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MEAN INDIVIDUAL BIOMASS (MIB) OF GROUND BEETLES (COLEOPTERA, CARABIDAE) AS INDICATOR OF SUCCESSION PROCESSES IN POSTINDUSTRIAL AREAS

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ABSTRACT

Carabid beetle mean individual biomass (MIB) was analysed in three postindustrial areas, where different environment regeneration types were observed. In total three postindustrial dumps were selected, two of them with spontaneous succession (age about 70 and 15–20 years) and one recultivated (age about 15–20 years). Moreover undisturbed forest was chosen as reference area. Additionally in research areas observations concerning changes in the abundance and dominance of individuals characteristic for open and forest habitats were done. During the field studies 1871 carabids were caught and indicated to species level. The results showed significant differences in MIB values according to regeneration type and succession age. Generally according to one-way Anova analysis MIB values increased with stand age, but there are also difference according to spontaneously revegetaed and recultivated areas. Comparing postindustrial areas with the same age, but with different type of regeneration (spontaneous or recultivation), the MIB values was lower in recultivated area. In these areas, the lowest number of carabids forest species was observed too, which may indicate a strongly disturbed and slow rate of assemblages regeneration. Our results indicate that the mean individual biomass index (MIB) can be usefull tool for assessment succession rate in strongly disturbed postindustrial areas.

Key words: recultivation, succession, dumps, carabid beetles, forest species, bioindicators

INTRODUCTION

Post-industrial areas exposed to very intensive anthropopressure frequently turn into sites where biological processes are extremely disturbed [Walker 1992, Hüttl and Gerwin 2005]. When left aside, such areas undergoes a spontaneous succession. Otherwise, post-industrial areas are submitted to various reclamation treatments with the aim of moderating the negative effects they may have on immediate surroundings [Haigh 2000, Kędzior et al. 2014]. For researchers, they can act as a training area for exploring succession changes which occur in the course of nature regeneration. Depending on environmental conditions, succession may proceed at different rates and with different efficiency. Succession transformations on post-industrial areas are particularly interesting because they depend on the physicochemical parameters of the substrate and the extent of degeneration, as well as on the applied land restroration treatments [Frouz et al. 2006]. In many cases, land improvements (e.g. planting of shrubs and trees) are an alternative to the slow rate of spontaneous regeneration [Hadcova and Prach 2003, Tropek et al. 2012, Skalski et al. 2016a]. In the context of natural succession, a question arises whether this form of regeneration of ecosystems in postindustrial

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areas is more effective with respect to the biodiversity parameters or species richness.

Many research papers emphasise the significance of spontaneous succession processes, which create much better results than afforestation does. Studies have been conducted in this field, based on various natural environment compartments, both abiotic (e.g. soil parameters) and biotic ones (e.g. plants or animals) [Frouz et al. 2008, Hedde et al. 2012, Kędzior et al. 2014]. Noteworthy are bioindication methods which take advantage of organisms to evaluate the status of a habitat and changes occurring within it. Owing to their permanent presence in the environment, organisms are better suited to reflecting processes connected with the regeneration of disturbed ecosystems [Pośpiech and Skalski 2006, Vandewalle et al. 2010], meaning that they can provide a better insight into the processes which significantly affect such badly degraded or disturbed environments.

