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Diversity of carabid beetle assemblages (*Coleoptera: Carabidae*) in a post-industrial slag deposition area

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In order to determine the effect of environmental degradation on species diversity and to determine the state and rate of recolonization of post-industrial areas, four types of research plots were set up on the Skawina Power Plant slag heap and on adjacent reference areas in a gradient of succession (the early-successional top of the slag heap and its late-successional rehabilitated embankments). A total of about 2,000 individuals belonging to 47 species of the carabid family were collected. Nonmetric multidimensional scaling indicated substantial differentiation of the composition and structure of the assemblages of the slag heap and reference areas (stress = 0.1). Every type of assemblage on the slag heap differed statistically significantly from the reference assemblages in terms of the Bray-Curtis similarity index (ANOSIM, $p<0.01$), both in the environmental degradation gradient and the succession gradient. A generalized linear model (GLM) showed that the severe transformation of the area and the unfavourable soil conditions statistically significantly differentiate parameters of carabid species diversity and richness, causing them to decrease irrespective of the stage of succession and land rehabilitation. This indicates a considerable delay in successional processes over the entire area studied, as well as the early-successional character of the carabid assemblages present there, which persists despite rehabilitation.

Key words: carabid beetles, post-industrial areas, degradation, succession, land rehabilitation, species diversity

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INTRODUCTION

The rapid growth and intensification of industry, while aimed at raising our standard of living, are one of main factors transforming the natural environment. The landscapes of industrial areas are often built on in a characteristic manner, and degradation is visible in the form of physical deformations of the surface of the land, such as pits or mounds (Eversham et al. 1996; Porębska 2005). Such changes unfavourably affect not only people, but also an enormous population of plants and animals for which the area is their living environment, causing disturbances in the functioning of the entire ecosystem and a loss of biodiversity (Dobson et al. 1997; Rahmanov & Parusel 2011).

The subject of the degradation of ecosystems and the rate of their regeneration in post-industrial areas has been studied extensively in the context of both spontaneous succession (Tropek et al. 2010) and various rehabilitation procedures (Schwerk & Szyszko 2006, 2011; Schwerk 2014; Skalski & Pośpiech 2006). In degraded areas with high spatial heterogeneity, species-diverse habitats are formed (Holec and Frouz 2005; Tropek et al. 2010) which are completely distinct from the original ones, creating a living environment only for particular specialized communities of plants and animals, and often constituting refuges for numerous rare species (Rostański 2000; Benes et al. 2003; Tropek & Konvicka 2008; Krauss et al. 2009). Artificial rehabilitation of these areas is aimed at restoring their natural ecological balance and reconstructing the natural landscape (Pośpiech & Skalski 2006; Skalski & Pośpiech 2006; Elmastodir et al. 2003; Zając & Zarzycki 2012). In this case contact with the surrounding landscape, enabling rapid recolonization, is extremely important in the shaping of post-industrial areas.

Among numerous groups of model organisms, beetles of the carabid family (Coleoptera; *Carabidae*) are frequently used in research on the effects of anthropogenic environmental disturbances (Niemelä et al. 2000; Magura et al. 2010, Skalski et al. 2010; Skalski et al. 2011, Kosewska et al. 2014). This is a very important ecological group of ground-dwelling predators that significantly contribute to the cycle of substances. Due to their sensitive and rapid response to changes in the surrounding environment, they are a suitable biological indicator of environmental changes (McGeoch 1998; Szyszko 2002; Rainio & Niemelä 2003; Skłodowski 2009; Koivula 2011; Skalski et al. 2012, Kosewska et al. 2013). Numerous adaptations enable them to rapidly recolonize degraded areas (Eversham et al. 1996; Goede & van Dijk 1998; Hendrychova et al. 2008).

The aim of the study was to show whether in an advanced stage of succession there occurs a regeneration of the structure and species composition of carabid assemblages, similar to that of reference areas. An attempt was also made to answer the question of whether the duration of spontaneous succession is the only factor influencing differentiation of assemblages.

MATERIAL AND METHODS

The study was carried out in Skawina, in the vicinity and on the grounds of a slag heap consisting of waste in form of a mixture of ash and slag produced by the Skawina Power Plant (Elektrownia Skawina S.A.). Four types of research plots were selected in gradients of environmental degradation (slag heap area 'O' – reference area 'N') and of stage of succession (early succession 'e' – late succession 'l'). The first, most severely degraded plot was situated on the top of the slag heap (Oe), where rehabilitation was carried out when the slag heap was no longer in use, involving evening out of the irregular surface of the terrain with non-hazardous waste. On these plots there was an early stage of succession with communities of herbaceous vegetation. On the embankments of the slag heap a late-successional type of research plot (Ol), covered with a strip of trees and shrubs, was established. The reference plots outside the slag heap were characterized by vegetation of a similar age and structure (herbaceous plants – Ne and trees and shrubs – Nl). In each type of plot 5 transects were established, in each of which 5 Barber traps containing ethylene glycol solution were placed 5 metres apart in a straight line (each transect was used as a sample unit). In total 125 traps were set up over the entire study area. Material was collected from May to September 2012, at intervals of about one month. Five samples were collected in total.

