

Succession of carabid fauna (*Coleoptera: Carabidae*)  
on post-industrial areas near Bełchatów (Central Poland) \*

Sukcesja fauny biegaczowatych (*Coleoptera: Carabidae*) na terenach  
zdegradowanych przez przemysł w okolicach Bełchatowa (środkowa Polska)

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**ABSTRACT:** Carabid beetles were collected in 2004 on two different post-industrial areas located south of Bełchatów. The first area comprises a large artificial heap consisting of ashes produced by a power station. Three sampling plots of different age were chosen on this heap. A nearby pine forest growing on natural soil was selected as reference plot. The second study area was heaped up from soil removed during the brown coal mining process. Four pine stands of different age were chosen for inventory of carabid beetles. Overall, 871 individuals of 49 species, four of them first time recorded in the Łódź Upland, were sampled. The results show that on the ash heap a delayed succession takes place. All sampling plots exhibit carabid coenoses typical for early stages of succession. The young stands on mining spoil may be characterized as early stages of succession, too, but after about 14 years a shift to forest typical coenoses takes places. However, the old stands on the mining heap differ significantly from the reference stand growing on natural soil. Body size of males as well as females of *Calathus erratus* (C. R. SAHLBERG, 1827) is smaller on the areas of the mining heap of early stage of succession when compared to individuals collected on the ash heap indicating a better food situation for larvae on the latter. On the other hand, male-to-female ratios indicate a worse feeding situation for the adults on this area. The soil parameters seem to be a main factor causing differences in carabid fauna as well as speed of succession of the analysed sampling plots. With respect to management of the areas the integration in the surrounding landscape is of importance. This includes stimulation as well as breaking of successional processes if necessary.

**KEY WORDS:** *Coleoptera, Carabidae*, succession, post-industrial areas, recultivation, Central Poland, landscape

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## Introduction

The industrialisation caused a dramatic change in the landscape with beginning of the 19<sup>th</sup> century. A loss of a high amount of natural habitats was accompanied by origin of areas resulting from industry – post-industrial areas. Since the last decades of the 20<sup>th</sup> century there is rising awareness, that these areas offer numerous possibilities concerning nature conservation purposes (e.g. KELCEY 1975; JOHNSON et al. 1978; GILLHAM & SMITH 1983; GEMMELL & CONNELL 1984; REBELE & DETTMAR 1996).

Several studies on post-industrial areas in Europe have been carried out in Germany and Great Britain (e.g. NEUMANN 1971; JOHNSON et al. 1978; GEMMELL & CONNELL 1984; VOGEL & DUNGER 1991). In Poland, however, such studies are missing to a high degree. Therefore, the present paper may help to fill this gap. It presents a study on carabid beetles on different post-industrial areas in Central Poland of different stage of succession. It is aimed on (1) a characterization of the species composition on these areas, (2) an analysis of the pattern of succession, (3) conclusions concerning the feeding situation for larvae and adults, and (4) implications concerning management of post-industrial areas.

## Material and Methods

### Sampling plots

The sampling plots are located in the Voivodship Lodz (Central Poland) near to the city of Bełchatów. Two different post-industrial areas located south of Bełchatów were studied in 2004. The first area comprises a large artificial heap consisting of ashes produced by a power station. Three sampling plots (A1, A2, A3) of different age were chosen on this heap. A nearby pine forest growing on natural soil was selected as reference plot (A4). The second study area was heaped up from soil removed during the brown coal mining process. The soil was excavated from a depth of about 0–300 m and consists mainly of loam and sand. Four pine stands of different age (B1, B2, B3, B4) were chosen for inventory of carabid beetles (Tab. I).

### Data elaboration

Collecting of beetles was carried out using pitfall traps following BARBER (1931) with modifications. Jar glasses were sunk in the ground and a funnel with an upper diameter of about 10 cm and a lower diameter of about 1.6 cm was placed above them flush with the soil surface. A roof was installed a few centimetres above the funnel. Ethylene glycol was used as trapping fluid. On each sampling plot three pitfall traps were installed. The sampling time covered middle of April to middle of October in 2004.

Tab. I. Description of the sampling plots  
Charakterystyka stanowisk badawczych

Plot Stanow.	Type Typ	Description Opis
A1	Ash heap Hałda popielna	About 7–8 years old vegetation on about 10 years old ashes, insignificant cover with plants Okolo 7–8 letnia rośliność na 10-letnim podłożu z popiołów
A2	Ash heap Hałda popielna	About 10 years old pioneer vegetation with dense cover of plants on about 12 years old ashes, planting of oak had been carried out on this area, but failed because of game bite Okolo 10-letnia rośliność pionierska o zwartym pokryciu na około 12-letniej hałdzie popiołów z nasadzeniem dębów, które nie przetrwały z powodu zgryzania przez zwierzę
A3	Ash heap Hałda popielna	About 12 years old shrub vegetation on about 15 years old ashes, dense cover of plants Okolo 12-letnia rośliność krzewista na 15-letniej hałdzie popiołów – zwarte pokrycie roślinnością
A4	Forest stand Stanowisko leśne	Pine stand of about 65 years on natural soil, used as reference plot 65-letni drzewostan sosnowy na glebie naturalnej, użyty jako powierzchnia kontrolna
B1	Brown coal site Odkrywka węgla brunatnego	Pine plantation, 3 years old 3-letnia uprawa sosnowa
B2	Brown coal site Odkrywka węgla brunatnego	Pine plantation, 10 years old 10-letnia uprawa sosnowa
B3	Brown coal site Odkrywka węgla brunatnego	Pine plantation, 14 years old 14-letnia uprawa sosnowa
B4	Brown coal site Odkrywka węgla brunatnego	Pine plantation, 21 years old 21-letnia uprawa sosny

