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Distribution and spatial preferences of Carabid species (Coleoptera: Carabidae) in a forest-field landscape in Poland

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The Carabid fauna of the research object "Krzywda" (west Poland), which is composed of forests and open areas of different stage of succession, was studied over a period of four years (2004-2007) using 53 pitfall traps placed in a grid. The study was aimed to answer the questions, whether (1) the different spatial elements of the research area are characterised by differences in stage of succession and (2) the dominant species show spatial preferences in the research area.

Altogether, 13004 individuals from 98 species were collected. Five species, namely *Calathus erratus*, *Calathus fuscipes*, *Harpalus rubripes*, *Harpalus tardus* and *Poecilus versicolor*, were collected with more than 1000 individuals. Together, these five species make up 52.6 % of all collected specimens. Comparing the different years of the study, the total species numbers stayed relatively constant, whereas total individual numbers as well as numbers of individuals of the dominant species showed comparatively high fluctuations.

The different landscape elements of the research object are characterized by different MIB values, clearly indicating differences in stage of succession. All of the dominant species are characteristic for young stages of succession. *Calathus erratus*, *Calathus fuscipes* and *Harpalus rubripes* preferred very young stages of succession, *Harpalus tardus* showed a rather balanced distribution and *Poecilus versicolor* preferred somewhat advanced stages of succession.

The conclusion is drawn that Carabid beetles are useful indicators to distinguish even small differences in stage of succession. However, sets of species with indicator value should be established under consideration of habitat type and geographical regions.

Key words: Carabidae, succession, bioindication, landscape, MIB

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INTRODUCTION

A landscape can be understood as a "set of interdependent ecosystems creating the ecological system of the highest order" (Andrzejewski 1992). Since different ecosystems – and also their formation in a given landscape – are the basis for the existence of species (e.g. Szyszko 2004), the management of landscapes is of importance with respect to species conservation. Important aspects are the structure and diversity of a landscape, but also the stage of succession of the respective ecosystems (e.g. Burel 1989, Ryszkowski et al. 2002, Latty et al. 2006, Schwerk & Szyszko 2008). Therefore, different ecosystems and different stages of succession constitute the basic "elements" of the respective landscape.

Since particularly the variability in succession stages seems to be of importance concerning the composition of species coenoses (Schwerk & Szyszko 2008), the understanding of processes of succession is of crucial importance with respect to landscape planning and species conservation. According to succession models, careful management of the early stages of succession is important with respect to the future development, and faunal as well as floral post-disturbance recovery (e.g. Bradshaw 1984, Tilman 1987, Jochimsen 2001).

The basic aim of the study was to analyse the spatial preferences of Carabid fauna on a research area located in western Poland composed of different landscape elements (different ecosystems of different stage of succession), which are forests, differently managed open areas and a wet area. The focus of the present publication was set on the following research questions:

1. To what extend are the different spatial elements of the research area characterised by differences in stage of succession?

Mean Individual Biomass (MIB) of Carabidae will be calculated to assess the stage of succession of the landscape elements. MIB has been proven to be a good indicator of succession stages (e.g. Szyszko 1990, Szyszko et al. 2000, Schwerk et al. 2006). The method assumes an ongoing process of succession with which the MIB of Carabids increases (Szyszko et al. 2000). In the present study the hypothesis is set that the studied landscape elements differ in stage of succession, i.e. MIB values, with advanced stages of succession characterised by high MIB values (hypothesis 1).

2. Do the dominant species show spatial preferences in the research area?

This question will be answered by studying the distribution of the collected individuals of the dominant species. Those parts of the landscape, where the majority of individuals are collected, will be considered as the preferred parts of the landscape for the respective species. The hypotheses are set that each of these species shows characteristic preferences for special landscape elements (hypothesis 2a) and that these preferences differ between the species (hypothesis 2b).

MATERIAL AND METHODS

Study sites and field methods

Carabid beetles were studied at the research area "Krzywda" (west Poland, Wałecki district) from 2004-2007. The area serves with different forests and post-agricultural areas of different stages of succession as well as about 68 ha of swamps highly eutrophicated due to man's economic activity, supplied by three watercourses. All these elements are subject to scientific research with the aim to study and analyse the process of succession (Rylke & Szyszko 2002).

