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Carabid beetle (Coleoptera: Carabidae) distribution in a rural landscape based on habitat diversity and habitat characteristics

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The spatial arrangement of ecosystems in an ecological landscape is assumed to be of importance with respect to species diversity. In order to improve current knowledge with respect to this aspect, carabid beetles were studied in six study sites, representing differently treated agricultural and post-agricultural areas and their surrounding habitats, over the period 2013-2015. Additionally, phytosociological surveys were elaborated on the study sites, in order to elaborate indicator values for selected environmental characteristics. We wanted to study (1) the similarities between the study sites and their contribution to overall species diversity, (2) the constancy of similarities between the study sites over several years, and (3) influence of environmental factors on the distribution of the species. Altogether, 1402 individuals belonging to 65 species were collected. Numbers of species differed strongly on the individual study sites in single years, but taking into account all three years the differences were much less significant. The number of exclusive species on the individual study sites ranged from 3 to 11 species, with the highest number on an agricultural field. Cluster analysis and correspondence analysis (CA) showed that the samples of the study sites from the different years were generally similar to each other. The distribution of the study sites along the ordination axis indicated a high importance of stages of succession (management intensity) followed by moisture conditions. The analysis of the indicator values, however, indicated light, acidity and humus content as most important. The study confirmed the assumption that a diversified landscape contributes to species diversity. In this context anthropogenic ecosystems should be taken into account.

Key words: Carabidae, rural landscape, biodiversity, environmental factors

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INTRODUCTION

Intensification of agriculture and change in land use are assessed to be main drivers of loss in biological diversity (e.g. Matson et al. 1997; Watt et al. 2007). In order to deal with this problem, we need substantial knowledge about agricultural landscapes. In this context the impact of landscape structure on species diversity is of importance. Since different species prefer different ecosystems and stages of succession, their spatial arrangement in an ecological landscape is assumed to be of importance with respect to overall diversity (Szyszko et al. 2011). Landscape structure, land-use intensity and habitat diversity influence species diversity patterns in agricultural landscapes (Hendrickx et al. 2007). Hence, studies dealing with different ecosystems and stages of succession in a landscape are useful in order to better understand and to counteract tendencies of decreasing biological diversity. Furthermore, knowledge with respect to the ecological characteristics of the respective landscape element is needed. Finally, such landscape elements may be subject to a temporally dynamic and studies carried out over several years may help to untangle ambiguities caused by this aspect.

Carabid beetles are considered to have good potential for indication of environmental variation (Koivula 2011), they react to management practices in grassland habitats (Rainio & Niemelä 2003), to changes in the stage of succession (Szyszko 1990) and to human disturbance (Brandmayr et al. 2009).

Błaszkiewicz & Schwerk (2013) studied the carabid fauna in an agricultural landscape on eight study sites, which represented different habitat types and different stages of succession. The study indicated that sites with high species numbers often, but not always, contributed to high ß-diversity. The authors concluded 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). However, this study covered only one year and did not take into account environmental characteristics of the study sites in detail. The paper at hand presents a consecutive study on carabid beetles on six of these study sites over the period 2013-2015. Additionally, phytosociological surveys were elaborated on the study sites, in order to elaborate indicator values for selected environmental characteristics.

We wanted to study (1) the similarities between the study sites and their contribution to overall species diversity, (2) the constancy of similarities between the study sites over several years, and (3) influence of environmental factors on the distribution of the species. Based on the results we wanted to draw preliminary conclusions with respect to land use in agricultural landscapes aimed at facilitation of species diversity.

MATERIAL AND METHODS

Study area, 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 eutrophicated mires being supplied by three water courses (Dymitryszyn et al. 2013).