Determination and nomenclature of the collected individuals was done according to FREUDE et al. (2004).

For determining the length of elytra of *Calathus erratus* (C. R. SAHL-BERG, 1827) the distance between the apex of right elytra and the venue of the basal margin with the scutellum was measured with an accuracy of 0.05 mm, using an ocular with reticule of lines.

### Statistical methods

Mean individual biomass (MIB) of *Carabidae* was calculated to assess the successional stage of the sampling plots. MIB is calculated by dividing the biomass of all sampled carabids by the number of specimens caught. Biomass values were obtained using the formula of SZYSZKO (1983a) that describes the relationship between the body length of a single carabid individual (x) and its biomass (y):

$$\ln y = -8.92804283 + 2.5554921 \times \ln x$$

MIB values have been proven to be a good indicator of the state of succession of a habitat. The higher the MIB value the more advanced is the successional stage (e.g. SZYSZKO 1990; SZYSZKO et al. 2000).

The CANOCO for Windows software package, version 4.5 (ter BRAAK 1987; ter BRAAK & ŠMILAUER 2002) was used to perform gradient analysis. Dominance values of carabid species on the sampling plots were used. Detrended Correspondence Analysis (DCA) was carried out in advance to select the appropriate statistical model. Based on the gradient length of first DCA-axis Correspondence Analysis (CA) was chosen as method. The CA analysis was performed using scaling on inter-sample distances (Hill's scaling). Species weight range was adjusted from 6 to 100. Therefore, the ten species with the largest impact on the analysis results are displayed (ter BRAAK & ŠMILAUER 2002).

Differences in length of elytra were tested using nonparametric one-way analyses of variance (Kruskal-Wallis tests) followed by pairwise comparisons using Mann-Whitney U tests with Bonferroni correction of significance levels (KRAUTH 1988).

## Results

### Species composition on the sampling plots

Table (Tab. II) provides with the inventory results on the sampling plots. Overall, 871 individuals of 49 species were trapped. Number of individuals as well as number of species differs strongly among the sampling plots, ranging from 198 individuals collected on plot A1 and plot A4 to only 13 individuals on plot B2. This very low number is due to a strong damage of the traps on this sampling plot by wild boar. Plot B2 shows also the lowest number of species (3 species), whereas plot A1 exhibits the highest number of species (18 species).

Tab. II Numbers of carabid beetles collected on the sampling plots (list of species in alphabetical order)

Liczba biegaczowatych odłowionych w poszczególnych stanowiskach badawczych (lista gatunków w porządku alfabetycznym)

Species Gatunek	A1	A2	A3	A4	B1	B2	B3	B4	Sum R-m
1	2	3	4	5	6	7	8	9	10
<i>Amara aenea</i> (DE GEER, 1774)			1		3				4
<i>Amara communis</i> (PANZER, 1797)			2					3	5
<i>Amara equestris</i> (DUFTSCHMID, 1812)		3							3
<i>Amara eurynota</i> (PANZER, 1797)					2				2
<i>Amara lunicollis</i> SCHIÖDTE, 1837		2	2						4
<i>Amara spreta</i> DEJEAN, 1831	34	1							35
<i>Badister bullatus</i> (SCHRANK, 1798)			1						1
<i>Bradycephalus csikii</i> LACZÓ, 1912			1						1
<i>Calathus ambiguus</i> (PAYKULL, 1790)	14	23			10				47
<i>Calathus cinctus</i> MOTSCHULSKY, 1850	4								4
<i>Calathus erratus</i> (C. R. SAHLBERG, 1827)	66	70	33		78	11			258
<i>Calathus fuscipes</i> (Goeze, 1777)					1				1
<i>Calathus melanocephalus</i> (LINNÉ, 1758)	6		5	1					12
<i>Calathus micropterus</i> (DUFTSCHMID, 1812)				3				2	5
<i>Carabus arvensis</i> HERBST, 1784				88					88
<i>Carabus auronitens</i> FABRICIUS, 1792								6	6
<i>Carabus granulatus</i> LINNÉ, 1758							1		1
<i>Carabus hortensis</i> LINNÉ, 1758			3	2					5
<i>Carabus problematicus</i> HERBST, 1786	1							4	5
<i>Carabus violaceus</i> LINNÉ, 1758							9	4	13
<i>Harpalus affinis</i> (SCHRANK, 1781)	1	1							2
<i>Harpalus anxius</i> (DUFTSCHMID, 1812)					5				5
<i>Harpalus autumnalis</i> (DUFTSCHMID, 1812)	1				3				4
<i>Harpalus calceatus</i> (DUFTSCHMID, 1812)	1	1							2
<i>Harpalus flavescens</i> (PILLER et MITTERPACHER, 1783)	33	28							61