53 pitfall traps were installed on former agricultural soils. The traps were placed in a grid forming seven columns (A-G) and eight rows (1-8). The columns were about 100 m apart, while the rows were about 50 m apart, with the exception of the distance between row 2 and row 3 that was

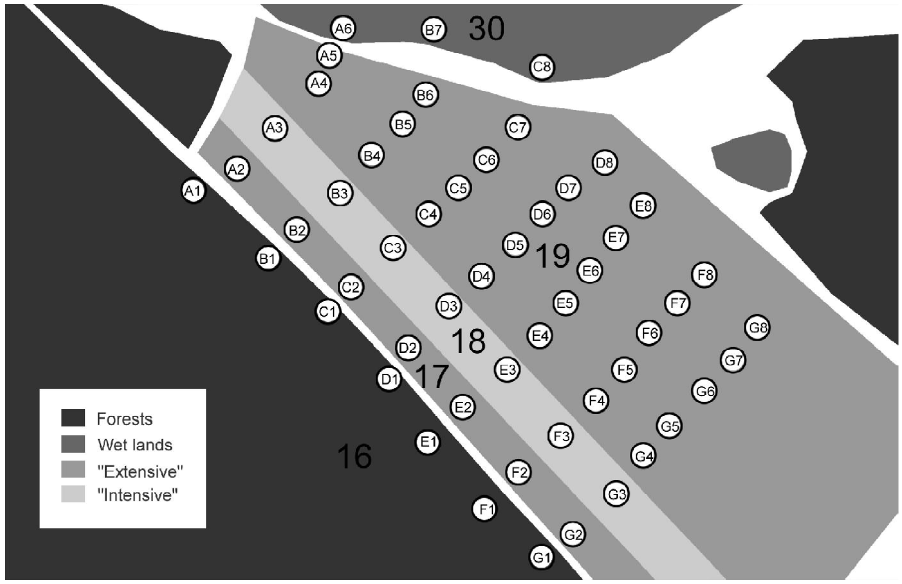

Fig. 1. Scheme of the spatial arrangement of the traps (A1-G8). Number 16, 17, 18, 19 and 30 indicate groups of traps regarded as study sites (see Tab. 1).

about 70 m. However, due to characteristics of the terrain, in some case the distances deviated a few meters from the values mentioned above (Fig. 1).

The traps were grouped to five different study sites (Fig. 1, Tab. 1). Each of them can be assessed as a landscape element of the research object (see Rylke & Szyszko 2002). Pitfall traps following Barber (1931) with modifications (Szyszko 1985) were used for collection of the beetles. Traps were jar glasses with a funnel, installed flush with the soil surface. A roof was suspended a few cm above the funnel and ethylene glycol was used as a killing agent and preservative.

Carabids were collected from 2004 to 2007. Sampling was carried out from mid-May to mid-September in every year of the study. All specimens were determined to the species level. Nomenclature follows Müller-Motzfeld (2004).

Statistical methods

In order to analyse differences between the study sites (landscape elements) with respect to MIB values and spatial preferences of dominant

Table 1. Characterisation of the studied landscape elements. Numbers of the landscape elements are according to Rylke & Szyszko (2002)

Landscape element	Site	Characterisation	Traps	N Traps
Pine forest	16	Pine forest of 26 years in 2004	Row 1	7
Extensive management	17	Former agricultural land, irregularly mown without removal of biomass	Row 2	7
Intensive management	18	Former agricultural land, regularly mown with biomass removal, used as airport runway	Row 3	7
Extensive management	19	Former agricultural land, irregularly mown without removal of biomass	Row 4-8*	29
Wet habitat	30	Wet area, peat-rich soil	A6, B7, C8	3

*: Except traps of site 30

species in the landscape, the data collected in the four years of study (2004-2007) were pooled for each trap.

Using these pooled data sets, for each trap the mean individual biomass (MIB) of Carabidae was calculated to assess the stage of succession. MIB is calculated by dividing the biomass of all sampled Carabids by the number of specimens caught. Biomass values were fixed for the recorded species using values from Szyszko (1990) or using the formula of Szyszko (1983) that describes the relationship between the body length of a single Carabid individual (x) and its biomass (y):

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

In order to assess the preferences of the dominant species for individual study sites the total number of collected individuals was calculated for each trap.

