key words: Carabidae, MIB, agriculture, fallow, landscape, species diversity, management, succession

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INTRODUCTION

Agricultural farming practices have strong influence not only on the crop yield but also on the species domiciled in agricultural landscapes. However, especially due to intensification, agriculture is assessed to be a main driver of loss in biological diversity (Matson et al. 1997, Krebs et al. 1999, Donald et al. 2006, Watt et al. 2007). Thus, different strategies have been developed and integrated into agri-environmental schemes and projects with the aim to counteract this tendency, such as improved farming techniques, organic agriculture and the creation of post-agricultural areas, i.e. to set aside agricultural fields and let them turn into fallow land (e.g. Haber & Fehrenbach 2004, Reidsma et al. 2006).

However, there are doubts that these measures are indeed successful in every case. While some studies report benefits (e.g. Peach et al. 2001) others show rather ambiguous results (e.g. Berendse & Kleijn 2004, Donald et al. 2006, Whitfield 2006). It seems that landscape structure has to be taken into account when implementing conservation measures (Guerrero et al. 2012). To conclude, even if a lot of effort was done in studying measures of improving biological diversity in agricultural landscapes, there seem to be still gaps in knowledge about the particular effects which have specific treatments and how they function together across a larger area (landscape).

The present paper presents a pilot study on highlighting aspects of species diversity in agricultural and post-agricultural areas under additional consideration of the surrounding habitats using carabid beetles as indicators. Carabid beetles are a well-known arthropod group and have been subject to various research in Europe since more than 40 years (Kotze et al. 2011). They are considered to have good potential for indication of environmental variation (Koivula 2011), they react to management practices in grassland habitats (Rainio & Niemelä 2003) and to changes in the stage of succession (Szyszko 1990). With respect to the latter the Mean Individual Biomass of Carabidae (MIB) has been proposed as an indicator (Szyszko 1990, Szyszko et al. 2000). The method assumes an ongoing process of succession with which the MIB of carabids increases.

The study aims to answer the questions (1) to what degree differently treated agricultural and post-agricultural areas differ with respect to stage of succession, species numbers and species composition, and (2) what is the impact of the different measures on the species diversity across a larger area (landscape).

MATERIAL AND METHODS

Study sites and field methods

The study was carried out on the research object "Krzywda" at Tuczno (west Poland, Wałecki district). The area is composed of different forests, agricultural and post-agricultural areas of different stages of succession, as well as about 68 ha of swamps highly eutrophicated due to wastewater inlet, supplied by three water courses (Rylke & Szyszko 2002). Eight study sites were selected for carabid sampling (Fig. 1): A forest divided into partly birch and partly spruce, 9 years old in 2011 (study site 1), an extensively used post-agricultural area, where the grass is cut and biomass removed (study site 2), a post-agricultural area turned into fallow land (study site 3), a post-agricultural area being ploughed in 2011 shortly before the start of the study (study site 4), an agricultural field (study site 5), a moist to wet grassland close to reed vegetation (study site 6), a reed vegetation (study site 7) and a pine forest, about 40 years old in 2011 (study site 8).

On each study site three pitfall traps following Barber (1931), modified according to (Szyszko 1985), with pure ethylene glycol as trapping liquid were installed. With respect to study site 1 the traps were located in the spruce part very close to the birch part. A funnel with a diameter of ca. 10 cm was installed over each trap flush with the soil surface to minimise by-catch, and a roof was installed a few cm above the funnel to protect the trap from rainfall. To cover the main activity periods of carabid beetles, collecting was carried out for about three weeks in autumn 2011 and about three weeks in spring 2012. In autumn 2011 the collecting period covered August 16 to September 4, with exception of the agricultural field, where due to trap loss the collection time covered August 28 to September 18. In spring 2012 the collection time covered April 26 to May 13.