1	2	3	4	5	6	7	8	9	10
<i>Harpalus hirtipes</i> (PANZER, 1796)	1								1
<i>Harpalus laevipes</i> ZETTERSTEDT, 1828								2	2
<i>Harpalus latus</i> (LINNÉ, 1758)		1	2						3
<i>Harpalus rubripes</i> (DUFTSCHMID, 1812)		5	3		1		3		12
<i>Harpalus rufipalpis</i> STURM, 1818	2			1					3
<i>Harpalus rufipes</i> (DE GEER, 1774)	7	6		2				1	16
<i>Harpalus servus</i> (DUFTSCHMID, 1812)					1				1
<i>Harpalus smaragdinus</i> (DUFTSCHMID, 1812)					1	1			2
<i>Harpalus solitarius</i> DEJEAN, 1829		1							1
<i>Harpalus tardus</i> (PANZER, 1796)	1	4	3						8
<i>Harpalus xanthopus</i> GEMMINGER et HAROLD								2	
<i>Leistus ferrugineus</i> (LINNÉ, 1758)				4			4		8
<i>Licinus depressus</i> (PAYKULL, 1790)				1					1
<i>Masoreus wetterhallii</i> (GYLLENHAL, 1813)			3						3
<i>Panagaeus bipustulatus</i> (FABRICIUS, 1775)			1	2					3
<i>Poecilus lepidus</i> (LESKE, 1785)	1	2							3
<i>Poecilus versicolor</i> (STURM, 1824)		1		4					5
<i>Pterostichus diligens</i> (STURM, 1824)			1						1
<i>Pterostichus melanarius</i> (ILLIGER, 1798)	1						1	2	4
<i>Pterostichus niger</i> (SCHALLER, 1783)				60		1	48	26	135
<i>Pterostichus oblongopunctatus</i> (FABRICIUS, 1787)				30			1	3	34
<i>Pterostichus strenuus</i> (PANZER, 1796)							2	2	4
<i>Syntomus truncatellus</i> (LINNÉ, 1761)	3		21						24
<i>Synuchus vivalis</i> (ILLIGER, 1798)	21								21
Sum – Razem	198	149	82	198	105	13	69	57	871

All sampling plot on the ash heap (A1, A2, A3) show a species composition characteristic for early stages of succession. Dominant species are *Amarra spreta* DEJ., *Calathus ambiguus* (PAYK.), *C. erratus* (C. R. SAHLB.), *Harpalus flavescens* (PILL. et MITT.), *Syntomus truncatellus* (L.), *Synuchus vivalis* (ILL.). The reference forest stand (A4), whereas, may be regarded as advanced stage of succession. Species typical for forests as *Carabus arvensis*

HERBST, *Pterostichus niger* (SCHALL.), *Pterostichus oblongopunctatus* (FABR.) are dominating. The young plantations on the brown coal site (B1, B2) show high numbers of *Calathus ambiguus* and *C. erratus* indicating an early stage of succession. The older plantations (B3, B4) may be classified as advanced stages of succession. Forest species like *Carabus auronitens* FABR., *Carabus violaceus* L., and *Pterostichus niger* (SCHALL.) are dominating.

Values of Mean Individual Biomass (MIB) of *Carabidae* on the sampling plots are shown in table (Tab. III). The MIB values affirm the rating of successional stages made above, characterizing sampling plots A1, A2, A3, B1, and B2 as early stages of succession and sampling plots A4, B3, and B4 as advanced stages of succession.

Tab. III. Mean Individual Biomass (MIB) values [mg] of carabid fauna on the sampling plots

Średnia biomasa osobnicza (SBO) [mg] biegaczowatych w analizowanych stanowiskach

Sampling plot Stanowisko	A1	A2	A3	A4	B1	B2	B3	B4
MIB value [mg] SBO [mg]	49.2	55.4	46.7	182.0	44.0	59.4	260.2	237.0

Fig. 1 shows the results of the CA analysis. Because of the biased results sampling plot B2 was not included into this analysis. The first axis explains 37% of the variance found within the dataset. The sampling plots are clearly separated along this axis concerning successional stage, with plots A1, A2, A3, and B1 located on the left side and plots A4, B3, and B4 located on the right side of the diagram. Accordingly, the carabid species are separated along the first axis with respect to habitat preference.

The second axis explains 19.5% of the remaining variance. This axis separates the plots of advanced stage of succession on the brown coal site (B3, B4) from the natural pine forest stand (A4).