Ground beetles (Coeloptera, Carabidae) are widely known as effective bioindicators and therefore are frequently selected to explore the above issues [Kędzior and Skalski 2013, Skalski et al. 2015, Skłodowski 2017]. First of all, they are sensitive to envirnomental changes, their taxonomy and ecology are well investigated [Koivula 2011]. Moreover, the carabids create relationships with other taxa (plants, soil and epigeic fauna, mammals, or birds), which indicates their important role in the proper functioning of ecosystems [Thiele 1977]. Many biomonitoring investigations which employ carabid communities to assess the condition of the natural environment are based on specific parameters of assemblages, such as species richness, diversity, dominance or abundance of species with specific life traits [Kosewska et al. 2014, Skalski et al. 2016b]. Whenever an attempt is made to identify succession changes in a community, which will indicate the rate of regeneration in a distrubed ecosystem, the mean individual biomass of Carabis based on the body size can serve as a very good parameter [Schwerk and Szyszko 2007, 2011 Skłodowski 2009]. It is presented as a formula in which the sum of biomass of all carabid individuals collected in a research site is divided by the total number of individuals. Thus, the MIB values grow in an undisturbed areas as the succession proceeds, which proves an increasing abundance of species with a large body size. Conversely, when the soil has been disturbed, it is reflected by the subsequently decreasing MIB value [Cárdenas and Hidalgo 2007, Schwerk 2014]. The literature contains many examples of using the MIB indicator to demonstrate changes which occur in ecosystems. For example, Kędzior et al. [2016] investigated the effects of restoration practise based on ecofriendly structures on riparian ground beetle communities, Skłodowski and Garblińska [2007, 2011] applied the MIB to investigate communities of ground beetles in order to assess the long-term succession of carabids in forests destroyed by a hurricane. Jelaska et al. [2011] employed mean individual biomass in a study on beech forests in different age, while Schwerk and Szyszko [2011] created a model of succession based on MIB values in degraded areas.

Considering the above information, our aim was to assess the indicative power of MIB in post-industrial areas. To this end, the following were compared: species composition and MIB values of ground beetles in post-industrial areas with different type and rate of regeneration processes: 15–20 and 70 years of spontaneous processess, 15–20 years of recultivation and, for comparison, undisturbed 70–80-year-old forests. Our hypotheses were: (i) the Mean Individual Biomass (MIB) index is higher in areas with spontaneous processess compared to recultivated ones, and (ii) in a long-term gradient, the proportion of forest species of Carabids in post-industrial areas is lower than in the reference forests, which suggests the persistence of disturbances in such environments.

MATERIAL AND METHODS

The study was conducted in post-industrial areas consisting of industrial dumps situated in the southern part of Poland. In total, three dumps were selected, which differed from one another in succession processes and age: (1) the dump restored by afforestation with trees planted regularly („Trzebionka”), aged around 15 to 20 years, where the tree stand was dominated mainly by silver birch, black locust and European aspen, (II) a spontaneously regenerating dump („Siersza”), aged around 15–20 years, where the plant communities consisted of distinctly differentiated and patch-like tree stands (silver birch, blac locust, European aspen, mountain ash and small amount of pine), (III) spontaneously regenerating dump aged around 60–70 years („Krze"), densely overgrown with compact tree communities of the species composition similar to the one in Siersza. Additionally, undistrubed reference forest (mixed fresh forest), situated at a distance of between 5 and 50 km from the analysed sites, were selected for the study.

In each of the above areas, 10 study sites were established, where Barber traps were placed. A single study site was represented by a transect of 5 pitfall traps, located 10 meters from one another. Barber trap is a plastic cup (7 cm in diameter and 10 cm in height), placed flush with the ground surface level and filled up to 1/3 of the height with ethylene glycol. In total, 40 study sites comprising 200 Barber traps were set up. Insects were caught during the entire plant growing period 2015 (in total four times, from May to October), the samples were sorted out and the caught beetles were species-identified using the keys [Hurka 1996].

For each of the 40 study sites, the content of selected heavy metals: Cd, Pb, Zn and Cu, was determined so as to find out if differences in the concentrations of these metals between the analysed areas are significant (Tab. 1). Determinations of the total content of the above trace elements were made on an atomic absorption spectrophotometer Solaar M6, according to the FAAS method [Ostrowska et al. 1991] (Tab. 1)

Table 1. Mean content of heavy matals in research areas with one-way ANOVA results.

Heavy metals $mg \cdot kgs.m.^{-1}$	20 years Recultivation	20 years Spontaneous succession	70 years Spontaneous succession	Forest	Anova results	
					F	p
Cd	18.87	8.04	11.07	6.42	0.4	0.674
Pb	1003.08	465.81	756.64	363.63	0.32	0.728
Zn	2925.53	1138.19	1901.34	243.82	0.78	0.468
Cu	70.64	29.64	40.42	50.55	0.53	0.593

The Mean Individual Biomass (MIB) values of ground beetles were calculated to evaluate the succession status of carabid assemblages in particular study sites [Schwerk and Szyszko 2007]. Values of biomass needed for determination of the MIB index were derived from the following formula [Szyszko 1983]:

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

where:

y – biomass of carabid,

x – the body length of a single individual.