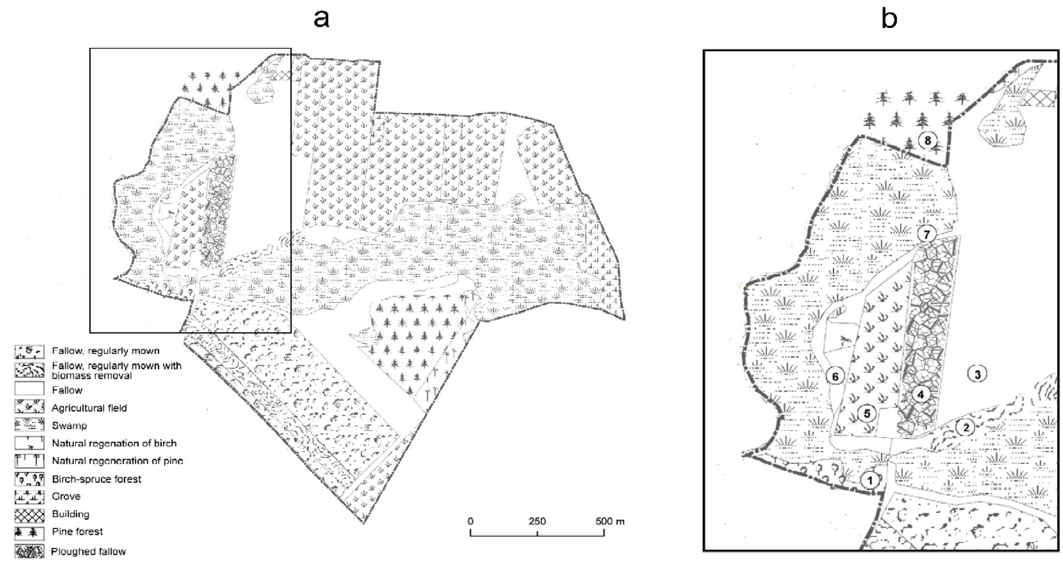

Fig. 1. Scheme of the research object "Krzywda" (a) and location of the study sites (1-8) (b).

All collected specimens were determined to the species level. Nomenclature follows Müller-Motzfeld (2004).

Statistical methods

Mean Individual Biomass of Carabidae (MIB) was calculated for each study site to assess the respective stage of succession. MIB is calculated by dividing the biomass of all sampled individuals by the number of specimens. Biomass values were fixed for the recorded species using values from Szyszko (1990) or using the formula from Szyszko (1983) that describes the relationship between body length of a carabid individual (x) and its biomass (y):

$$\ln y = -8.92804283 + 2.55549621 \times \ln x \qquad \text{(eq. 1)}$$

The number of recorded species was taken as measure for species diversity (α-diversity, Meffe et al. 2002) of the individual study sites.

To assess differences in species composition, i.e. the degree of species diversity between the sample units within a given area (ß-diversity), all pairs of variation in carabid coenoses structure among the study sites were calculated using a) Jaccard's (1902) index of species similarity according to Mühlenberg (1989) and b) ß-diversity according to Meffe et al. (2002) (Anderson et al. 2011). These two parameters differ insofar that, in contrast to the Jaccard index, the maximum possible value for ß-diversity depends on the amount of species collected on the study sites. Thus, pairs of study sites with a comparatively high similarity according to the Jaccard index must not necessarily be characterized by low ß-diversity and the other way round.

The total number of species in the study was taken as measure of species diversity across the studied landscape (γ-diversity, Meffe et al. 2002).

To assess the role of the individual study sites with respect to their contribution to overall species diversity (γ-diversity) more detailed, an additional focus was set on how "unique" the species are on the individual study sites. For each study site the degree of presence of each species recorded there was calculated. Degree of presence means the percentage share of study sites holding the respective species within the total number of study sites. The mean value of the degree of presence for the species on a given study site was considered as a measure of the "uniqueness" of the respective species coenoses.

Unconstrained ordination can be used to explore relationships between the structure of the carabid coenoses and factors or environmental variables (Anderson et al. 2011). Thus, Canoco for Windows version 4.53 (ter Braak 1987, ter Braak & Šmilauer 2002) was used to perform an indirect gradient analysis. Detrended Correspondence Analysis (DCA) was carried out first to select the appropriate statistical model, based on the gradient length of the first DCA axis (Ter Braak & Prentice 1988). Based on DCA, a Correspondence Analysis (CA) was applied using scaling on inter-sample distances and Hill's scaling, as recommended for long gradients (ter Braak & Šmilauer 2002). Because the dominance values were used, the data were not transformed. A biplot on species and sites was created by adjusting species weight range in such a manner that the 25 species with the largest impact on the results of the analysis are displayed (ter Braak & Smilauer 2002).

RESULTS

Altogether 933 individuals from 61 species were collected (Tab. 1). The number of species collected on the different study sites ranged from 8 (young birch-spruce forest) to 24 (post-agricultural area being ploughed, agricultural field), whereas the number of collected individuals ranged from 24 (young birch-spruce forest) to 419 (post-agricultural area being ploughed). Remarkably, the post-agricultural area being ploughed and the agricultural field, which are under strong human influence, were characterised by the highest numbers of species and individuals.