Six study sites were selected for carabid sampling (Fig. 1): A forest of about 0.45 ha divided into partly birch and partly spruce, 11 years old in 2013 (study site 1), an extensively used post-agricultural area of about 1.3 ha, where the grass is cut and biomass removed (study site 2), a post-agricultural area turned into fallow land of about 1.5 ha (study site 3), an agricultural field of about 1.3 ha where triticale was cultivated (study site 4), a moist to wet grassland close to reed vegetation with its range fluctuating dependent on the water level

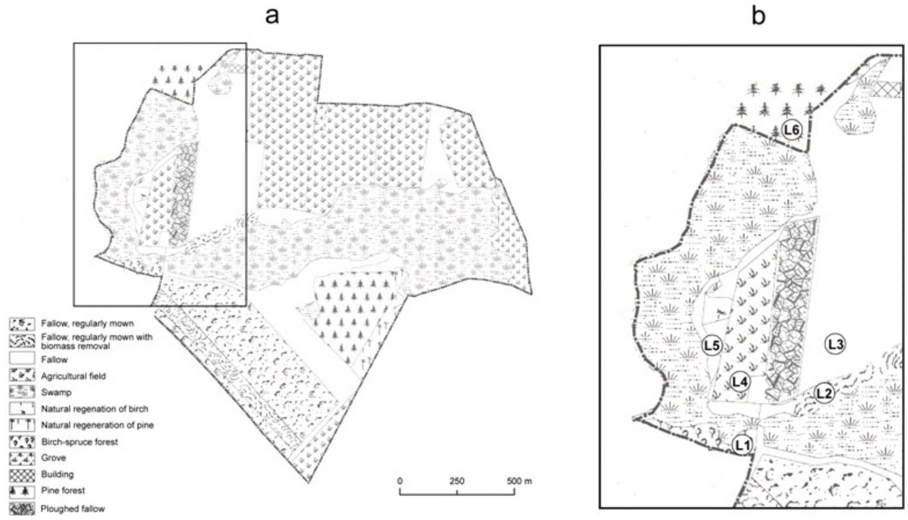

Fig. 1. Scheme of the research object “Krzywda” (a) and location of the study sites (1-6) (b) (After Błaszkiewicz & Schwerk (2013), modified).

(study site 5), and a pine forest of about 1.05 ha, about 42 years old in 2013 (study site 6). Fig. 1 shows the distance between these sites.

On each study site three pitfall traps following Barber (1931), with pure ethylene glycol as trapping liquid were installed with a distance of 5 m to each other. With respect to study site 1 the traps were located in the spruce part very close to the birch part. On each study site the location of the traps was the same in each year of study. 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. Trapping time covered the period from mid-May to mid-September in 2013, 2014, and 2015. All collected specimens were determined to the species level. Nomenclature follows Müller-Motzfeld (2004).

At each study site an area of 6 m x 6 m was marked in order to elaborate a phytosociological survey. The surveys were elaborated in the second week of June 2015 (before the first mowing on the treatment sites) by recording the species and describing their occurrence using the cover-abundance scale of Braun-Blanquet (1964).

Statistical method

The results of the three traps were pooled to one sample for each study site. Next, two datasets were elaborated: A first dataset with the results of the three years separated for the individual study sites and a second dataset with the results of the three years pooled for each study site. For both datasets for each species the total number of individuals per study site and the dominance value (percentage share of the individuals of the respective species on the total number of individuals collected at the study site) was calculated.

For each phytosociological survey the values of coverage of the plant species were transformed to a value of mean percentage cover according to Braun-Blanquet (1964): + - 0.1%, 1 - 5%, 2 - 17,5%, 3 - 37,5%, 4- 62,5%, and 5 -87,5%. Next, for each study site ecological indicator values of vascular plants were calculated according to Zarzycki et al. (2002). The ecological values according to Zarzycki are a modification of the method of ecological values of vascular plants according to Ellenberg (1974) adapted to the conditions of the Polish climate. Ecological indicator values for light, temperature, soil moisture, trophy (fertility), soil acidity (pH), soil granulometric composition, and organic matter content (humus) were calculated as a weighted average value of particular plant species cover values.