#### Length of elytra and male-to-female ratios of *Calathus erratus*

Concerning length of elytra for both males (Fig. 2) and females (Fig. 3) the Kruskal-Wallis test revealed significant differences in the data sets ( $p < 0.05$  for males,  $p < 0.01$  for females). Concerning males Mann-Whitney U tests with Bonferroni correction of significance levels show that sampling plots A1 and A2 differ significantly from sampling plot B1. Sampling

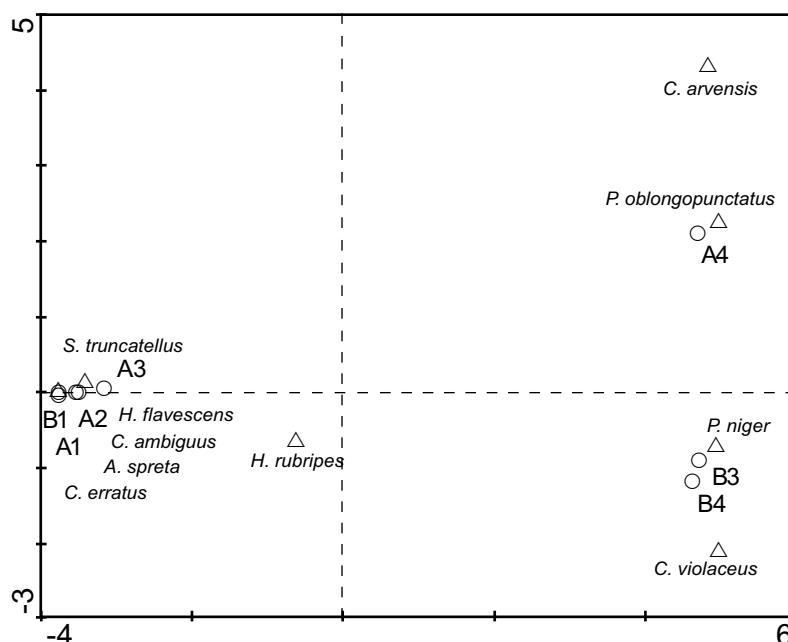


Fig. 1. Correspondence Analysis (CA) of the sampling results

Ryc. 1. Analiza odpowiedniości wyników odłówów

plot A3 does not differ significantly from B1. However, Fig. 2 shows smaller length of elytra for the latter. Concerning females all sampling plots on the ash heap (A1, A2, A3) differ significantly from sampling plot B1.

Sampling plot B1, located on the brown coal site, shows the highest male-to-female ratio with a value of 1.69. On the sampling plots located on the ash heap values of 1.54 (A3), 1.2 (A1), and 0.75 (A2) exist (Tab. IV).

Tab. IV. Male-to-female ratios of *Calathus erratus* (C. R. SAHLBERG, 1827) on sampling plots A1, A2, A3, and B1

Stosunek ilości samców do samic gatunku *Calathus erratus* (C. R. SAHLBERG, 1827) na stanowiskach A1, A2, A3 i B1

Sampling plot – Stanowisko	A1	A2	A3	B1
Males – Samce	36	30	20	49
Females – Samice	30	40	13	29
Ratio – Stosunek ilości	1.2	0.75	1.54	1.69