The material collected was identified to the species level using Hurka's key (1996). The results took into account such parameters of the structure of the carabid assemblages as the Shannon-Wiener species diversity index (H), the Berger-

Parker dominance index, total number of species, abundance, biomass, and mean individual biomass (MIB) (Schwerk & Szyszko 2007, Szyszko et al. 2002, Skłodowski 2014).

Soil material was collected from each research plot. In the laboratory the material was mineralized and the content of selected trace elements was determined by FAAS in a Solaar M6 Atomic Absorption Spectrometer. The granulometric composition of the soils was determined by Casagrande's method, organic matter content by thermogravimetry, and pH in a KCL suspension by potentiometry (Ostrowska et al. 1991).

Principal component analysis (PCA) was used to determine the most significant environmental factors associated with degradation of the area. The analysis was carried out using the statistical package CANOCO v.4.5 (Lepš & Šmilauer 2003). Nonmetric multidimensional scaling (NMDS) was performed in order to show the differences in species composition between assemblages from each type of plot. The Bray-Curtis index was used as the distance between assemblages. Statistically significant differences between assemblages were tested by ANOSIM. For parameters of assemblage structure that lacked characteristics of normal distribution, a generalized linear model (GLM) was used, from the Statistica package for Windows v. 9.0.

RESULTS

During the field research a total of 1,639 beetles of the carabid family (*Coleoptera*; *Carabidae*), belonging to 47 species, were collected and identified. The PCA ordination diagram indicated the occurrence of two main environmental gradients on the research plots (Figure 1). The first gradient is associated with Zn and Cu content and the degree of transformation of the environment (slag heap area) (Table 1), while the second gradient is associated with the concentrations of Cd and Pb in the soil. The results clearly indicate that the

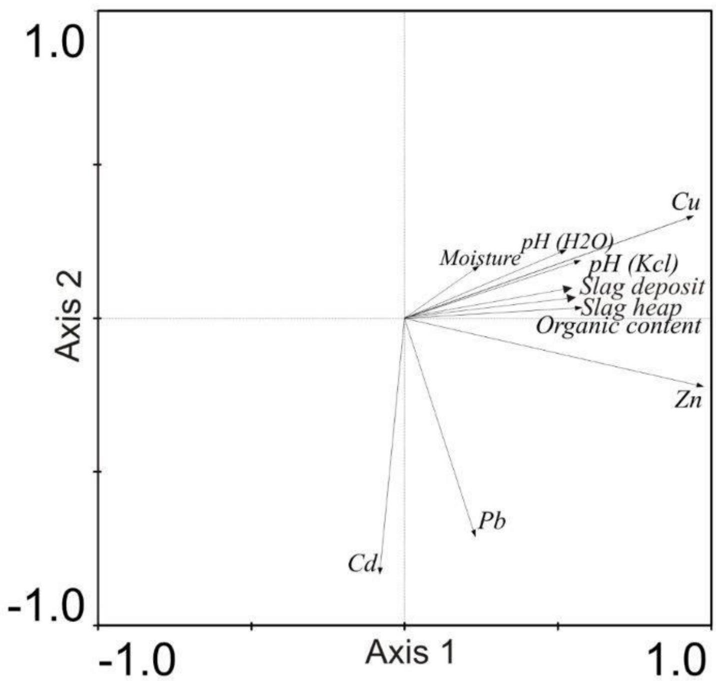

Fig. 1. Principal Component Analysis (PCA) for the environmental parameters of the slag heap area

environmental factors having the strongest influence on the structure of the assemblages are parameters directly associated with transformation of the area.

Nonmetric scaling analysis indicated a clear separation of assemblages from particular types of research plots, depending on the type of succession and the degree of degradation (Figure 2). The stress for the first two ordination axes is small, at 0.1. Not only assemblages from the early successional plots are clearly separated in the gradient of environmental transformation (Oe and Ne), but also assemblages from the late stage of succession, which indicates different mechanisms shaping the assemblages on the area of the slag heap (Table 2).