Similarities between the carabid coenoses were studied with a hierarchical cluster analysis using PAST v. 2.17c (Hammer et al. 2001; Hammer 2012), with Euclidian distance as distance measure and agglomeration according to Ward. The dominance values of the species at the respective study sites were used. The strength of the nodes was tested by bootstrapping analysis (1999 resamplings). Bootstrap proportions (percentage of replicates where the node is still supported) of e”70% correspond to a probability of e”95% that the respective clade is correct (Hillis & Bull 1993). With each dataset (years of study separated for the study sites; results of the three years of study pooled for each study site) an individual cluster analysis was carried out.

The CANOCO for Windows version 4.53 (ter Braak 1987; ter Braak & Šmilauer 2002) was used to perform gradient analyses. DCA and DCCA were first used to select the appropriate statistical model based on the longest gradient (Lepš & Šmilauer 2003) and then correspondence analyses (CA) and canonical correspondence analysis (CCA) were carried out. Indirect gradient analysis (CA) was used to obtain information about the environmental basis determining the major pattern in variation (ter Braak & Prentice 1988). Just as the cluster analyses the CA was carried out with both datasets. The analyses were performed using inter-sample distance scaling and Hill s scaling and un-weighted data for each of the species. Because dominance values were used, the data were not transformed. CanoDraw for Windows version 4.14 was used to create a biplot with species weight range adjusted in such a manner that the 15 species (individual years) or 13 species (years pooled) with the largest impact on the analysis results were displayed (ter Braak & Šmilauer 2002).

In order to test the significance of the individual environmental variables (plant indicator values), direct gradient analyses (CCA) was carried out with the data elaborated in 2015 using Monte Carlo permutation tests (unrestricted, 1999 permutations) first for each variable separately and then using automatic forward selection of variables (reduced model) (ter Braak & Šmilauer 2002).

RESULTS

Altogether 1402 carabid beetle individuals belonging to 65 species were collected (Tab. 1). The total number of species in the single years increased from 2013 to 2014 and dropped again in 2015. The highest numbers of 23 species were detected on the fallow ground (L3) and the agricultural field (L4), whereas low numbers were detected in the forests (L1, L6). 37 species (56.9 %) were collected exclusively on one study site. The agricultural field showed the highest number of exclusive species (11 species). The lowest number of exclusive species was collected on the post-agricultural area with cutting of grass (3 species). Total numbers of collected individuals dropped constantly over the years. The highest number of 390 individuals was collected on the fallow ground (L3) and the lowest number (115 individuals) in the moist-wet area (L5). Very low numbers of both species and individuals were collected in the latter in 2013, due to an increased water level in this year causing a temporally flooding of the traps.

Tab. 1. Numbers of species and numbers of individuals recorded on the study sites in 2013, 2014, 2015, and 2013-15 (in brackets are numbers of species detected exclusively on the respective study site)

Study site	Number of species				Number of individuals			
	2013	2014	2015	2013-15	2013	2014	2015	2013-15
L1	8	10	13	16 (6)	24	112	90	226
L2	17	10	12	20 (3)	123	19	77	219
L3	19	15	11	23 (5)	227	124	39	390
L4	15	17	8	23 (11)	138	70	32	240
L5	3	16	9	20 (6)	7	81	27	115
L6	10	10	14	18 (6)	46	88	78	212
Total	40	46	37	65	565	494	343	1402