The highest MIB value of 249.3 mg was observed for the young forest site (Tab. 1). The 40 years old pine forest had an unexpected low value of only 142.6 mg. The lowest MIB values were observed for the ploughed post-agricultural area (45.7 mg) and the agricultural field (72.1 mg).

As expected, study sites with high species numbers (the ploughed post-agricultural area and the agricultural field) were included in pairs with above average high ß-diversity values. However, most often included in pairs with particularly low Jaccard values was the reed vegetation, which is characterized by a low species number (Tab. 2).

The reed vegetation also exhibited the most "unique" carabid coenoses (i.e. the lowest mean degree of presence). Four of the ten species recorded on this study site did not appear on any other study site. Comparatively low "uniqueness" (high mean degree of presence) with respect to their carabid coenoses showed the young birch-spruce forest, the extensively used post-agricultural are, where the grass is cut and biomass removed, and the post-agricultural area (Tab. 1).

The first axis of the CA explained 30.8 % and the second axis explained 23.4 % of the variance of species data (Fig. 2). Based on the CA the study sites were assigned to three groups: Group 1 comprised the forest sites (young birch-spruce forest, about 40 years old pine forest), group 2 consisted of sites of more or less moist conditions under comparatively low human influence (extensively used post-agricultural area, where the grass is cut and biomass removed, post-agricultural area, moist to wet grassland, reed vegetation) and group 3 were study sites under strong human influence (post-agricultural area being ploughed, agricultural field). The latter were separated from the study sites under lower human impact along the first ordination axis, whereas the forest sites were separated from the sites of group 2 along the second ordination axis. The location of the 25 most important species reflected the distribution of the study sites, with *Carabus nemoralis* and *Carabus hortensis* (for-

Table 1. Numbers of individuals of the species (in alphabetical order), total number of individuals, total number of species, MIB values, and mean degree of presence of the species for the study sites

Species	**Study site 1**	**Study site 2**	**Study site 3**	**Study site 4**	**Study site 5**	**Study site 6**	**Study site 7**	**Study site 8**	**Sum**
Agonum fuliginosum							1		**1**
Agonum sexpunctatum						1			**1**
Amara aenea				16	9				**25**
Amara apricaria					2				**2**
Amara aulica			1		2				**3**
Amara bifrons				1	1				**2**
Amara communis		6	2			1			**9**
Amara consularis				1					**1**
Amara convexior			6		1				**7**
Amara eurynota				1					**1**
Amara familiaris				3					**3**
Amara lunicollis		3	5					1	**9**
Amara plebeja					1	2			**3**
Amara tibialis								1	**1**
Anisodactylus nemorivagus			1						**1**
Badister bullatus			1			1			**2**
Bembidion gilvipes							1		**1**
Bembidion properans			1		1				**2**
Blethisa multipunctata						1			**1**
Broscus cephalotes				1					**1**
Calathus cinctus				1	4				**5**
Calathus erratus			4	25	1	1			**31**
Calathus fuscipes			8	17	11				**36**
Calathus melanocephalus		1	4	7	1	1			**14**
Carabus granulatus		1					2		**3**
Carabus hortensis	3		1					2	**6**
Carabus nemoralis	8	1	1					1	**11**
Carabus violaceus			1		1				**2**
Clivina fossor						3			**3**
Dyschirius globosus						1	1		**2**
Elaphrus cupreus			1						**1**
Epaphius secalis						7	2	1	**10**
Harpalus affinis				10	13	1			**24**
Harpalus anxius				1	3				**4**
Harpalus laevipes								2	**2**
Harpalus latus	1	1	1					2	**5**
Harpalus luteicornis		2		10	1				**13**
Harpalus rubripes		1	8	12	8	2			**31**
Harpalus rufipalpis				9					**9**
Harpalus rufipes		1	2	74	25				**102**
Harpalus signaticornis				192	3	1			**196**
Harpalus smaragdinus				4	1				**5**
Harpalus tardus			1	19	14	1		1	**36**

Table 1. (Continuation)

