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Epigeic and soil carabid fauna (Coleoptera: Carabidae) in relation to habitat differentiation of an insulated semi-natural habitat in Western Poland

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The carabid fauna of a 0.6 ha large semi-natural habitat peninsula in an agricultural landscape was studies using pitfall traps and traps for collecting carabids in the soil. Five characteristic habitat types of the study area (one edge of an ephemeral pond, two different grass sites and two different woody sites) were chosen for inventory and their environmental characteristics were determined by phytosociological surveys. Altogether, 648 individuals from 53 species were collected. In the traps specific for collection of carabids in the soil some species were collected, which are not known for cave-digging behavior. The results of the study showed that the diversification in habitat types and their environmental characteristics are important for the species diversity in the area. The study area was also assumed to play an important refugee function on the landscape scale, for example as overwintering habitat for arthropods or in enriching species diversity in the agricultural landscape.

Key words: Carabidae , insulated habitat, biological diversity, soil fauna, landscape

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INTRODUCTION

Agricultural practices like system of soil tillage affect species composition and abundance of carabids (e.g. Kosewska et al. 2014, Skłodowski 2014) and their influence on regional biological diversity may be visible even after several centuries (Dambrine et al. 2007). Therefore, we have to be aware that our current farming systems will affect future patterns of biological diversity and all the more important is to develop ecologically worthwhile strategies of agriculture and managing agricultural landscapes. In this context, many studies show that natural and semi-natural elements as boundary ridges of agricultural fields, groves or other elements untouched by agriculture play an important role in forming arthropod assemblages in landscapes dominated by agriculture (e.g. Asteraki et al. 1995, Fournier

& Loreau 1999, Holland & Fahrig 2000, Pfiffner & Luka 2000, Holland et al. 2001, Millán de la Peña 2003, Kosewska et al. 2007, Retho et al. 2008, Fisher et al. 2013). Hence such elements should be included in the respective regional agricultural management schemes.

In many of the above mentioned studies carabid beetles were used as indicators. Carabids have been assessed to be sensitive to human-altered abiotic conditions (Koivula 2011) and to be affected by grassland managing practices (Rainio & Niemelä). Therefore, they are suitable as indicators in the context of studying the impact of different farming systems and the spatial composition of habitat elements in agricultural landscapes.

In this paper we present a study of the carabid fauna in a small parcel of land, which lies fallow for several decades and which is almost completely surrounded by agricultural landscape. However, it is connected by a forest stripe with a larger forest area. The aim of the paper is to get a picture of the diversity and characteristics of the carabid fauna in this "habitat peninsula" as comprehensively as possible. Hence the different habitat types of the research area were distinguished, characterized by their environmental characteristics and sampled using pitfall traps. We hypothesize that the habitat diversity of the research area will support its species diversity and we want to discuss if the area, due to a lack of soil management for several decades, may enrich the carabid fauna on the landscape scale. A second focus was set on the rarely studied question which carabid species may occur belowground. In order to realize this task soil carabid fauna was inventoried using additional traps specific to the collection of specimens in the soil.

METHODS

Study sites and field methods

Carabid beetles were studied at the research area "Płatkowo" (Western Poland, Wałecki district) in 2014. "Płatkowo" is an area of 0.6 ha of former farm land with the shape of a triangle which lies fallow for several decades. Southwesterly runs a dirt road, in the north a railway line. The area is mainly surrounded by agricultural fields, only in the north it is connected by a about 25-75 m wide forest stripe with a larger forest complex, which is located west of the study area (Fig. 1).