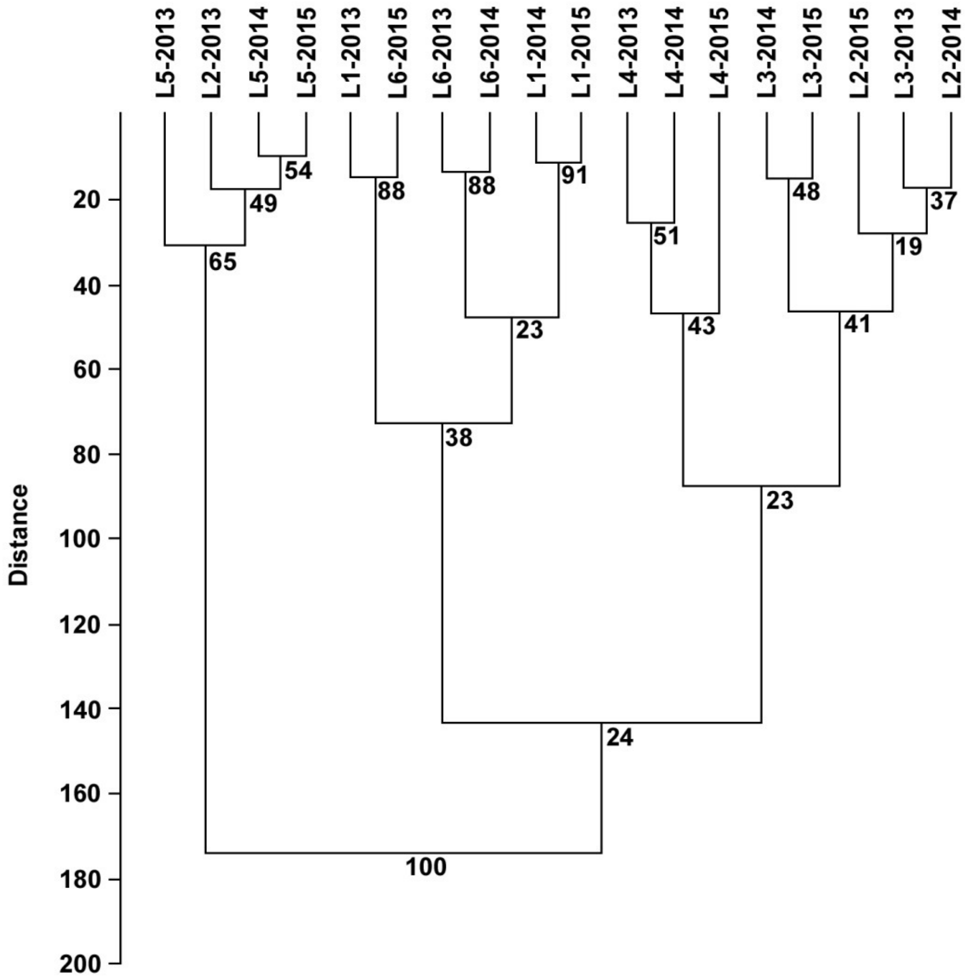

Fig. 2. Cluster analysis of the results (individual years separated) based on Euclidian distance as distance measure and agglomeration according to Ward. Numbers indicate the percentage of replicates where each node is still supported (Hammer 2012)

Considering the samples of the study years separately, the cluster analysis (Fig. 2) resulted in three main clusters, of which basically the first one comprises the samples from the moist-wet grassland (L5), the second one the samples from the forest sites (L1, L6) and the third one the samples from the post-agricultural areas (L2, L3) and the agricultural field (L4). Within the latter the samples from the post-agricultural areas are separated from the samples from the agricultural field. As only exception the sample from the post-agricultural area with cutting of grass from the year 2013 (L2-2013) is included in the cluster of the samples from the moist-wet grassland (L5). While the separation of the cluster of samples from the moist-wet grassland is strongly supported by a bootstrapping proportion of 100%, the other two clusters are separated with a rather low bootstrapping proportion of 24%. Samples of consecutive years (2013, 2014 and 2014, 2015 respectively) are generally closer related than samples of 2013 with those of 2015. The results of the cluster analysis were corroborated by the results of the correspondence analysis (CA) (Fig. 3), with the first ordination axis explaining 22.1 % and the second ordination axis explaining 15.6 % of the variance of species data. The study sites are separated along the first ordination axis with the samples from the agricultural field (L4) located most to the left side and the samples from the forest sites (L1, L6) located most to right side of the diagram. The samples from the agricultural field (L4) were also located most in the lower part, whereas the samples from the moist-wet grassland (L5) were located most in the upper part of the diagram. Species related to the agricultural field were *Amara plebeja*, *Harpalus affinis*, *Harpalus rufipes* and *Harpalus tardus*, species related to the moist-wet grasslands were *Calathus melanocephalus*, *Clivina fossor* and *Pterostichus niger*, and species related to the forest sites were *Carabus hortensis*, *Carabus nemoralis* and *Pterostichus oblongopunctatus*. *Amara convexior*, *Harpalus rubripes*, *Poecilus versicolor*, *Harpalus latus* and *Pterostichus melanarius* were located close to the post-agricultural areas, with the first three species located closer to the fallow (L3) and the latter two located closer to the post-agricultural area with cutting of grass (L2).