Next, the biomass of all individuals caught was summed up and divided by the total number of individuals in a given sample. Differences in th MIB and abundance of forest and open-area species between the three habitat types (two in different age, spontanelously revegetated and one recultivated) and reference forest were tested for significance with one-way ANOVA, followed by Tukey's multiple comparison test., first checking the distribution of variables with the Shapiro-Wilk test. All statistical analyses were performed in a Statistica version 12.0 software package [StatSoft 2012].

RESULTS

During the field study, 1871 beetles of the family Carabidae, which belonged to 36 species, were caught and identified. The general dominance analysis indicated the greatest contribution of *Calathus erratus* (C.R. Sahlberg, 1827) (14%), *Pterostichus niger* (Schaller, 1783) (13%), *Harpalus rufipes* (De Geer, 1774) (12%), *Pterostichus oblongopunctatus* (Fabricius, 1787) (10%), *Platynus assimilis* (Paykull, 1790) (7%), *Carabus granulatus* (Linné, 1758) (5%) and *Carabus arcensis* (Herbst, 1784) (5%). Considering each area separately, the dominance of particular species was distinctly varied (Fig. 1).

There were only two dominant species on the recultivated areas: *Harpalus rufipes* (62%) and *Calathus erratus* (8%) (Fig. 1). Slightly greater variation was noted on the spontaneously regenerating dump, where – apart from *Calathus erratus* (40%) – other species with a considerable contribution were ones of the genera Pterostichus (e.g. *Pt. niger* – 21%, *Pt. oblongopunctatus* – 21%) and Carabus (e.g. *C. problematicus Sturm, 1815*. – 10%, *C. granulatus* – 9%). In the forests, among the most dominant species were *Playnus assimilis* (20%), *Pterostichus oblongopunctatus* (16%), *Carabus arcensis* (15%), *Carabus violaceus Linné, 1787.* (10%) (Fig. 1).