Results were visualized as box-whiskers plots and differences in MIB values between the study sites and preferences of the dominant species for individual study sites were tested using non-parametric one-way ANOVA (Kruskal-Wallis test, Sachs 1984), followed by pair-wise comparisons using Mann-Whitney U tests with sequentially rejective Bonferroni correction of significance levels (Holm 1979).

RESULTS

The basic results of the study are summarized in Tab. 2. Altogether, 13004 individuals from 98 species were collected (see Appendix). Total numbers of collected individuals varied strongly between the years, but total species number stayed rather constant.

Five species, namely *Calathus erratus*, *Calathus fuscipes*, *Harpalus rubripes*, *Harpalus tardus* and *Poecilus versicolor*, were collected with more than 1000 individuals. Together, they make up 52.6 % of all collected individuals. All these species showed noticeable fluctuations in total numbers between the years (Tab. 2).

The calculated MIB values varied significantly between the studied landscape elements (Fig. 2). The lack of statistical significant differences of the wet area (study site 30) to most of the other study sites is due to the low sample size (compare also Figs. 3-7). The highest MIB values (median value of 214.6 mg) were found for the pine forest (study site 16), followed by the wet area (study site 30, median value of 161.0 mg). The extensive managed areas (study sites 17 and 19) showed very similar MIB values (median values of 60.0 mg and 59.6 mg respectively), whereas the intensive managed area (study site 18) showed the lowest MIB values (median value of 45.5 mg).

Whiskers indicate range of data with exception of outliers (distance from the edge of the box between 1.5 and 3 times of the box length, shown as circles) and extreme values (distance from the edge of the box more than 3 times of the box length,

Table 2. Differences in numbers of species and individuals in consecutive years. Numbers are presented for all sites and the five dominating species

	Year				
	2004	**2005**	**2006**	**2007**	**Total**
Species	77	80	73	65	98
Individuals	2591	3689	5153	1571	13004
Calathus erratus	157	290	583	48	1078
Calathus fuscipes	156	302	603	169	1230
Harpalus rubripes	321	544	892	281	2038
Harpalus tardus	269	388	213	197	1067
Poecilus versicolor	232	440	602	154	1428

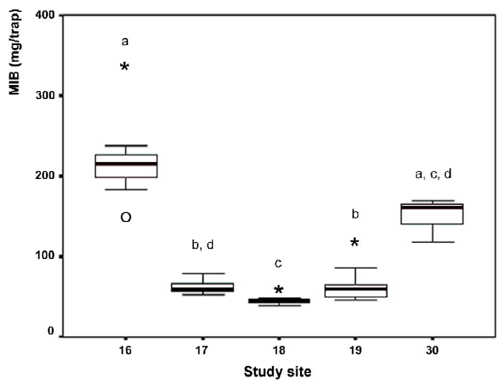

Fig. 2. MIB values of the study sites of the research object "Krzywda". Median values are drawn in; the boxes represent the inter-quartile distances. Whiskers indicate range of data with exception of outliers (distance from the edge of the box between 1.5 and 3 times of the box length, shown as circles) and extreme values (distance from the edge of the box more than 3 times of the box length, shown as asterisks). Kruskal-Wallis test, p <0.001; lower-case letters indicate statistically significant differences (Mann-Whitney U tests with Bonferroni correction).

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shown as asterisks). Kruskal-Wallis test, p <0.001; lower-case letters indicate statistically significant differences (Mann-Whitney U tests with Bonferroni correction).

The numbers of individuals of the five dominating species collected in the four years of study on the different study sites (landscape elements) are shown as box-whisker plots in Figs. 3-7. All species showed clear preferences for the young stages of succession (study sites 17, 18, 19).

Calathus erratus (Fig. 3) showed a significant preference for the intensive managed area (study site 18, median value of 91 individuals). On the extensive managed areas (study sites 17 and 19) this species was collected only occasionally (median values of 3 and 1 individuals respectively, with two outliers on study site 19) and in the pine forest (study site 16) and the wet area (study site 30) almost no individuals were recognized (median values of 0 individuals on both study sites).