When using the dataset with the results of the three years pooled for each study site, the cluster analysis indicates a quite similar clustering as when using the samples for each individual year of study (Fig. 4). However, the past-agricultural area with cutting of grass (L2) is clustered with the moist-wet grassland (L5), indicating that the results from 2013 have an important impact. Accordingly, in the CA with the pooled data (Fig. 5; first ordination axis explained 38.6 % and the second ordination axis 26.3 % of the variance of species data) the location of the study sites and the species with the largest impact are quite similar to Fig. 3 (CA with years of study separated). The post-agricultural area with cutting of grass (L2) is located between the fallow land (L3) and the moist-wet grassland (L5), with a bit closer position to the latter along the first ordination axis.

The plant indicator values differ between the study sites (Tab. 2). Highest values for moisture, trophy, acidity and granulometric composition showed the moist-wet grassland (L5). Values for light and temperature were highest on the fallow ground (L3) and humus was highest in the young forest (L1). The latter study site showed the lowest values for temperature, acidity and granulometric composition. Values for moisture and trophy were lowest in the post-agricultural area with cutting of grass (L2), the value for humus was lowest in the agricultural field (L4) and the value for light was lowest in the pine forest (L6). Testing the environmental parameters separately, light and acidity had a significant influence on the formation of the carabid assemblages (Tab. 3). Even if not statistically significant, the amount of humus also showed a clear trend. However, using forward selection the additional variance explained by acidity and humus was markedly

Tab. 2. Plant indicator values recorded for the study sites in 2015 (L, light; T, temperature; M, moisture; Tr, trophy; A, acidity; GC, granulometric composition; H, humus)

Study site	L	T	M	Tr	A	GC	H
L1	3.50	2.50	3.50	2.50	2.00	3.00	2.50
L2	3.87	3.29	2.07	2.20	3.71	3.01	1.87
L3	4.29	3.81	2.67	3.37	4.12	3.71	1.96
L4	4.05	3.45	2.84	3.34	3.79	3.84	1.55
L5	4.07	3.46	3.76	3.84	4.33	3.95	2.24
L6	3.22	3.33	3.20	2.53	3.18	3.50	1.98

Tab. 3. Results of Monte Carlo permutation tests of the environmental variables tested separately and using automatic forward selection of variables (reduced model). During forward selection of variables "granulometric composition" and "trophy" were not added to the model due to collinearity. Lambda-1 - variance explained by the environmental variables separately; Lambda-A - additional variance explained when included in the model using forward selection

Variable	Tested separately			Forward selection		
	Lambda-1	F	*p*	Lambda-A	F	*p*
Light	0.76	1.59	0.030	0.76	1.59	0.030
Acidity	0.74	1.55	0.039	0.57	1.58	0.253
Humus	0.70	1.42	0.070	0.60	1.38	0.228
Temperature	0.67	1.35	0.127	0.42	1.36	0.414
Moisture	0.45	0.81	0.789	0.31	0.00	1.000
Gran. comp.	0.44	0.79	0.837	-	-	-
Trophy	0.43	0.79	0.838	-	-	-

reduced when including these variables in the model.