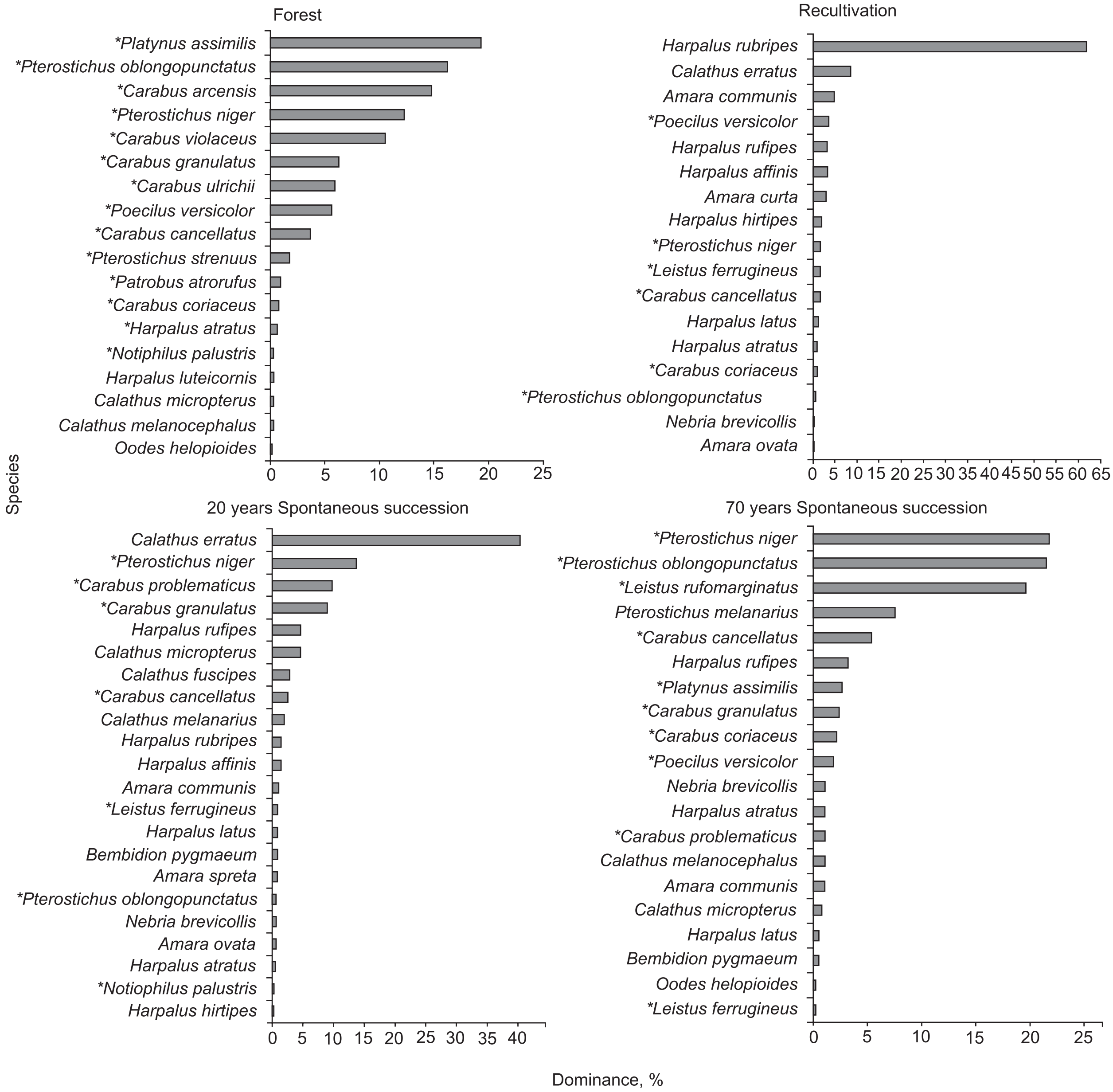

Fig. 1. Dominance of ground beetle species collected in three research areas (recultivated, spontaneous revegetated in different age) and reference forest (* indicates species of Carabidae preferring forest habitats).

Rank-abundance curves (Fig. 2) showing the abundance of carabid assemblages, in the dominance series, for the selected research areas (recultivated, with spontaneous succession aged around 15–20 years, with spontaneous succession aged around 60–70 years, and reference forests) showed that the areas with spontaneous regreneration processes experienced an increase in the total number of species among the dominant species in a community. The shape of both curves of the areas with spontaneous succession are closer to the shape of the curve plotted for forest assemblages, which indicates a more rapid and efficient process of regeneration and reproduction of carabid assemblages in these areas. On the other hand, the shape of the curve plotted for re-

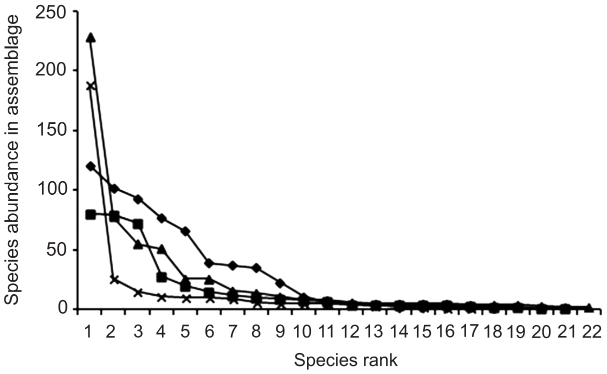

Fig. 2. Ground beetle rank-abundance curves collected in three research areas and reference forest (diamond – forests, cross – recultivation, triangle – 20 years spontaneous succession, square – 70 years spontaneous succession).

cultivated areas is most strongly divergent from the one drawn for the forest communities, thus implicating severe disturbances in the succession processes occurring within these communities of Carabidae (Fig. 2).

The MIB index was calculated for communities of carabid beetles in each type of the regenerating area. The results of a one-way of Anova analysis pointed to statistically significant differences in the MIB values depending on the type of a regenerating environment (Tab. 2).

Table 2. One-way ANOVA for the carabid beetle assemblage parameters.