Calathus fuscipes (Fig. 4) significantly preferred the intensive managed area (study site 18), too (median values of 63 individuals), but was also collected to some extent in the extensive managed study sites 17 and 19 (median values of 9 and 16 respectively). Almost no individuals were recognized at the pine forest (study site 16) and

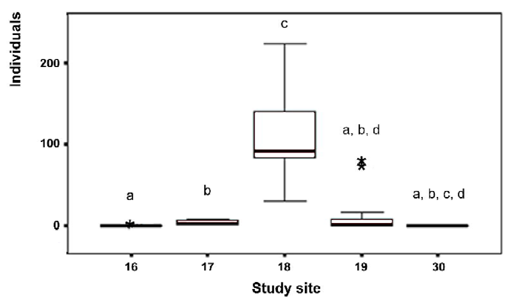

Fig. 3. Numbers of individuals of *Calathus erratus* collected on the study sites of the research object "Krzywda" (For more details compare Figure 2). Kruskal-Wallis test, p <0.001; lower-case letters indicate statistically significant differences (Mann-Whitney U tests with Bonferroni correction).

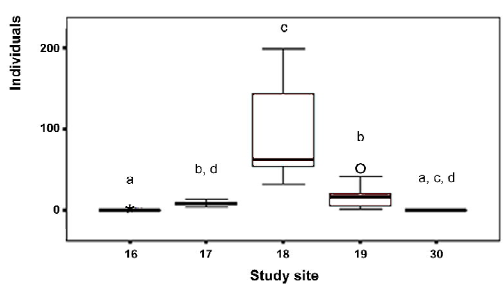

Fig. 4: Numbers of individuals of *Calathus fuscipes* collected on thestudy sites of the research object "Krzywda" (For more details compare Figure 2). Kruskal-Wallis test, p <0.001; lower-case letters indicate statistically significant differences (Mann-Whitney U tests with Bonferroni correction).

the wet area (study site 30) (median values of 0 individuals on both study sites).

A similar pattern as for *Calathus fuscipes* was observed for *Harpalus rubripes* (Fig. 5). However, the differences are less pronounced and lack a statistically significant difference between the intensive manged area (study site 18) and the extensive managed areas (study sites 17 and 19). *Harpalus rubripes* exhibits median values of 124 individuals on the intensive managed area (study site 18), median values of 21 and 37 individuals respectively for the extensive managed areas (study sites 17 and 19), and median values of 0 individuals on the pine forest (study site 16) and the wet area (study site 30).

Harpalus tardus (Fig. 6) was collected in rather equal numbers in the intensive and extensive managed areas (study sites 17, 18 and 19) with median values of 9 (study site 17), 15 (study site 18) and 18 (study site 19) individuals. The species was rarely collected in the pine forest (study site 16, median value of 0 individuals) and the wet area (study site 30, median value of 2 individuals).

Poecilus versicolor (Fig. 7), however, largely avoided the intensive managed area (study site

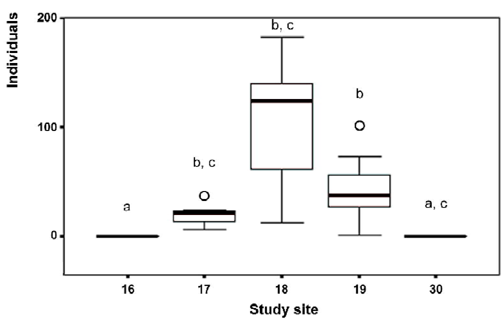

Fig. 5. Numbers of individuals of *Harpalus rubripes* collected on the study sites of the research object “Krzywda” (For more details compare Figure 2). Kruskal-Wallis test, p <0.001; lower-case letters indicate statistically significant differences (Mann-Whitney U tests with Bonferroni correction).