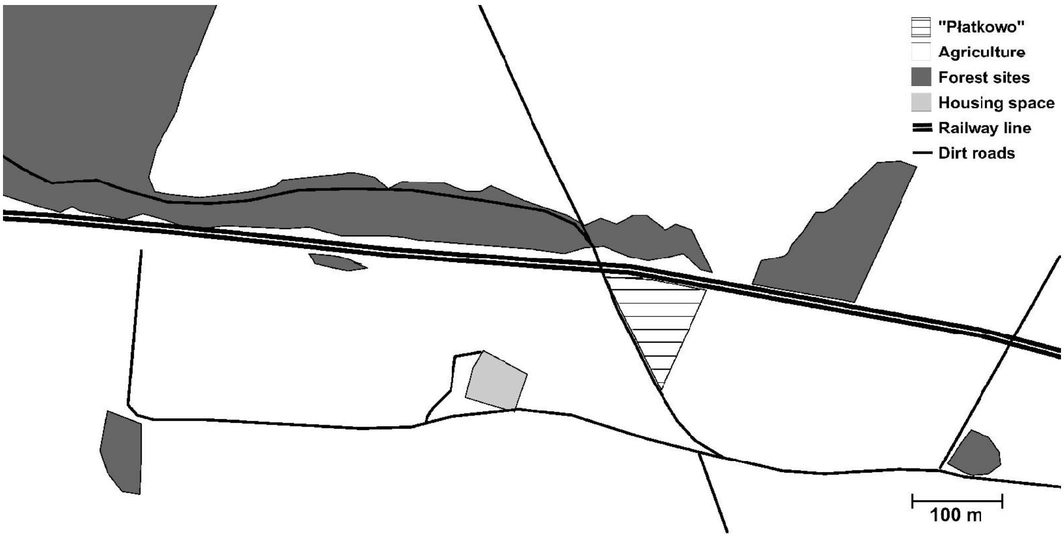

Fig. 1. Map showing the location of the research area "Płatkowo" and the surrounding landscape

Five study sites, which represent characteristic habitat types of the research area, were chosen for inventory. These study sites were the edge of an ephemeral pond dominated by *Galium palustre*, *Agrostis gigantea*, *Carex* spec., *Elymus repens*, *Potentilla anserina* and *Salix cinerea*(study site P1), a grass site dominated by *Arrhenatherum elatius*, *Dactylis glomerata* and *Festuca rubra* (study site P2), a grass site dominated by *Aegopodium podagraria*, *Dactylis glomerata*, *Elymus repens* and *Urtica dioica* (study site P3), a woody habitat dominated by *Ulmus glabra* in the tree layer and *Aegopodium podagraria* in the grass layer (study site P4), and a woody habitat dominated by *Prunus domestica* and *Symphoricarpos albus* in the tree and bush layer and *Aegopodium podagraria* and *Urtica dioica* in the grass layer (study site P5) (Tab. 1).

At each study sites three pairs of traps, one trap to collect epigeic carabid and a second trap to collect carabids in the soil, were installed. Epigeic carabids were collected using pitfall traps following Barber (1931). Traps were glass jars topped with a funnel (upper diameter of about 10 cm) set flush with the soil surface. A roof was suspended a few cm above the funnel.

Soil carabids were collected using closed plastic containers with three lateral slots of about 1cm height and 5 cm length. These containers were dug about 10 cm deep tight into the soil. Thus, arthropods could only enter the traps through the lateral slots. In both types of traps ethylene glycol was used as a killing agent and preservative. Carabids were sampled from mid-May to mid-September.Determination and nomenclature was carried out according to Freude et al. (2004).

Tab 1. Description of the study sites (P1 – P5) including the respective indicator values, number of recorded plant species, and percentage share of plant species recorded exclusively at a study site on the number of plant species recorded at this site

Study site	**P1**	**P2**	**P3**	**P4**	**P5**
Description	Edge of ephemeral pond dominated by *Galium palustre*, *Agrostis gigantea*, *Carex* spec., *Elymus repens*, *Potentilla anserina* and *Salix cinerea*	Grass site dominated by *Arrhenatherum elatius*, *Dactylis glomerata* and *Festuca rubra*	Grass site dominated by *Aegopodium podagraria*, *Dactylis glomerata*, *Elymus repens* and *Urtica dioica*	Woody site dominated by *Ulmus glabra* in the tree layer	Woody site dominated by *Prunus domestica* and *Symphoricarpos albus* in the tree and bush layer
Light	3.98	4.44	4.23	3.45	3.61
Temperature	3.34	3.63	3.54	3.36	3.34
Humidity	4.14	2.94	3.08	3.45	3.43
Fertility (trophy)	3.59	3.63	3.85	4.18	4.23
Soil acidity	4.05	4.13	4.19	4.23	4.07
Granulometric composition	3.91	3.79	3.77	3.86	3.80
Soil organic content (humus)	2.30	2.02	1.96	2.05	2.04
Number of plant species	23	24	13	12	9
Plant species exclusive to the study site (%)	82.6	62.5	23.1	75.0	22.2

At each study site an area of 5 m x 5 m was marked in order to elaborate phytosociological survey. The surveys were elaborated in mid-September 2014 by recording the species and describing their occurrence using the cover-abundance scale of Braun-Blanquet (1964).

Statistical methods

All collected carabids were determined to the species level. Numbers of individuals of the species were calculated for each study site and trap type. For the data collected by the pitfall traps dominance values of the species were calculated for further statistical analyses.