Parameter	SS	df	MS	F	p
MIB					
Residual	100246.79	1	100246.79	309.87	***
Regeneration type	13432.75	3	4477.58	13.84	***
Error	11646.19	36	323.50		
Abundance of open area species					
Residual	17935.22	1	17935.22	213.70	***
Regeneration type	5258.47	3	1752.82	20.88	***
Error	3021.3	36	83.92		
Abundance of forest species					
Residual	25806.4	1	25806.4	211.84	***
Regeneration type	10252.2	3	3417.4	28.05	***
Error	4385.4	36	121.81		

Figure 3 shows that the MIB values increase with the age of an ecosystem undergoing regeneration. The lowest MIB value was demonstrated for the assemblages of ground beetles from recultivated dump, followed by the ones found on the spontaneously regenerating areas, of which the one undergoing spontaneous regeneration for about 70 years presented the MIB values closest to those obtained for the reference forests (Fig. 3). It is therefore evident that differences in the MIB values arise not only from the age of developing tree stands but also from the type of regeneration (spontaneous vs recultivation).

The ANOVA analysis applied to the distribution of forest and open-area species of the Carabidae showed statistically significant differentiation depending on the type of regenerating areas (Tab. 2). The highest number of forest species was noted in the reference forests. Among study sites, there was an evident increase in the share of forest species inhabiting the dump that has been regenarating the longest, which proves the progressing succession (Fig. 4a), whereas among the study sites where succession has lasted shorter (about 15–20 years), the contribution of forest species is negligible but distinctly lower on the landfill where regeneration occurs as a result of tree planting. A reverse situation was observed while analysing the distribution of the abundance of species characteristic for open areas (Fig. 4b). They were the most numerous on the recultivated dump but demonstrably rarer in areas which have been regenerating for a longer time.

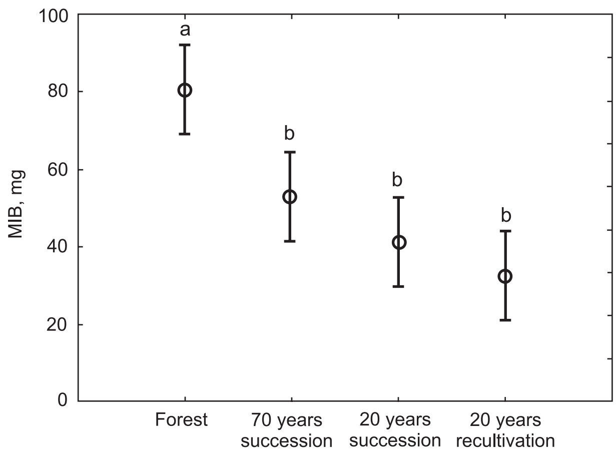

Fig. 3. Mean MIB values for carabid assemblages of forest, spontaneously revegetated and recultivated study sites. Different letters denote significant differences (Tukey, $p < 0.05$).