DISCUSSION AND CONCLUSIONS

Our study confirmed that spatial arrangement of ecosystems in an ecological landscape is of importance with respect to species diversity. The very high number of species detected exclusively on one study site indicates the significance of diversification with respect to ecosystems and stages of succession. It has to be mentioned that many of these species were collected only with one or two individuals. However, some species were recorded numerous on the respective sites, e.g. *Harpalus affinis* in the agricultural field (L4) and *Calathus rotundicollis* in the birch-spruce forest (L1).

A remarkable result is the high number of species as well as exclusive species collected in the agricultural field (L4). However, former studies have proven that high numbers of species may exist in such areas. Important influence on the numbers of species and individuals have, amongst others, the amount of pesticides used and the tillage system (Holland & Luff 2000; Marasas et al. 2001; Kosewska et al. 2009; Kosewska et al. 2014). On the other hand, on the genus level the diversity of carabids in the agricultural field was less pronounced, because a very high amount of the detected species (56.5 %) belonged to the genera *Amara* and *Harpalus*.

The cluster analysis and CA with the datasets for the single years indicated generally consistent results between the years. but the result obtained for the post-agricultural area with cutting of grass (L2) in 2013 differed from the results obtained in 2014 and 2015. In 2013 an increased water level was observed in the whole study area, causing the flooding of the traps in the moist-wet grassland (L5) in this year. Carabid beetles react on frequency, duration and level of inundation events (Spang 1999). Since the post-agricultural area with cutting of grass (L2) was located rather close to a swamp, this may have caused to change the environmental conditions on this areas in the direction of the moist-wet grassland in this year. When using the pooled data, the results from 2013 was dominant over the results from 2014 and 2015. In 2013 a remarkable high number of *Pterostichus niger* was collected on the post-agricultural area with cutting of grass (L2), a species being regularly dominant in the moist-wet grassland (L5).

The CA indicated importance of stage of succession and also moisture conditions as important factors for formation of the carabid assemblages. Of major significance for stage of succession is the degree of impact due to human management. For example, in a study by Petit & Usher (1998) ungrazed woodland habitats were crucial for carabid diversity. Agricultural land use and management has been proven to influence the ecological composition of carabid assemblages in Scottish farmland (Cole et al. 2002). Since such area often are subject to soil preparation, the method of soil preparation is of importance, too (e.g. Skłodowski 2017). The analysis of the indicator values depicted particularly light as important environmental factor. Light can be related to stage of succession, because particularly in the