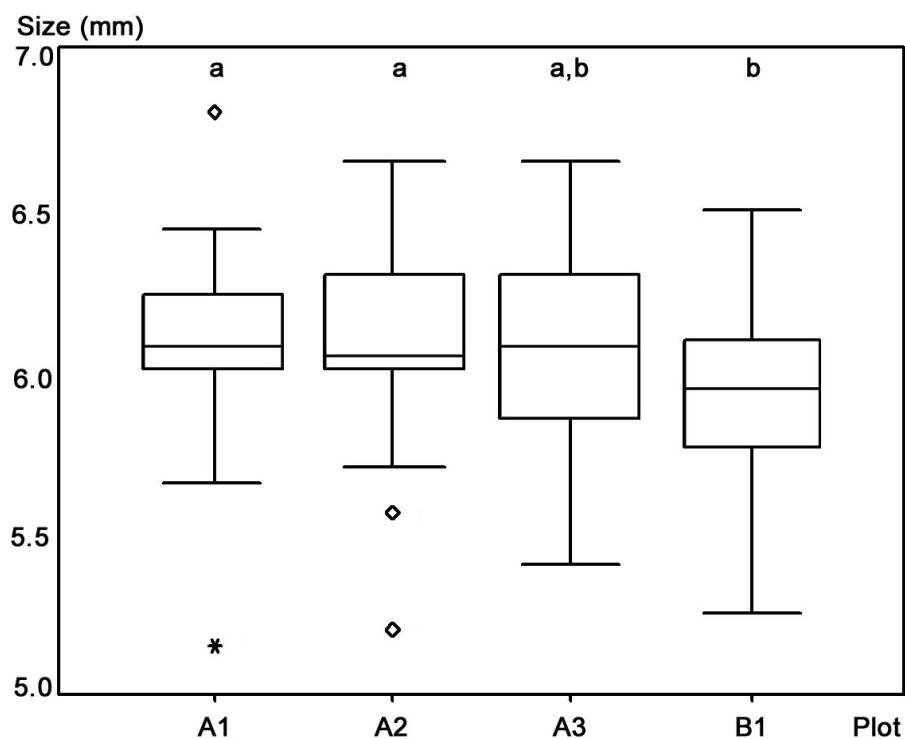


Fig. 2. Length of elytra of males of *Calathus erratus* (C. R. SAHLBERG, 1827) on sampling plots A1 ( $n=36$ ), A2 ( $n=29$ ), A3 ( $n=20$ ), and B1 ( $n=49$ ) shown as box-whisker-plots. Median values are drawn in, the boxes represent the inter-quartile distances. Whiskers indicate range of data with exception of outliers (distance from the edge of the box between 1.5 and 3 times of box length, shown as rhombi), and extreme values (distance from the edge of the box more than 3 times of the box length, shown as asterisks).

Kruskall-Wallis test:  $p < 0.05$ ; median values with same letter (a, b) do not differ significantly using Mann-Whitney U tests with Bonferroni correction of significance levels

Ryc. 2. Długość pokryw skrzydeł samców gatunku *Calathus erratus* (C. R. SAHLBERG, 1827) na stanowiskach A1 ( $n=36$ ), A2 ( $n=29$ ), A3 ( $n=20$ ) i B1 ( $n=49$ ) przedstawione jako wykres pudełkowy. Do wykresu wrysowano wartości mediany oraz rozstęp ćwiartkowy. Linie poziome wskazują rozpiętość danych z wyjątkiem wartości skrajnych (dystans od krawędzi pudełka pomiędzy 1,5 i 3-krotnością rozpiętości pudełka, oznaczono rombami) oraz wartości skrajne (dystans pomiędzy krawędzią pudełka większy niż 3-krotna szerokość pudełka, oznaczono gwiazdką).

W teście Kruskalla-Wallisa:  $p < 0,05$ ; wartości mediany oznaczona tymi samymi symbolami (a, b) nie różnią się znacząco w porównaniu z U testem Manna'a-Whitney'a z poprawką Bonferroniego

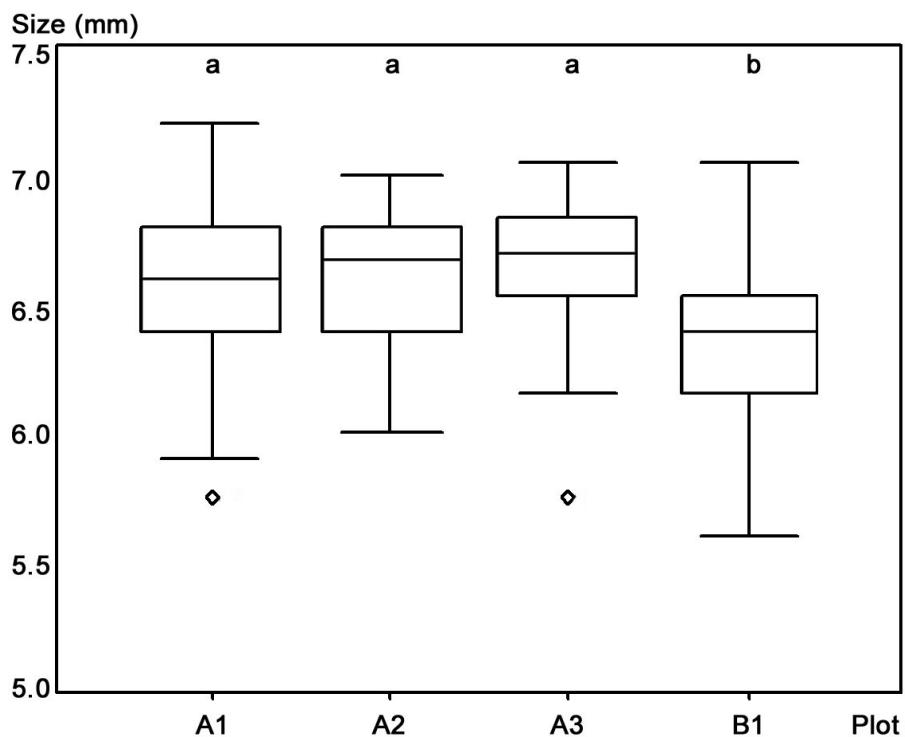


Fig. 3. Length of elytra of females of *Calathus erratus* (C. R. SAHLBERG, 1827) on sampling plots A1 (30), A2 (n=38), A3 (n=13), and B1 (n=29) shown as box-whisker-plots plotted as in Fig. 2.

Kruskall-Wallis test:  $p < 0.01$ ; median values with same letter (a, b) do not differ significantly using Mann-Whitney U tests with Bonferroni correction of significance levels

Ryc. 3. Długość pokryw skrzydeł samic gatunku *Calathus erratus* (C. R. SAHLBERG, 1827) na stanowiskach odlowu A1 (n=30), A2 (n=38), A3 (n=13), and B1 (n=29) pokazane na wykresie pudełkowym nałożonym na Ryc. 2.