Table 1. PCA eigenvalues of particular environmental factors for ordination axes 1 and 2. Statistically significant results printed in bold

NAME	AX1	AX2
Moisture	0.2424	0.1711
Organic content	**0.5775**	0.0343
pH (H_2O)	**0.5276**	0.2227
pH (KCl)	**0.5740**	0.1877
Cd	-0.0823	**-0.8332**
Pb	0.2307	**-0.7108**
Zn	**0.9742**	-0.2224
Cu	**0.9420**	0.3322
Succession stage	-0.2008	-0.3471
Open area	0.2008	0.3471
Dump area	**0.5874**	0.0651
Dump top	**0.6839**	0.1113

The generalized linear model shows that degradation of the environment significantly affects parameters of the structure of carabid assemblages (Table 3). Irrespective of the stage of succession, the values for all parameters of assemblage structure in the slag heap areas were found to decrease (Figure 3). Only the Berger-Parker dominance index is not associated with this factor.

The generalized linear model with two quantitative factors significantly statistically differentiates the total number of species, abundance, and the biomass of carabid assemblages. These parameters decrease in the degradation gradient (Figure 3).

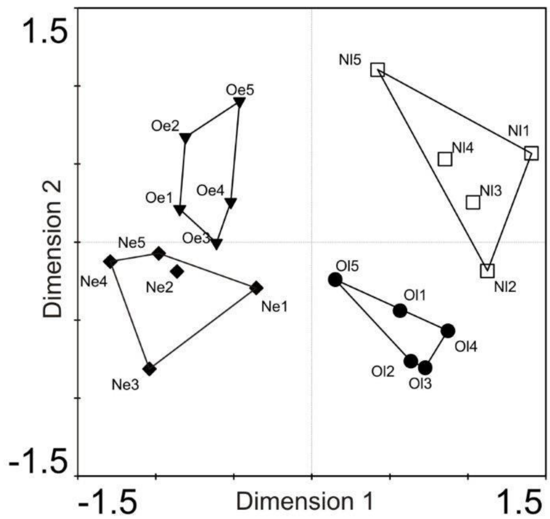

Fig. 2. Diagram of non-metric multidimensional scaling for carabid beetle assemblages of the area studied, classified according to degradation and succession gradients (Ne: reference, early succession, Oe: slag heap, early succession, Nl: reference, late succession, Ol: slag heap, late succession)

Table 2. Result of analysis of similarities (ANOSIM) of carabid assemblages in particular classes of succession and transformation

	Mean range in group	Mean range between groups	R	p
Nl-Ne	13.95	30.24	0.72	0.007
Nl-Ol	11.70	32.04	0.90	0.011
Nl-Oe	10.80	32.76	0.97	0.007
Ne-Ol	10.78	32.78	0.97	0.009
Ne-Oe	11.35	32.32	0.93	0.007
Ol-Oe	19.30	25.96	0.29	0.030

Table 3. Generalized linear model for carabid assemblage structure parameters in relation to two factors: succession and slag heap. Statistically significant results printed in bold

Species number	df	Wald's Statistic	p
Residual	1	**952.656**	0.000
Slag heap	1	**20.949**	0.000
Succession	1	**4.699**	0.030
Slag heap *Succession	1	**4.699**	0.030
Shannon-Wiener			
Residual	1	2.369	0.124
Slag heap	1	**3.888**	0.049
Succession	1	0.080	0.778
Slag heap *Succession	1	0.330	0.566
Berger			
Residual	1	**4.558**	0.033
Slag heap	1	1.357	0.244
Succession	1	0.100	0.751
Slag heap *Succession	1	0.020	0.887
Abundance			
Residual	1	**22660.420**	0.000
Slag heap	1	**48.810**	0.000
Succession	1	**298.930**	0.000
Slag heap *Succession	1	**9.760**	0.002
Biomass			
Residual	1	**3505589.000**	0.000
Slag heap	1	**5498.000**	0.000
Succession	1	**5755.000**	0.000
Slag heap *Succession	1	**182.000**	0.000
MIB			
Residual	1	**11593.840**	0.000
Slag heap	1	**12.320**	0.000
Succession	1	**29.100**	0.000
Slag heap *Succession	1	0.840	0.359