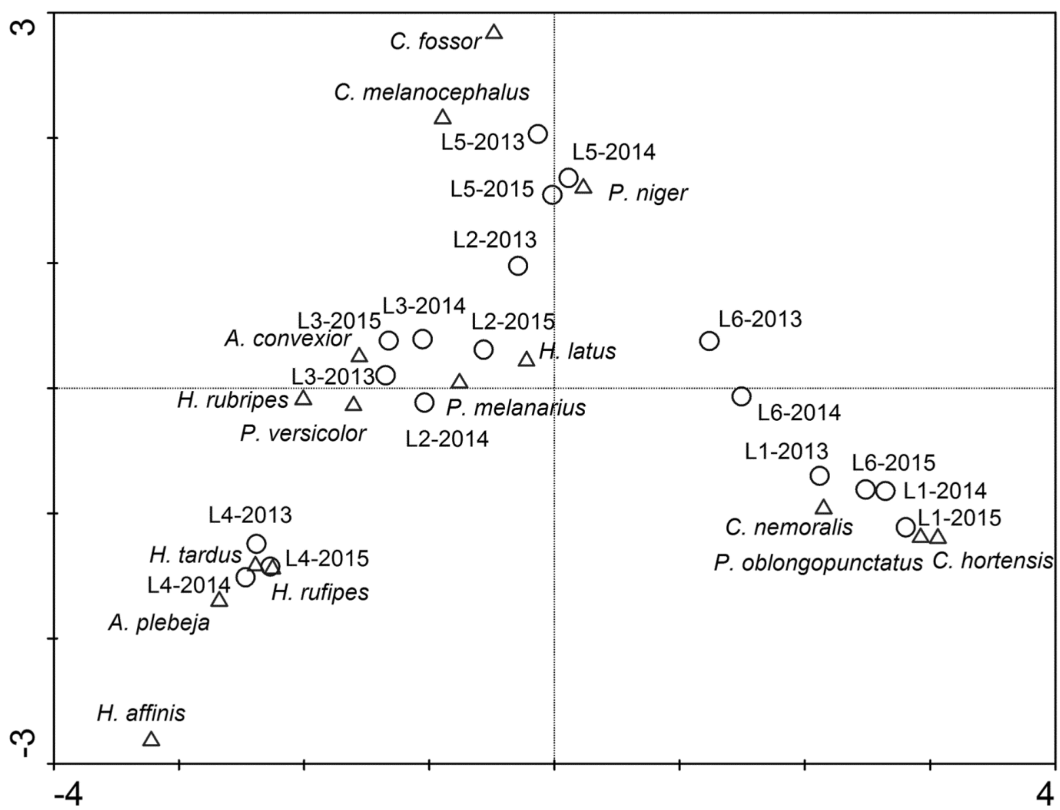

Fig. 3. Ordination plot based on correspondence analysis (CA) of the results (individual years separated) for study sites (open circles) and species (open triangles)

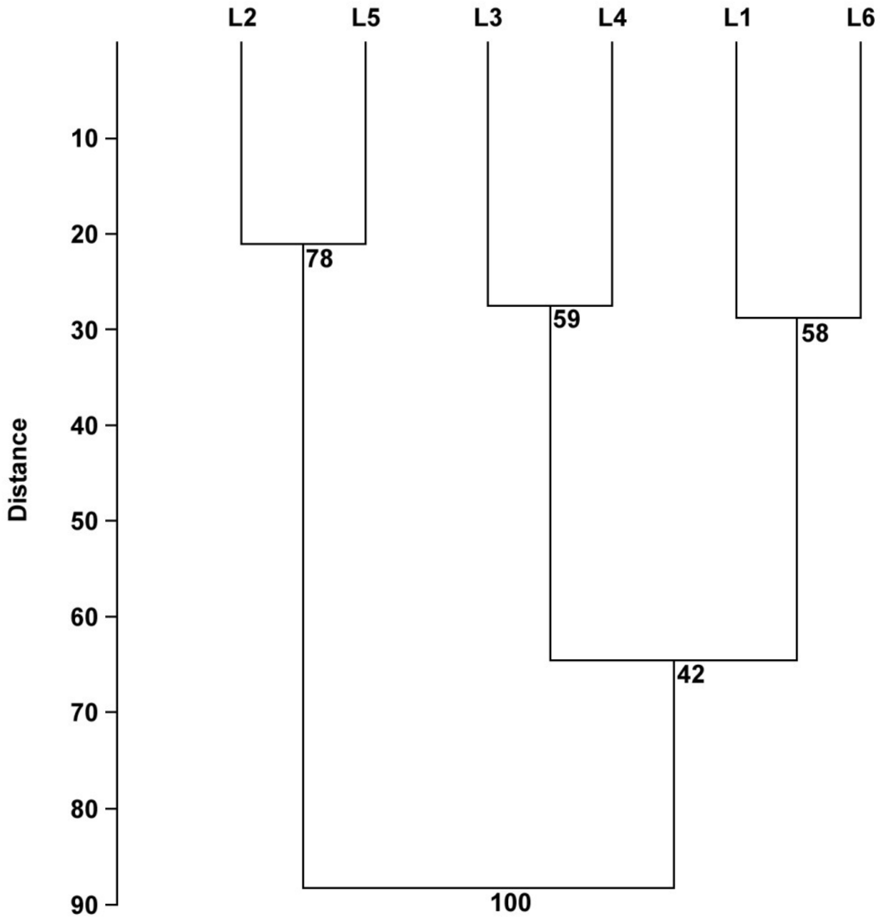

Fig. 4. Cluster analysis of the results (years for the study sites pooled) based on Euclidian distance as distance measure and agglomeration according to Ward. Numbers indicate the percentage of replicates where each node is still supported (Hammer 2012)

forests the canopy cover reduces the amount light penetrating to the ground.