For each phytosociological survey dominance values for the plant species were determined based on the cover scale of Braun-Blanquet (1964) assuming the following average percentage covers: 5 –87,5 %, 4 – 62,5 %, 3 – 37,5 %, 2 – 17,5 %, 1 – 5 %, + - 0,1 %, and r – 0 %. Next, for each study site indicator values for light conditions, temperature, humidity at ground level, fertility (trophy), soil acidity, granulometric composition, and soil organic content (humus) according to Zarzycki et al. (2002) were calculated (Tab. 1). The 5-grade scale of ecological values according to Zarzycki is a modification of the method of ecological values of vascular plants according to Ellenberg (1974) adapted to the conditions of the Polish climate. For almost all study sites the indicator values were fixed by calculating the arithmetic mean, with exception of study site 3, for which due to the low number of recorded plant species the weighted mean according to Diekmann (2003) was calculated.

The Canoco for Windows version 4.53 (ter Braak 1987, ter Braak & Šmilauer 2002) was used to perform a direct gradient analysis in order to analyze the relationships of the carabid assemblages with the environmental parameters (ter Braak & Prentice 1988). Detrended Canonical Correspondence Analysis (DCCA) were first used to select the appropriate statistical model based on the longest gradient (Lepš & Šmilauer 2003) and then Canonical Correspondence Analysis (CCA) was carried out. The CCA was done with 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.The significance of the individual environmental variables included in the CCA was tested using Monte Carlo permutation tests (unrestricted,1999 permutations). CanoDraw for Windows version 4.14 was used to create a triplot with species weight range adjusted in such a manner that the 13 species with the largest impact on the analysis results were displayed (ter Braak & Šmilauer 2002).

RESULTS

Altogether, 648 individuals (13 of them in the traps for collecting soil carabids) of 53 species were collected (Tab. 2). Species collected in the soil were *Clivina fossor* (9 specimens), *Agonum fuliginosum* (1 specimen), *Pterostichus diligens* (1 specimen), *Pterostichus minor* (1 specimen), and *Syntomus truncatellus* (1 specimen). All these species were also collected in the pitfall traps for epigeic fauna. 23 of the 53 species (43.4%) were collected exclusively at only one study site. Of special importance are study site P1 with 9 exclusive species and study site P4 with 7 exclusive species. These two study sites exhibited also the highest total numbers of collected species.

From 62 plant species, which were recorded altogether, many were recorded exclusively on single study sites. As for exclusive carabid species, the highest percentage of exclusive plant species showed study sites P1 and P4 with 82.6 % and 75.0 % respectively. Comparatively low numbers of exclusive plant species exhibited study sites P5 (22.2 %) and P3 (23.1 %) (Tab. 1).

Tab 2. Numbers of carabid beetles collected on the study sites (P1 – P5). In brackets are numbers of individuals and species collected with the soil traps

Species	**P1**	**P2**	**P3**	**P4**	**P5**	**Sum**
Acupalpus exiguus	1					**1**
Agonum fuliginosum	57 (1)		6	1	4	**68 (1)**
Amara aulica		1				**1**
Amara communis	1			3	1	**5**
Amara consularis				1		**1**
Amara convexior		6	3			**9**
Amara plebeja		1				**1**
Badister bullatus	1	1	17	28	3	**50**
Badister dilatatus	3					**3**
Badister lacertosus		2	3	6		**11**
Badister sodalis	1					**1**
Bembidion gilvipes			4			**4**
Calathus fuscipes				1		**1**
Calathus melanocephalus				2		**2**
Calathus rotundicollis				5	4	**9**
Carabus granulatus	19	1	5	3		**28**
Carabus nemoralis					3	**3**
Chlaenius nigricornis	1					**1**
Clivina fossor	6 (9)			1		**7 (9)**
Cychrus caraboides		1				**1**
Dyschirius globosus	7		1	1		**9**
Epaphius secalis	6	21	1			**28**
Harpalus laevipes				1		**1**
Harpalus latus	1	2	1	8	1	**13**
Harpalus rubripes					1	**1**
Harpalus rufipalpis			1			**1**
Harpalus rufipes	4	9	27	98	8	**146**
Harpalus tardus				3		**3**
Harpalus xanthopus		1	1	24		**26**
Leistus terminatus	2		4	2	3	**11**
Limodromus assimilis				1	1	**2**
Loricera pilicornis	1					**1**
Nebria brevicollis		1		1		**2**
Notiophilus biguttatus				5	2	**7**
Notiophilus palustris				5		**5**
Oodes helopioides	6		1			**7**
Ophonus rufibarbis	1		7	12	7	**27**
Oxypselaphus obscurus	49			1	1	**51**
Panagaeus bipustulatus		1		1		**2**
Poecilus versicolor				1		**1**
Pterostichus anthracinus	1					**1**
Pterostichus diligens	6 (1)					**6 (1)**
Pterostichus melanarius	2		1		4	**7**
Pterostichus minor	6 (1)					**6 (1)**
Pterostichus niger	11	1	2	4	3	**21**
Pterostichus nigrita	1					**1**
Pterostichus oblongopunctatus				5	2	**7**
Pterostichus strenuus	1	1	5	7	1	**15**
Pterostichus vernalis		1	1			**2**