Species	Study site 1	Study site 2	Study site 3	Study site 4	Study site 5	Study site 6	Study site 7	Study site 8	Sum
Leistus terminatus	1	1						2	**4**
Loricera pilicornis							1		**1**
Notiophilus biguttatus								1	**1**
Oodes helopioides		1				1	1		**3**
Panagaeus bipustulatus		1							**1**
Philorhizus sigma						1			**1**
Poecilus lepidus				7	10	1			**18**
Poecilus versicolor		12	14	3	1	5		1	**36**
Pterostichus diligens							4		**4**
Pterostichus melanarius	2	16	5	2					**25**
Pterostichus niger	2	35	38	2	1	69	14	17	**178**
Pterostichus nigrita		1					3		**4**
Pterostichus oblongopunctatus	6							11	**17**
Pterostichus strenuus						1		1	**2**
Syntomus truncatellus		1							**1**
Synuchus nivalis	1								**1**
Trechus obtusus		4				3			**7**
Trechus quadristriatus				1	1				**2**
Individuals	**24**	**89**	**106**	**419**	**116**	**105**	**30**	**44**	**933**
Species	**8**	**18**	**21**	**24**	**24**	**21**	**10**	**14**	**61**
MIB (mg)	**249.3**	**130.7**	**127.2**	**45.7**	**72.1**	**153.0**	**124.0**	**142.6**	**-**
Mean degree of presence (%)	**45.3**	**43.8**	**43.5**	**38.0**	**39.1**	**38.7**	**30.0**	**41.1**	**-**

est sites), *Pterostichus diligens*, *Pterostichus nigrita* and *Carabus granulatus* (moist conditions) and *Harpalus signaticornis* and *Amara aenea* (human influence) located at the outskirts of the diagram.

DISCUSSION

The range of MIB values from below 50 mg to almost 250 mg shows that the study sites cover a wide range of successional stages. However, very advanced stages of succession, which are characterised by far higher MIB values (Szyszko 1990, Schreiner 2011) are missing. The ploughed post-agricultural area and the agricultural field, which show the lowest MIB values, are also characterised by the highest species numbers. In contrary, the nine years old birch-spruce forest shows the highest MIB value and the lowest species number. A reduction in species numbers with increasing stage of succession has been shown, amongst others, by Szyszko (1990) and Schwerk (2008). However, the high number of species on the agricultural field arouses interest, since particularly intense agriculture often leads to declining numbers of carabid species (Holland & Luff 2000): Studying soil samples, Sądej et al. (2012) detected higher numbers of species on fallow grounds compared to areas subject to agricultural use. However, in this context also the agricultural practices are important, e.g. soil preparation (Skłodowski 2005, 2013, Hatten et al. 2007) or crop type (Bourassa et al. 2008). Diversified crop rotation may have a positive influence on carabid diversity (O'Rourke et al. 2008). Kosewska et al. (2012) determined plantation age and surrounding as important factors for differentiation of carabid coenoses on strawberry plantations.

Table 2. Jaccard values in % (bottom left) and ß-diversity values (top right) for all pairs of study sites

	Study site 1	**Study site 2**	**Study site 3**	**Study site 4**	**Study site 5**	**Study site 6**	**Study site 7**	**Study site 8**
Study site 1		16	19	28	30	27	16	10
Study site 2	23,81		19	27	30	25	20	20
Study site 3	20,83	34,48		27	21	26	29	21
Study site 4	6,67	20,00	25,00		12	27	32	32
Study site 5	3,23	16,67	36,36	60,00		25	32	32
Study site 6	3,57	18,18	23,53	25,00	40,00		23	25
Study site 7	5,88	16,67	3,33	3,03	3,03	14,81		20
Study site 8	37,50	23,08	25,00	8,57	8,57	16,67	9,09	

The difference in species composition between the study sites (ß-diversity) is a crucial aspect with respect to γ-diversity in the whole area. However, high ß-diversity values do not always correspond with low Jaccard indices for the respective pairs of study sites. It seems that special attention has to be drawn particularly to species, which are rare in the studied landscape, and to the respective habitats. In this regard the reed vegetation seems to be of importance in the present study. This assumption is supported by the lowest value of mean degree of presence for this study site and a high percentage of species, which were collected exclusively on this site. However, the results may to some degree be influenced by the short collection period and the comparatively low total number of individuals. Galhoff (1992) recommends a minimum collecting program of three pitfall traps on each study site and catching periods in spring and late summer of six weeks each. Thus, despite the high number of 61 species we probably have not detected the full species stock in the study area. It is noteworthy that most of the species, which were found only on one study site, are single catches. The spatial scale of the study has to be considered, too. For example, microhabitats may be a more important factor in determining variation in structure of a coenoses than the respective sites, as shown for stream macroinvertebrates (Costa & Melo 2008).