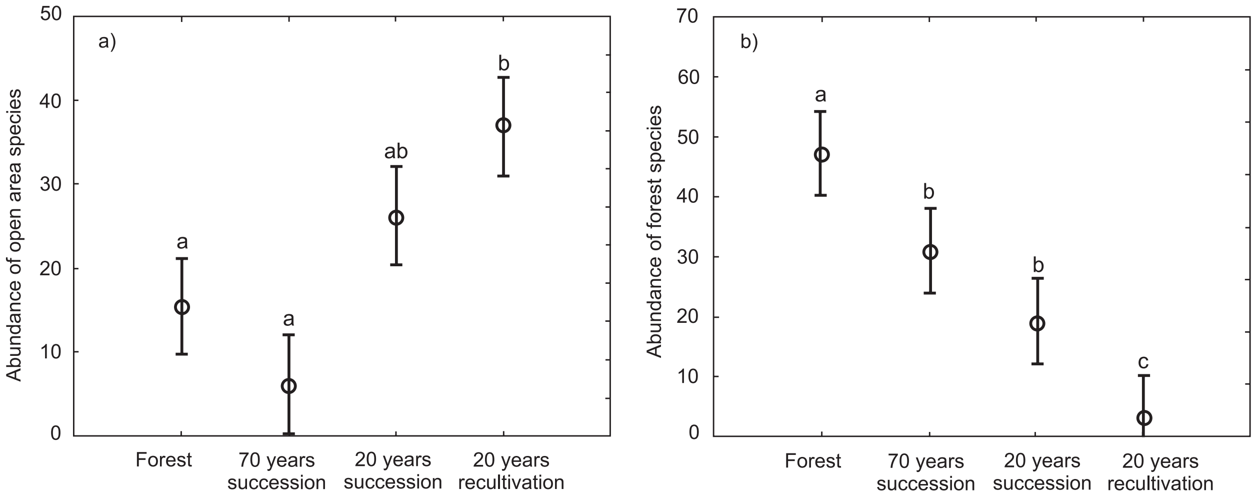

Fig. 4. Mean abundance of open area (a) and forest (b) carabid species of forest, spontaneously revegetated and recultivated study sites. Different letters denote significant differences (Tukey, $p < 0.05$).

DISCUSSION AND CONCLUSIONS

The results indicate that the MIB index can be successfully used for making assessments of the succession in post-industrial areas. We observed that the MIB values increased as the regeneration of the analysed study sites lasted longer. There were also significant differences in the MIB values depending on the type of regeneration (spontaneous or by recultivation). Many researchers report that under natural conditions the MIB values can be expected to increase in parallel to the progressing succession in an ecosystem [Skłodowski 2009, Jelaska et al. 2011]. This is connected with an increase in the share of species with a large body size in an assemblage, and most of such species belong to the group of forest habitat specialists with high environmental requirements [Skłodowski and Garbalińska 2011]. A large share of forest species in a community of ground beetles suggests that environmental conditions have stabilised and succession is advanced, which is a situation typical of many undistrubed forest ecosystems [Skłodowski and Sławski 2003, Skalski et al. 2015]. The results of our investigations show that postindustrial sites have not achieved a stable condition despite the lengthy regeneration period. The MIB in the analysed beetle communities remains on a statistically significantly lower level than in the reference forests, and the share of typical forest species in the communities of carabid beetles is still relatively small [Kędzior et al. 2017]. Despite the succession lasting for 60 or 70 years, assemblages of ground beetles mostly consist of species distinguished by high ecological flexibility, which can appear in large numbers in disturbed areas, e.g. *Harpalus rufipes*, *Calathus erratus*.

What might exaplain the low MIB persisting there in comparison to undisturbed areas? Despite the development of plant assemblages, which in time turn into compact tree stands, there can be other factors that interfere with the succession of ground beetles in these areas. Many authors suggest that biota in post-industrial areas are influenced by a number of factors, which play a key role in the formation of species composition within the mentioned communities as well as in the efficiency of succession processes which occur in such areas [Schwerk 2014, Skalski et al. 2016a, Kędzior et al. 2017]. The primary factors include physicochemical parameters of the substrate/soil, which for many organisms is an essential condition for their occurrence in a given habitat, either as its fundamental element or as the source of nutrients [Frouz et al. 2006, Hendrychová et al 2012]. In industrial areas, this compartment of the natural environment is often exposed to disturbances, for example due to contamination with heavy metals, which increases the lethality among colonising organisms, or because of some physical transformations of the ground. Frequently, the absence of a properly formed structure of soil is a serious limitation to the presence of diverse soil fauna, which for many epigeic groups (including predatory carabid beetles) is a food supply [Kędzior et al. 2014]. Another factor affecting the rate and efficiency of succession processes in post-industrial areas could be composed of changes caused by physical deformations resulting from man's activity (spoil heaps, pits, etc.) as well as the type of land management. In natural conditions, spontaneous succession creates heterogeneous spatial systems, which in time are settled down by organisms with appropriate habitat requirements. In contrast, recultivation in post-industrial areas very often involves techniques of planned tree planting (afforestation) over deformed land relief structures remaining after industrial activity, so as to minimise the negative effects. The resulting are homogeneous systems, with very few factors that would differentiate habitat types for potential recolonising organisms [Hadcova and Prach 2003, Frouz et al. 2006, Tropek et al. 2012].