Tab. 2. (continuation)

Stomis pumicatus		1	1	2		**4**
Syntomus truncatellus		3 (1)		1		**4 (1)**
Synuchus vivalis		1	1	2	2	**6**
Trechus quadristriatus				1	3	**4**
Individuals	**195 (12)**	**56 (1)**	**93**	**237**	**54**	**635 (13)**
Species	**25 (4)**	**19 (1)**	**21**	**32**	**19**	**53 (5)**

With exception of light study site P1 showed for all environmental factors either the highest value (humidity, granulometric composition, soil organic content) or the lowest value (temperature, fertility, soil acidity) among the study sites. Study site P2 showed the highest values for light and temperature, but also the lowest humidity. Study site P3 exhibited the lowest value for granulometric composition and soil organic content and study site P4 the highest soil acidity and the lowest light value. The highest fertility among all study sites showed study site P5, which also had the same low temperature value as study site P1. (Tab. 1).

The first ordination axis of the CCA explained 40.4 % and the second ordination axis explained 33.4 % of the variation in the dataset. Humidity is closely related to the first ordination axis. Even if not statistically significant (p = 0.079) this environmental variable accounted for most of the variance. Accordingly study site P1 (edge of an ephemeral pond) is separated from the other study sites along the first ordination axis. Positively correlated with humidity are the ecological factors soil organic content (humus) and granulometric composition, which also differ on study site P1 from the other sites. Acidity is negatively correlated with these factor. Study site P2 is separated from study

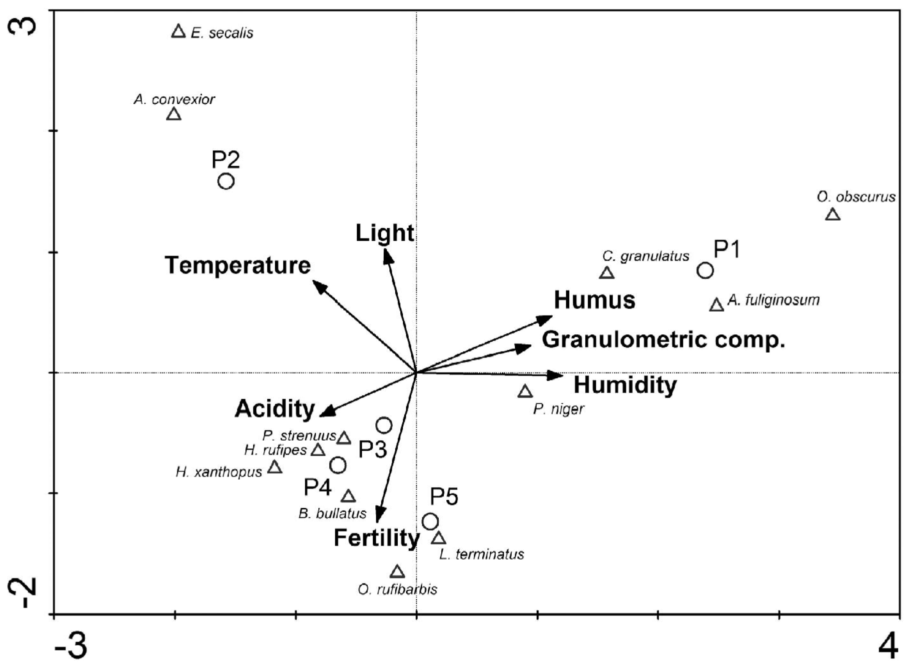

Fig. 2. Ordination plot based on canonical correspondence analysis (CCA) ofthe results for study sites (open circles), species (open triangles), and environmental variables (arrows)

sites P3, P4, and P5 along the second ordination axis. The former study site is correlated with increasing temperature and light, whereas the latter ones are correlated with increasing fertility. Among the displayed species *Carabus granulatus*, *Agonum fuliginosum* and *Oxypselaphus obscurus*are located close study site P1, *Epaphius secalis* and *Amara convexior* are close to study site P2, and *Ophonus rufibarbis, Leistus terminatus, Pterostichus strenuus, Harpalus rufipes, Harpalus xanthopus* and *Badister bullatus* are close to study sites P3, P4, and P5. *Pterostichus niger* is located more in the center of the diagram between the study sites.