DISCUSSION

Increasing attention is given to the aspect of nature as efforts are made to restore the ecological balance of degraded land. Hence in numerous countries, including Poland, the principle holds that damage in post-industrial areas should be repaired and the area should undergo rehabilitation (Hildmann & Wunsche 1996; Porębska 2005). The various rehabilitation procedures, whether in the form of mechanical work aimed at stabilizing and evening out the post-industrial terrain and regulating the water regime, measures increasing soil fertility, or biological reclamation via the introduction of new species, are focused on one goal, which is the restoration of the natural landscape (Dunger et al. 2001). The results of the present study indicate that recolonization of degraded areas takes place very slowly, and despite rehabilitation it is not always possible to restore the natural diversity of such an ecosystem. Not only is there is a visible difference in the species composition of carabids in the early-successional slag heap and reference plots, which underscores the strong negative influence of degradation of the environment, but on the late-successional plots there are also carabid assemblages with a different species composition than the reference plots with a similar stage of succession. Besides the environmental degradation itself, other factors of great importance for the rate of recolonization of post-industrial areas may be present. Such factors unquestionably include soil conditions. Many studies emphasize the importance of soil conditions as the main factor shaping differentiation of ground-dwelling fauna (including carabids) and the rate of succession (Ponge 2003; Schwerk & Szyszko 2006; Pośpiech & Skalski 2006; Hendychová et al. 2012, Skłodowski 2013).

Simmonds et al. (1994) emphasized the importance of the presence of leaf litter for assemblages of ground-dwelling species. The surface layer of the soil reduces fluctuations in temperature, helps to maintain suitable moisture conditions, increases food availability, and creates good conditions or refuges for predators (Uetz 1979). Changes in these factors caused by human activity lead to the loss of many habitats and to the disappearance and exchange of numerous species of ground-dwelling specialists (Skłodowski 2006; Kwiatkowski 2011). In the system studied, the process of rehabilitation was limited to the planting of a layer of trees of the same age, leaving the restoration of other environmental parameters to spontaneous succession. The present study indicates that when soil parameters are not taken into account the process of regeneration is very slow. The species composition of the assemblages of the rehabilitated areas is very similar to that observed in the early-successional areas, which suggests that in both types of ecosystem only early colonizers are

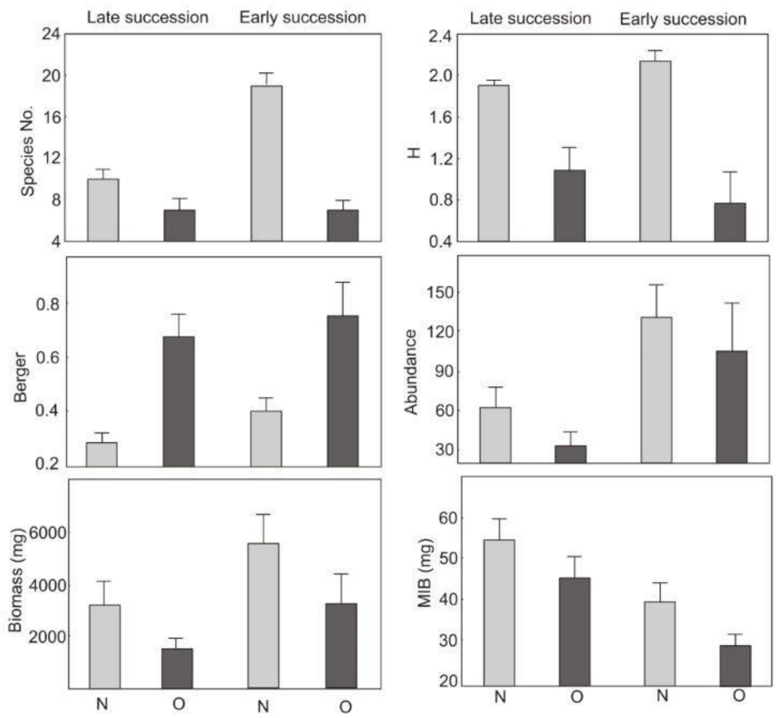

Fig. 3. Mean values for parameters of carabid beetle assemblages in two gradients: environmental degradation and stage of succession (N – reference areas, O – slag heap areas)

present. Skalski & Pośpiech (2006) point out that the structure of beetle assemblages on post-industrial areas where only tree-planting was carried out is similar to early-successional structure, despite the fact that the reclamation process covered about 100 years. These observations indicate that spontaneous colonization of ground-dwelling fauna has become very difficult.

CONCLUSION

- Degradation of the environment is a phenomenon having a significant influence on the species diversity of post-industrial areas. The results obtained indicate differentiation of the species composition and structure of the carabid (*Coleoptera*; *Carabidae*) assemblages in the slag heap areas in comparison to the reference areas, although the stage of succession was very similar.

- Recolonization in post-industrial areas is strongly dependent not only on their degree of degradation, but also on soil conditions, upon which the occurrence of many living organisms, including carabids, depends.

- Due to the type of waste stored on the slag heap, taking the form of a mixture of ash and slag, no increase was noted in the species richness or species diversity of the beetles studied, even on the late-successional plots. The study showed that in terms of similarity they are comparable to early-successional assemblages.

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