W teście Kruskalla-Wallisa:  $p < 0,01$ ; wartość mediany oznaczona tymi samymi symbolami (a, b) nie różnią się znacząco w porównaniu do wartości mediany z U testem Manna'a-Whitney'a z poprawką Bonferroniego

## Discussion

Four of the collected species, namely *Calathus cinctus* MOTSCH., *Harpalus calceatus* (DUFTSCH.), *Harpalus hirtipes* (PANZ.), and *Licinus depressus* (PAYK.), were recorded first time for the region of Lodz Upland (JASKUŁA et al. 2002; JASKUŁA 2003). This result might be due to the fact, that such habitat types are not commonly studied. On the other hand, it is known that on post-industrial areas in general high numbers of rare species exist (REBE-

LE & DETTMAR 1996). The reason may be found in the frequent extreme environmental conditions of the areas. Many of these species may have been common in past, but became rare because of loss of their habitats as result of changes in land-use (e.g. GEMMELL & CONNELL 1984; REBELE & DETTMAR 1996; ABS et al. 1999). The post-industrial areas may serve as secondary habitats.

A comparison of sampling plot A3 with sampling plot B3 indicates a delayed succession on the ash heap. This result may be explained by the extreme soil conditions of the ashes. Based on nematode fauna DMOWSKA (2005) demonstrated very slow changes on ash heaps, too. On sampling plots heaped up from waste stone material of deep coal mining in the Ruhr Valley Area (Western Germany) a delayed succession was detected, too (SCHWERK et al. 2004).

The results indicate that the initial stages on post-industrial areas have similar carabid compositions, even if the environmental conditions (e.g. soil) are different. The old stages of succession on the brown coal site (B3, B4) differ significantly from the forest growing on natural soil (A4). This result might be explained by differences in age as well as soil conditions. Both factors seem to be of importance. Studying heaps from brown coal mining in western Germany NEUMANN (1971) could demonstrate that 28 years old sampling sites had a higher similarity to natural forest than a sampling site of 25 years of age. It will be interesting to observe, if the carabid coenosis on sampling plot B4 will change towards the carabid coenosis on sampling plot A4 in future. Concerning sampling sites on reclaimed strip mines in southwestern Wyoming PARMENTER & MACMAHON (1987) could demonstrate that sampling plots with topsoil differ from those without topsoil. They stress the importance of the soil conditions. Their study sites showed a very low similarity to undisturbed reference plots, too. According to the authors a fauna similar to undisturbed areas is not possible in the foreseeable future.

Particularly concerning the settlement of species typical for old stages of succession being unable to fly the species composition in the surrounding might be of importance, too (NEUMANN 1971). Moreover, it is important to be aware that the rate of succession may differ between different strata of the soil (DUNGER 1989).

Differences in soil conditions are expressed by differences in feeding situation for *Calathus erratus* (C. R. SAHLB.), too. Concerning *Carabidae* there are evidences that bigger adults indicate a better feeding situation for the larvae. This was shown by NELEMENS (1987) for *Nebria brevicollis* (FABR.) and by SZYSZKO et al. (1996) for *Pterostichus oblongopunctatus* (FABR.), whereas a lower male-to-female ratios indicate a better feeding situation for the adults (SZYSZKO et al. 2004). According to this a better feeding situation

for larvae on the ash heap, but a better feeding situation for adults on the brown coal site exists. Both on afforested arable fields and afforested forest soils SZYSZKO (1983b) describes an increase of the male-to-female ratio of *Calathus erratus* with increase of the age of the stand. However, females predominated on these areas in general.

For a sustained management of the areas their integration into the surrounding landscape seems to be of special importance. This means to utilize the landscape elements in such a way that their natural resources are not subject to degradation. There is a special need for an identification of the different successional stages of different parts of the landscape, each of them with its own advantages and disadvantages (SZYSZKO 2004).

Some parts of the ash heap should be kept in an early stage of succession to save the environmental conditions for species rare on the regional scale. However, with respect to use the studied areas for forestry particularly on the ash heap an improvement of the soil conditions and acceleration of the speed of succession is of importance. These tasks might be tackled by imitating the process of a natural succession (JOCHIMSEM 1996, 2001). A manipulation during the early stages of succession seems to be interesting concerning the later development. Carabid beetles as indicators may help dealing with these tasks (e.g. SZYSZKO 1990). However, besides forestry the areas derived from brown coal mining offer numerous possibilities for a sustained development on a regional scale (PFLUG 1998).

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### STRESZCZENIE

W dwóch różnych terenach zdegradowanych przez przemysł, znajdujących się na południe od Bełchatowa (Wysoczyzna Bełchatowska), przeprowadzono odłowy biegaczowatych. Trwały one od kwietnia do października 2004 r. Pierwszy teren obejmował dużą hałdę zbudowaną z popiołów wytworzonych przez elektrownię. Wybrano trzy stanowiska różniące się okresem powstania (A1 – A3).

Do porównania wybrano teren z drzewostanem sosnowym, wykształconym na glebach naturalnych (A4).