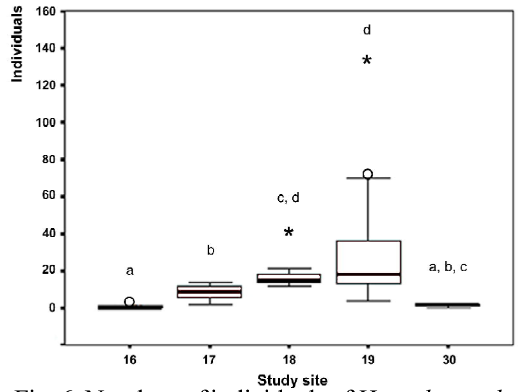

Fig. 6. Numbers of individuals of *Harpalus tardus* collected on the study sites of the research object “Krzywda” (For more details compare Figure 2). Kruskal-Wallis test, p <0.001; lower-case letters indicate statistically significant differences (Mann-Whitney U tests with Bonferroni correction).

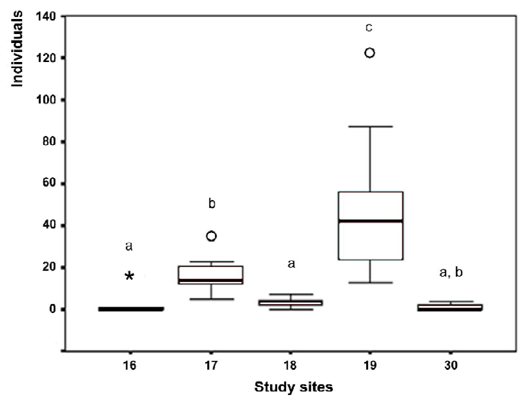

Fig. 7. Numbers of individuals of *Poecilus versicolor* collected on the study sites of the research object “Krzywda” (For more details compare Figure 2). Kruskal-Wallis test, p <0.001; lower-case letters indicate statistically significant differences (Mann-Whitney U tests with Bonferroni correction).

18, median value of 4 individuals) and showed significant preferences for the extensive managed study sites 17 and 19 (median values of 14 and 42 individuals respectively). Both in the pine forest (study site 16) and the wet area (study site 30) the species was collected in very low numbers (median values of 0 individuals on both study sites).

DISCUSSION

All research hypotheses could be verified. The different landscape elements are characterised by different stage of succession (hypothesis 1), the dominant species show spatial preferences in the landscape (hypothesis 2a) and these preferences differ between the studied species (hypothesis 2b).

High fluctuations in total numbers of individuals as well as the dominant species combined with rather stable values of total species numbers, as shown in present study, have been also demonstrated for a post-industrial area in western Germany (Schwerk et. al 2006). The authors of this study mention "spreading of risk" (den Boer 1968) as a possible explanation for this result.

Carabid beetles are widely used as bioindicators (Müller-Motzfeld 1989, Rainio and Niemelä 2003), including as indicators of succession stages (e.g. Szyszko 1990). In the present study the MIB values distinctively indicate even small differences in stage of succession. The one extraordinary high MIB value on study area 19 was calculated for trap A5 and can be explained by an influence of the adjacent wet area (study site 30). Fluctuations in the water level may provoke moving of individuals of large sized species from this area to adjacent areas and result in a higher catch in trap A5. Indeed, clearly increased numbers of *Pterostichus niger*, the dominant species on study site 30 (see Appendix), could be observed in trap A5 compared to the other traps located in study site 19.

All of the five dominant species are characteristic for young stages of succession, but the present study shows that they are sensitive even to small changes in the stage of succession of a habitat. With respect to advancing stage of succession the species may be ordered as follows:

Calathus erratus, Calathus fuscipes → *Harpalus rubripes* → *Harpalus tardus, Poecilus versicolor*

This rating fits quite well to an ordination of more than 100 study sites on degraded areas (degraded pine forests, post-agricultural areas and post-industrial areas), which included also the study sites of the present paper, by Schwerk (2008). Along the first ordination axis, which was interpreted to express the arrangement of the study sites with respect to stage of succession, *Calathus erratus*, *Harpalus rubripes*, *Harpalus tardus* and *Poecilus versicolor* were arranged in the aforementioned order (Schwerk 2008). Concurrent results were observed by Neumann (1971), who studied the Carabid coenoses on brown coal mining sites in the Rhineland, with *Calathus erratus* as early pioneer and *Poecilus versicolor* as somewhat late pioneer. On the other hand, in a study by Mader (1985) likewise carried out on areas derived from brown coal mining in the Rhineland, which were exposed to natural succession, *Calathus erratus* was not among the first pioneers. Skłodowski (2006) detected high numbers of individuals of *Poecilus versicolor* in 5 years old plantations. However, younger areas were not examined in his study.