In our results we observed such situation in the recultivated sites where plants (mostly trees and shrubs) had been planted in regular layouts. This is where we noted the lowest MIB values, which is indicative of the persistent early succession character of the carabid communities inhabiting this area. Despite the 15–20 years of regeneration, these assemblages are continually strongly dominated by species distinguished by high ecological plasticity and low habitat demands, such as *Harpalus rufipes* and *Calathus erratus*. These species are characteristic for open areas, where the stability of environmental conditions is low. In turn, our analysis of the MIB obtained for the sites of a similar age but regenerating spontaneously showed higher values. Moreover, the above site comprised a higher share of typical forest species with bodies larger in size, e.g. of the genera Carabus czy Pterostichus, than noted in the recultivated area, although its composition was still highly divergent from the one of ground beetle communities in the reference forests. We suspect that this could have been a consequence of the parameter associated with the higher habitat heterogeneity found on the spontaneously regenerating area [Kędzior et al. 2017]. The plants developing there formed irregular patches of vegetation that differed in size and structure, which probably made the recolonisation process easier.

We conclude that the MIB inex can be helpful in making an assessment of the rate and efficiency of succession of ground beetle communities in post-industrial areas. Admittedly, the MIB index has been used in numerous studies, where it served to indicate succession changes in habitats, mostly forest ones, e.g. tree stands of different age regenerating after some severe disturbance, like a hurricane or a forest management treatment [Schwerk and Szyszko 2007, 2011, Skłodowski 2009, 2017]. However, in severely deformed post-industrial areas this index can also reveal changes in communities of ground beetles in a time gradient, thus demonstrating to what extent the succession process itself is slow or disturbed [Cárdenas and Hidalgo 2007, Szyszko 2014, Kędzior et al. 2014, 2017]. We also conclude that there is a need for more detailed research in the future which can assist in the identification of directions of wasteland management that will be beneficial not only for man but also for the plants and animals recolonising such areas.

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ŚREDNIA BIOMASA OSOBNICZA (SBO) BIEGACZOWATYCH (COELOPTERA, CARABIDAE) JAKO WSKAŹNIK OCENY PRECESÓW SUKCESYJNYCH W OBSZARACH POPRZEMYSŁOWYCH

STRESZCZENIE

Głównym celem pracy było przetestowanie użyteczności wskaźnika SBO w ocenie tempa procesów sukcesyjnych w obszarach poprzemysłowych. Porównaniu poddano wartości wskaźnika SBO opisującego sukcesję zgrupowań biegaczowatych w obszarach o różnym wieku oraz sposobie regeneracji (procesy spontanicznej sukcesji oraz rekultywacja). Ponadto obliczono udział gatunków leśnych w regenerujących się zgrupowaniach biegaczowatych w celu określenia stabilności zgrupowań w różnych typach środowiskowych.

Badania prowadzone były na obszarach poprzemysłowych, które stanowiły trzy składowiska: dwa różniące się wiekiem, regenerujące się w wyniku spontanicznych procesów, oraz składowisko rekultywowane metodą zadrzewiania. Dodatkowo dla celów porównawczych wybrano niezaburzone obszary leśne jako powierzchnie referencyjne. Chrząszcze z rodziny biegaczowatych zbierano czterokrotnie z wykorzystaniem pułapek ziemnych w ciągu całego sezonu wegetacyjnego 2015 roku.

Wyniki indeksu SBO różnicują się istotnie w zależności od charakteru obszaru badawczego. Zaobserwowano istotny wzrost wartości indeksu SBO wraz z wiekiem regeneracji składowisk, aczkolwiek nawet pomimo długiego okresu odtwarzania (około 70 lat) wartości te utrzymują się na istotnie statystycznie niższym poziomie względem stanowisk referencyjnych. Najniższe wartości SBO zanotowano na rekultywowanym składowisku, gdzie wykazano również najmniejszy udział gatunków leśnych w zgrupowaniu biegaczowatych, co wskazuje na bardzo powolne i zaburzone tempo regeneracji zgrupowań. Przeprowadzone badania wskazują, iż indeks średniej biomasy ososbniczej (SBO) może być wykorzystywany jako wskaźnik sukcesji naobszarach poprzemysłowych.

Słowa kluczowe: rekultywacja, sukcesja, składowiska poprzemysłowe, biegaczowate, gatunki leśne bioindykatory