Drugi teren badawczy usytuowany był na hałdzie spryzmowanych gleb pozyskanych podczas wydobycia węgla brunatnego metodą odkrywkową. Do inwentaryzacji biegaczowatych (*Coleoptera: Carabidae*) wybrano tu cztery stanowiska znajdujące się w drzewostanach sosnowych w różnym wieku (B1–B4).

Celem pracy była charakterystyka składu gatunkowego wybranych stanowisk, jak również analiza zaawansowania procesów sukcesyjnych oraz zasobności bazy pokarmowej larw i dorosłych chrząszczy. Wyniki dostarczyć miały wytycznych do rekultywacji terenów zdegradowanych przez przemysł.

W sumie odłowiono 871 osobników należących 49 gatunków, w tym cztery po raz pierwszy zarejestrowane na Wyżynie Łódzkiej. Wyniki wskazują, że na hałdzie utworzonej z popiołów procesy sukcesyjne są opóźnione.

Na wszystkich stanowiskach stwierdzono zgrupowania biegaczowatych typowe dla wcześniejszych stadiów sukcesji.

Młode drzewostany na hałdzie pokopalnianej także charakteryzuje wczesne stadium sukcesji, które jednakże po 14 latach zmieniały się na zgrupowania typowe dla lasów (zaawansowanych stadiów sukcesji). Jednakże stare drzewostany na hałdzie pokopalnianej różnią się znacząco od porównywanych drzewostanów porastających gleby naturalne. Fakt ten można wyjaśnić innymi warunkami glebowymi, jednak wpływ miał również wiek drzewostanów.

Osobniki samców, jak też i samic gatunku *Calathus erratus* (C. R. SAHLBERG, 1827) odłowionych na hałdzie pokopalnianej we wczesnym stadium sukcesji, mają mniejsze rozmiary ciała niż osobniki tego gatunku odłowione na hałdzie utworzonej z popiołów elektrowni, co wskazuje na lepsze warunki pokarmowe dla larw w drugim z badanych rodzajów środowiska. Z drugiej strony, stosunek ilości samców do samic wskazuje na gorszą sytuację pokarmową dla osobników dorosłych w tym środowisku.

Właściwości gleby zdają się być głównym czynnikiem powodującym zróżnicowanie fauny biegaczowatych oraz tempa procesów sukcesyjnych analizowanych stanowisk. Ponadto, terytoria te są wtórnym środowiskiem bytowania gatunków rzadkich w skali regionu. Wyniki te odpowiadają rezultatom badań przeprowadzonych na terenach zdegradowanych przez przemysł w innych regionach geograficznych. W odniesieniu do kształtowania terenów poprzemysłowych, znaczenie ma również zachowanie łączności z otaczającym krajobrazem. Oznacza to możliwość stymulowania lub, w razie potrzeby, hamowania procesów sukcesyjnych.

## REFERENCES

- ABS M., SCHWERK A., ZEIß A. 1999: Bergehalde im Ruhrgebiet eine Oase für Tiere? BIUZ, **6**: 346-352.
- BARBER H. S. 1931: Traps for cave inhabiting insects. J. Mitchel. Soc., **46**: 259-266.
- DMOWSKA E. 2005: Nematodes colonizing power plant ash dumps. II. Nematode communities in ash dumps covered with turf-effect of reclamation period and soil type. Pol. J. Ecol., **53**: 37-51.
- DUNGER W. 1989: The return of soil fauna to coal mined areas in the German Democratic Republic. [In:] MAJER J. D. (ed.): Animals in primary succession. The role of fauna in reclaimed lands. Cambridge University Press, Cambridge, New York, Port Chester, Melbourne, Sydney: 307-337.
- FREUDE H., HARDE K.-W., LOHSE G. A., KLAUSNITZER B. 2004: Die Käfer Mitteleuropas. Bd. 2, *Adephaga* 1, *Carabidae* (Laufkäfer), 2. (erweiterte) Aufl. Spektrum-Verlag, Heidelberg/Berlin. 521 pp.
- GEMMELL R. P., CONNELL R. K. 1984: Conservation and creation of wildlife habitats on industrial land in Greater Manchester. Lands. Plann., **11**: 175-186.