The present study suggests that Carabid beetle species are responsive to small changes in stage of succession and that – besides MIB – at least some species might be useful for differentiation of young stages of succession. However, such species may differ among different habitats and have to be detected for each habitat type separately. Moreover, since the ecological responses of species may be regionally different (Nettmann 1992), in different geographical regions the respective sets of species should be verified for each habitat type.

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Appendix: Carabids (in alphabetical order) caught on the study sites. Mean biomass values (mg) used for calculation of MIB values are given.

Species	Mean biomass (mg)	Study site 16	17	18	19	30	Sum
Acupalpus flavicollis (Sturm, 1825)	3					1	1
Acupalpus parvulus (Sturm, 1825)	3					1	1
Agonum emarginatum (Gyllenhal, 1827)	27					1	1
Agonum fuliginosum (Panzer, 1809)	13	32	5			10	47
Agonum sexpunctatum (Linné, 1758)	27					1	1
Amara aenea (De Geer, 1774)	27		4	440	80		524
Amara apricaria (Paykull, 1790)	19				1		1
Amara aulica (Panzer, 1797)	93				6		6
Amara bifrons (Gyllenhal, 1810)	11	2	4	102	35		143
Amara brunnea (Gyllenhal, 1810)	13	31					31
Amara communis (Panzer, 1797)	13	14	1		34	1	50
Amara consularis (Duftschmid, 1812)	36		1	2	9		12
Amara convexior Stephens, 1828	13		16	3	28		47
Amara equestris (Duftschmid, 1812)	61		2	5	5		12
Amara eurynota (Panzer, 1797)	30				2		2
Amara familiaris (Duftschmid, 1812)	13		3	4	10		17
Amara fulva (O.F. Müller, 1776)	43				8		8

Species	Mean biomass (mg)	Study site 16	17	18	19	30	Sum
Amara lucida (Duftschmid, 1812)	3			7			7
Amara lunicollis Schiödte, 1837	19	2	12	114	86		214
Amara municipalis (Duftschmid, 1812)	27				2		2
Amara ovata (Fabricus, 1792)	21			1	6		7
Amara plebeja (Gyllenhal, 1810)	13		8	3	12		23
Amara tibialis (Paykull, 1798)	2				6		6
Anchomenus dorsalis (Pontoppidan, 1763)	13				2		2
Anisodactylus binotatus (Fabricius, 1787)	76					2	2
Badister bullatus (Schrank, 1798)	12		14		8		22
Badister lacertosus Sturm, 1815	12	1	1		1		3
Badister unipustulatus Bonelli, 1813	26					1	1
Bembidion gilvipes Sturm, 1825	2				1	1	2
Bembidion lampros (Herbst, 1784)	3	2	1	1	2		6
Bradycellus caucasicus (Chadoir, 1846)	3				2		2
Broscus cephalotes (Linné, 1758)	281			1	1		2
Calathus ambiguus (Paykull, 1790)	45	1		6	1		8
Calathus cinctus Motschulsky, 1850	19		1	48			49
Calathus erratus (C. R. Sahlberg, 1827)	46	1	28	793	256		1078
Calathus fuscipes (Goeze, 1777)	76	1	61	687	480	1	1230
Calathus melanocephalus (Linné, 1758)	19	5	67	252	390	1	715
Calathus micropterus (Duftschmid, 1812)	19	25			1		26
Carabus arvensis Herbst, 1784	219	27	2				29
Carabus cancellatus Illiger, 1798	317	2			2		4
Carabus granulatus Linné, 1758	185					24	24
Carabus hortensis Linné, 1758	548	180	2		3		185
Carabus nemoralis O. F. Müller, 1764	400	64			29	1	94
Carabus violaceus Linné, 1758	750	6			11		17
Clivina fossor (Linné, 1758)	8	3	2		9	3	17
Cymindis angularis Gyllenhal, 1810	36		5	1	3		9
Dolichus halensis (Schaller, 1783)	160				2		2
Dyschirius globosus (Herbst, 1784)	1		6	2	22	41	71
Elaphrus cupreus Duftschmid, 1812	26					4	4
Harpalus affinis (Schrank, 1781)	49		2	4	39		45
Harpalus anxius (Duftschmid, 1812)	19		1	12	1		14
Harpalus autumnalis (Duftschmid, 1812)	48		1				1
Harpalus griseus (Panzer, 1796)	69		2	7	13		22
Harpalus laevipes Zetterstedt, 1828	61	7					7
Harpalus latus (Linné, 1758)	45	4	2	4	65	4	79
Harpalus luteicornis (Duftschmid, 1812)	19			3	115	1	119
Harpalus picipennis (Duftschmid, 1812)	15			1	4		5
Harpalus pumilus Sturm, 1818	9		2	31	10		43
Harpalus rubripes (Duftschmid, 1812)	48	2	138	720	1178		2038
Harpalus rufipalpis Sturm, 1818	41	1	1	8	6		16
Harpalus rufipes (De Geer, 1774)	126	15	66	115	368	3	567
Harpalus signaticornis (Duftschmid, 1812)	16	1	1	3	2		7
Harpalus smaragdinus (Duftschmid, 1812)	46			18	8		26
Harpalus solitaris Dejean, 1829	61		1				1
Harpalus tardus (Panzer, 1796)	48	5	60	131	867	4	1067
Harpalus xanthopus winkleri Schauberger, 1923	19				1		1
Lebia chlorocephala (J.J. Hoffmann et al., 1803)	16			1	1		2
Leistus ferrugineus (Linné, 1758)	25	3					3
Leistus terminatus (Hellwig in Panzer, 1793)	25	11	3			1	15
Licinus depressus (Paykull, 1790)	36		1		1		2
Masoreus wetterhallii (Gyllenhal, 1813)	5			5	1		6
Microlestes minutulus (Goeze, 1777)	2			2	1		3
Notiophilus aquaticus (Linné, 1758)	7			2	14		16