The differences between the individual study sites and their specific impact on the overall land-

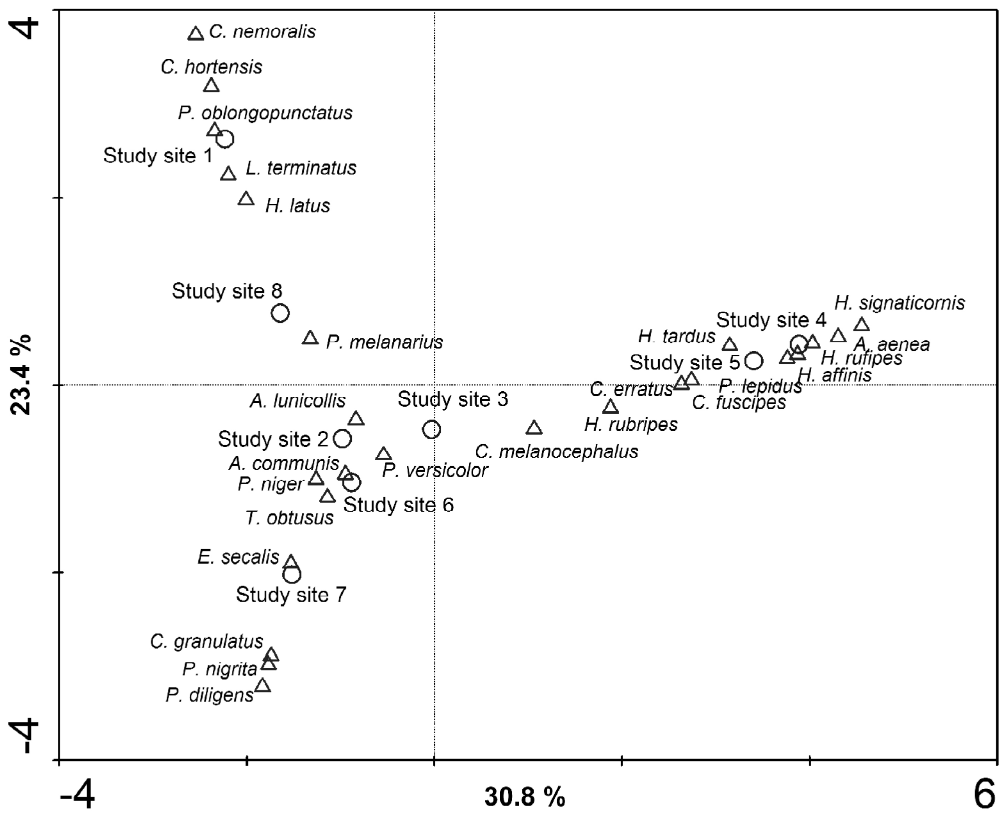

Fig. 2. Ordination plot based on correspondence analysis (CA) of carabid species (triangles) and study sites (circles).

scape's diversity are reflected in the ordination diagram (Fig. 2). The first ordination axis seems to express human management impact, which seems to be of special importance with respect to differentiation of the carabid coenoses. Schwerk & Szyszko (2009, 2012) demonstrated that individual species may react very sensitive on management measures as applied in the present study.

The study indicates that the value of a single site with respect to biological diversity has to be assessed in the context of a larger area, in which it is embedded (landscape). It is necessary to identify those types of landscape elements (often characterized by specific successional stages), which are missing to exploit the full potential of the landscape. This is the more important, since many species need more than one landscape element or successional stage for survival (Szyszko et al.2011). Since very advanced successional stages are missing, the assumption is justified that such areas would positively contribute to γ-diversity in the studied landscape. On the other hand, studying different taxonomic groups in several 16 km^2 covering landscape test sites all over Europe Hendrickx et al. (2007) concluded that increased habitat diversity was of secondary importance to γ-diversity, but caused a shift in the relative contribution of α- and β-diversity. In their study the total landscape species richness was most strongly affected by increased proximity of semi-natural habitat patches. Thus, in this context not only the individual landscape elements but also the landscape structure is of importance (Millán de la Peña et al. 2003).

CONCLUSIONS

The study sites, which were characterised by different management measures and different habitat type, differ with respect to stage of succession, species numbers and species composition. The resulting ß-diversity values lead to increased γ-diversity across the whole study area (landscape).

High ß-diversity values do not always correspond with low Jaccard indices for the respective pairs of study sites. It seems that special attention has to be drawn particularly to species, which are rare in the studied landscape, and to the respective habitats.

Human management impact seems to be of special importance with respect to differentiation of the carabid coenoses.

The value of a single site with respect to biological diversity has to be assessed in the context of a larger area, in which it is embedded (landscape). The identification of those types of landscape elements, which are missing to exploit the full potential of the landscape, is necessary. In this regard not only the individual landscape elements but also the landscape structure is of importance.

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