- GILLHAM M. E., SMITH J. K. 1983: Industry and wildlife: compromise and coexistence. *Endeavour*, New Series, **7**: 162-172.
- JASKUŁA R. 2003: Biegaczowate (*Coleoptera: Carabidae*) w wybranych rezerwatach okolic Łodzi. Parki nar. Rez. Przyr., **22**: 549-560.
- JASKUŁA R., KOWALCZYK J. K., WATALA C. 2002: Ground beetles of Lodz Upland, Central Poland. *Baltic J. Coleopterol.*, **2**: 117-125.
- JOCHIMSEN M. E. 1996: Reclamation of colliery mine spoil founded on natural succession. *Water Air Soil Poll.*, **91**: 99-108.
- JOCHIMSEN M. E. 2001: Vegetation development and species assemblages in a long-term reclamation project on mine spoil. *Ecol. Eng.*, **17**: 187-198.
- JOHNSON M. S., PUTWAIN P. D., HOLLIDAY R. J. 1978: Wildlife conservation value of derelict metalliferous mine workings in Wales. *Biol. Conserv.*, **14**: 131-148.
- KELCEY J. G. 1975: Industrial development and wildlife conservation. *Environ. Conserv.*, **2**: 99-108.
- KRAUTH J. 1988: Distribution-free statistics: an application-orientated approach. Elsevier, Amsterdam, New York, Oxford. 381 pp.
- NELEMANS M. N. E. 1987: On the life-history of the carabid beetle *Nebria brevicollis* (F.). Egg production and larval growth under experimental conditions. *Neth. J. Zool.*, **37**: 26-42.
- NEUMANN U. 1971: Die Sukzession der Bodenfauna (*Carabidae [Coleoptera], Diplopoda* und *Isopoda*) in den forstlich rekultivierten Gebieten des Rheinischen Braunkohlenreviers. *Pedobiol.*, **11**: 193-226.
- PARMENTER R. R., MACMAHON J. A. 1987: Early successional patterns of arthropod recolonization on reclaimed strip mines in southwestern Wyoming: the ground-dwelling beetle fauna (*Coleoptera*). *Environ. Entomol.*, **16**: 168-177.
- PFLUG W. (ed.) 1998: Braunkohlentagebau und Rekultivierung: Landschaftsökologie – Folgenutzung – Naturschutz. Springer Verlag, Berlin, Heidelberg, New York, Barcelona, Budapest, Hongkong, London, Mailand, Paris, Santa Clara, Singapur, Tokio.
- REBELE F., DETTMAR J. 1996: Industriebrachen. Ökologie und Management. Verlag Eugen Ulmer, Stuttgart. 188 pp.
- SCHWERK A., GEISS O., ERFMANN M., ABS M. 2004: Multivariate analysis of a long-term study on carabid beetles (*Coleoptera: Carabidae*) on a colliery spoil heap in the Ruhr Valley Area. *Baltic J. Coleopterol.*, **4**: 13-22.
- SZYSZKO J. 1983a: Methods of macrofauna investigations. [In:] SZUJECKI A., MAZUR S., PERLIŃSKI S., SZYZSKO J. (eds.): The process of forest soil macrofauna formation after afforestation of farmland. Warsaw Agricultural University Press, Warsaw: 10-16.
- SZYSZKO J. 1983b: Some population and individual features of selected macrofauna species. [In:] SZUJECKI A., MAZUR S., PERLIŃSKI S., SZYZSKO J. (eds.): The process of forest soil macrofauna formation after afforestation of farmland. Warsaw Agricultural University Press, Warsaw: 176-188.

- SZYSZKO J. 1990: Planning of prophylaxis in threatened pine forest biocoenoses based on an analysis of the fauna of epigeic *Carabidae*. Warsaw Agricultural University Press, Warsaw. 96 pp.
- SZYSZKO J. 2004: Foundations of Poland's cultural landscape protection – conservation policy. [In:] DIETERICH M., VAN DER STRAATEN J. (eds.): Cultural landscapes and land use. Kluwer Academic Publishers, The Netherlands: 95-110.
- SZYSZKO J., GRYUNTAL S., SCHWERK A. 2004: Differences in locomotory activity between male and female *Carabus hortensis* (*Coleoptera: Carabidae*) in a pine forest and a beech forest in relation to feeding state. Environ. Entomol., **33**: 1442-1446.
- SZYSZKO J., VERMEULEN H. J. W., DEN BOER P. J. 1996: Survival and reproduction in relation to habitat quality and food availability for *Pterostichus oblongopunctatus* F. (*Carabidae, Col.*). Acta Jutl., **71**: 25-40.
- SZYSZKO J., VERMEULEN H. J. W., KLIMASZEWSKI K., ABS M., SCHWERK A. 2000: Mean Individual Biomass (MIB) of *Carabidae* as an indicator of the state of the environment. [In:] BRANDMAYR P., LÖVEI G., ZETTO BRANDMAYR T., CASALE A., VIGNA TAGLIANTI A. (eds.): Natural history and applied ecology of carabid beetles. Pensoft Publishers, Sofia, Moscow: 288-294.
- ter BRAAK C. J. F. 1987: CANOCO – A FORTRAN program for canonical community ordination by [partial][detrended][canonical] correspondence analysis, principal components analysis and redundancy analysis (version 2.1). DLO-Agricultural Mathematics Group, Wageningen.
- ter BRAAK C. J. F., ŠMILAUER P. 2002: CANOCO reference manual and CanoDraw for Windows User's guide: Software for Canonical Community Ordination (version 4.5). Microcomputer Power, Ithaca.
- VOGEL J., DUNGER W. 1991: Carabiden und Staphyliniden als Besiedler rekultivierter Tagebau-Halden in Ostdeutschland. Abh. Ber. Naturkundemus. Görlitz, **65**: 1-31.