Species	**Mean biomass (mg)**	**Study site 16**	**17**	**18**	**19**	**30**	**Sum**
Notiophilus biguttatus (Fabricius, 1779)	7	13					13
Notiophilus palustris (Duftschmid, 1812)	7	1			1		2
Oodes helopioides (Fabricius, 1792)	29					20	20
Ophonus azureus (Fabricius, 1775)	26				1		1
Ophonus puncticeps Stephens, 1828	26		1		27		28
Oxypselaphus obscures (Herbst, 1784)	4	7				1	8
Panagaeus bipustulatus (Fabricius, 1775)	15		1	1	17		19
Poecilus cupreus (Linné, 1758)	78		1	1	4		6
Poecilus lepidus (Leske, 1785)	84		21	93	141		255
Poecilus versicolor (Sturm, 1824)	56	18	119	24	1263	4	1428
Pterostichus diligens (Sturm, 1824)	18	1				13	14
Pterostichus gracilis (Dejean, 1828)	38					1	1
Pterostichus melanarius (Illiger, 1798)	134	29	6	6	303	14	358
Pterostichus minor (Gyllenhal, 1827)	19				1	9	10
Pterostichus niger (Schaller, 1783)	220	360	52	3	213	273	901
Pterostichus nigrita (Paykull, 1790)	40				1	2	3
Pterostichus oblongopunctatus (Fabricius, 1787)	57	207	1	2	4		214
Pterostichus strenuus (Panzer, 1796)	13	8			1		9
Pterostichus vernalis (Panzer, 1796)	19		3		2	2	7
Stenolophus mixtus (Herbst, 1784)	10					2	2
Syntomus foveatus (Geoffroy, 1785)	2		1	237	31		269
Syntomus truncatellus (Linné, 1761)	2	1	29	21	227	2	280
Synuchus vivalis (Illiger, 1798)	19	1	33	8	225	4	271
Trechus obtusus Erichson, 1837	3				2	10	12
Trechus quadristriatus (Schrank, 1781)	3			1			1
Individuals	-	1094	795	3936	6715	464	13004
Species	-	38	48	47	74	35	98

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