DISCUSSION

The diversification of carabid fauna on the research area "Płatkowo" is mainly due to differentiation between the study sites in moisture conditions and the amount of wooden vegetation, leading to higher variation of light, temperature and fertility (trophy) conditions. Consequently, the collected species cover a wide range of ecological preferences. The results are reflected by the plant associations. The number of recorded plant species can be assessed as high, even if the inventory was done during the suboptimal autumn time. Study sites characterized by high numbers of exclusive carabid species are also characterized by high numbers of exclusive plant species.

However, strict stenotopic forest species are missing among the registered carabids. This might be explained by the spatial isolation, size or habitat quality of the woody habitats of "Płatkowo". Fourier & Loreau (2001), who studied the role of hedges and forest patch remnants in an agricultural landscape, described that especially small remnants had few typical forest carabid species. They conclude that " small remnants do not behave as 'climax' habitats in this intensive agricultural landscape, probably because of their small size and strong isolation." When assessing the species diversity in the research area, edge effects have to be taken into account. For example, Roume et al. (2011) discovered higher diversity at the edges than in the center of woodlots in agricultural landscapes. Species with high dispersal power might have penetrated from the adjacent agricultural fields into the study area.

With respect to the soil traps the significant number of individuals of *Clivina fossor*, due to its life history, is an expected result. Yet no individuals of *Dyschirius globosus* were collected in these traps, even if the species was collected in the pitfall traps for epigeic fauna. The other four species are not known for cave-digging behavior. However, former studies have also proven species not known for such behavior in soil samples. Scherney (1955) mentions that *Pterostichus melanarius* and *Harpalus rufipes* may dig themselves up to 25 cm deep into the soil in order to search for prey. Pfiffner & Luka (2000), studying the overwintering of arthropods in the soil of arable fields and adjacent semi-natural habitats by analyzing 25 cm deep soil samples, mention the species *Bembidion lampros*, *Agonum muelleri* and *Demetrias atricapillus*. However, it is not clear from their study, how deep these species penetrated into the soil.

The species diversity proven in the study has to be assessed on two levels. Firstly, the habitat diversity in the research area is an important factor for the species diversity of "Płatkowo". This is corroborated by the fact that more than 40 % of the collected species were registered at only one study site. Secondly, it can be assumed that "Płatkowo" has a function with respect to the carabid diversity over a larger landscape. According to its history the research area "Płatkowo" can be regarded as an abandoned agroecosystem. Felipe-Lucia & Comín (2015), who studied the relationship between ecosystem services and biodiversity in a floodplain area of the River Piedra in Spain, mentioned that abandoned parts of agroecosystems, saved as set-aside areas, had the highest abundance and plant species richness in comparison to other ecosystems in the agricultural landscape. Błaszkiewicz & Schwerk (2013) in their study of different habitat types in an agricultural landscape discovered a special importance of a reed vegetation along the edge of a swamp. A similar role may be attributed to the edge of the ephemeral pond on "Płatkowo", which is characterized by highest or lowest values for many environmental factors and several exclusive species, both carabids and plants. Semi-natural habitats adjacent to arable fields are also important as overwintering sites for arthropods (Pfiffner & Luka 2000). Analyzing the function of "Płatkowo" on the landscape scale it might be an interesting task to study in future, to which degree the forest stripe plays a role as migration corridor for forest species with low dispersal power. Such corridors are of importance, because species successful in colonizing habitat islands are generally characterized by small body size and long wings (Ranta & Ås 1982), which are features of species with high dispersal power. Species with low dispersal power as *Pterostichus niger* or *Carabus nemoralis* might have used the forest stripe for colonizing "Płatkowo". Both species were detected in the forest west of "Płatkowo" by Błaszkiewicz & Schwerk (2013). However, *Carabus hortensis*, which was also collected by Błaszkiewicz & Schwerk (2013) in this forest, was not proven in our study. According to Skłodowski (1999) *Pterostichus niger* and *Carabus nemoralis* tend to move towards ecotones and even to cover significant distances in open areas. Accordingly, they might be able to use even narrow forest stripes as corridors. In the context of ecological corridors on the landscape scale the type of the linear woody habitat is also important (Fischer et al. 2013). However, since not all species of our study are to be expected in the surrounding agricultural fields, the assumption is supported that "Płatkowo" has a function in enriching species diversity on the landscape scale. Thus, the results of the study are very valuable and informative for managers maintaining agricultural landscapes.

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