The results of our study are to a high degree in agreement with those obtained by Błaszkiewicz & Schwerk (2013), who also detected human management impact as key factor with respect to formation of the carabid assemblages. As in our study, they detected a high number of species on the agricultural field. Both studies showed that a diversified landscape contributes to species diversity. In this context anthropogenic ecosystems should be taken into account. Some landscape elements may be subject to temporal dynamics (e.g. flooding events). Studies carried

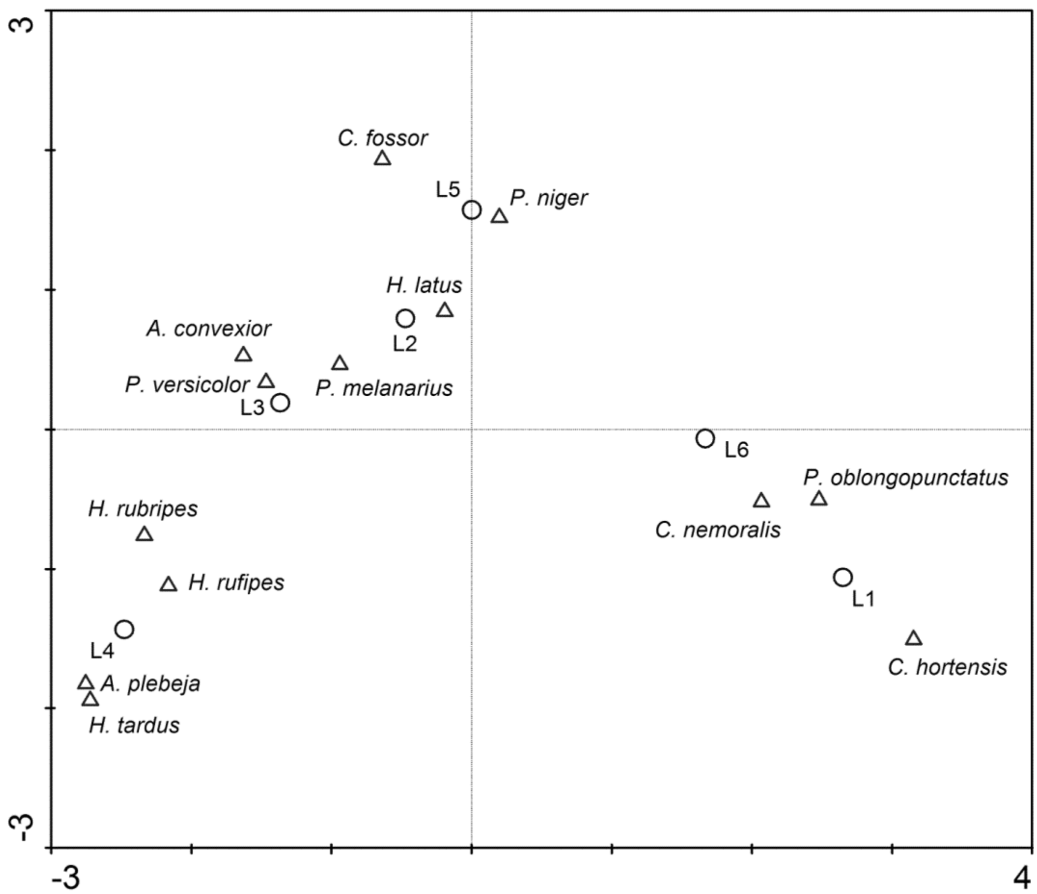

Fig. 5. Ordination plot based on correspondence analysis (CA) of the results (years for the study sites pooled) for study sites (open circles) and species (open triangles)

out over several years are helpful to detect and describe the impact of such disturbances.

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