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Role of reclamation in the formation of functional structure of beetle communities: A different approach to restoration

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ABSTRACT

The main objective of reclamation activities is to accelerate the restoration of post-industrial areas. However current ecological studies that compare reclaimed and non-reclaimed habitats evaluate these areas mainly by species richness and conservation potential. We thus tested which environmental characteristics of the spoil heap determine the structure of the beetle communities and their successional rate. During the years 1993–2007, we sampled epigeic beetles on reclaimed and non-reclaimed parts of a spoil heap in the city of Ostrava, Czech Republic. For comparison, we used multivariate methods and functional diversity indices. Our ordination models revealed that the beetle communities on the non-reclaimed part of the spoil heap were determined by forest cover and time; in contrast, the communities on the reclaimed habitat were determined by herb cover and bare ground cover. Compositional heterogeneity was significantly higher on the non-reclaimed part of the spoil heap. A comparison of the functional diversity indices showed significantly higher functional richness and evenness on the spontaneously restored part of the spoil heap. Our results provide evidence that technical reclamation is a significant disturbance that slows down the successional rate of beetle communities and negatively influences their structure. We thus recommend that at least some parts of the areas needing to be reclaimed be allowed to undergo spontaneous succession during reclamation. The areas undergoing spontaneous succession would become refuges for particular species while also supporting the heterogeneity of the habitat.

1. Introduction

Deep underground mining has a fundamental impact on the landscape (Szczepanska and Twardowska, 1999; Walker, 2012; Hodecek et al., 2015), transforming original habitats and leaving landscapes in altered states. An additional consequence of mining activities is the depositions of spoil on the surface leading to the formation of spoil heaps. There are three main approaches to managing disturbed landscapes: (1) technical reclamation, which usually involves covering the areas with fertile topsoil, sowing grass-herb mixtures and planting trees; (2) spontaneous succession without any human intervention; and (3) assisted site recovery, or directed succession, which is still rarely used and combines both of the previously noted approaches, e.g. through the manipulation of spontaneous succession by sowing seeds of plants desirable to conservation, transferring species-rich hay to the area or by suppressing invasive plants (Prach and Hobbs, 2008; Tropek et al., 2012; Baasch et al., 2012). Because the replacement of original habitats with disturbed post-industrial sites has been considered in most cases as a negative event, efforts to 'heal the landscape' through technical reclamation are common responses (Tropek et al., 2010).

A lack of post-restoration monitoring and research means that few opportunities have been taken to improve the theory and practice of ecological restoration on mined lands (Cooke and Johnson, 2002; Prach and Hobbs 2008). A number of studies have focused on restoration success after seeding or planting (Jochimsen, 2001; Ruiz-Jaen and Aide, 2005), but direct comparisons of the different restoration approaches are still scarce (Holec and Frouz, 2005; Tropek et al., 2010). Current comparisons of value between reclaimed and non-reclaimed sites focus on the conservation potential of the non-reclaimed areas (Hodacova and Prach, 2003; Holec and Frouz, 2005; Hendrychova et al., 2008; Tropek et al., 2010,

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2014; Salek, 2012; Schwerk, 2014). However, these studies lack successional series data and therefore cannot adequately quantify the effects of reclamation on biodiversity and predict future development. Furthermore, the conservation value of an area is not equal for all studied taxa, which suggests that the conservation values of post-industrial sites are not universal.

Succession in temperate zones leads to forest-like types of ecosystems (Walker and Moral, 2003). Such ecosystems are defined by the presence of forest species. Higher proportions of forest species in temperate ecosystems can thus be considered as a feature of later successional seres (Majer, 1989). The change in the proportion of species with a link to open habitats and forest species per unit time can thus be interpreted as a successional rate. The typical aim of technical reclamation is to increase the speed of habitat succession from open land to forest. However, technical reclamations do not consider the specific conditions of the spoil heaps (e.g. exposed spoil, geomorphology, consistency of geological material, etc.). The specific microclimate and other environmental conditions of spoil heaps thus influence the species, the functional structure of the communities and the successional rate of the habitat (Walker and Moral, 2003).

Species diversity and richness are the traditional approaches used for studying the effects of reclamation on communities (Walker and Moral, 2003; Ruiz-Jaen and Aide, 2005). However, these approaches do not fully reflect the relationships among organisms and the changes in their environments (Walker, 2012). In contrast, the concept of functional diversity (FD) offers a better approach to understanding what determines community structure and how the communities respond to changes in environmental conditions (Tilman, 2000; Díaz and Cabido, 2001; Mason et al., 2005; Gerisch et al., 2012). Therefore, FD also can be a valuable method for studying community function after disturbance (Gerisch et al., 2012). Technical reclamation can be considered to be a significant long-term disturbance, due to covering the spoil heap surface by topsoil, seeding of grass-herb mixtures and planting trees. This can lead to species replacement in the affected area (Walker, 2012) and to the formation of new communities as a results of the specific abiotic conditions on the spoil heap after reclamation.

We assume that under natural conditions, spatial complexity (e.g. vegetation structure) increases during the succession time followed by the niche and trophic complexity (Roth, 1976; Southwood, 1977). This is the basis for the increase of species and functional diversity. Moreover, as trophic complexity increases through successional stages, predators will become more abundant with more important effect on the community (Menge and Sutherland, 1976; Southwood, 1977). On the other hand early successional stages after disturbance (i.e. technical reclamation) should be represented by omnivores with broad niches (Southwood, 1977). Relatively homogeneous environmental conditions in the reclaimed habitats could lead to decrease of the species specialization and resource diversity (Slobotkin and Sanders, 1959). Broad niche, low resource diversity and low number of habitat specialists should lead to low species and functional diversity (Gerisch et al., 2012).

In this study, we compared the effects of technical reclamation and spontaneous succession over a period of approximately 15 years based on the functional and species diversity of a community of epigeic beetles. The main hypothesis in this study was that technical reclamation leads to a slower successional rate in post-industrial habitats. This hypothesis reflects our earlier suggestion that technical reclamation is a significant disturbance that leads to homogenization of habitat. We assumed that reclamation will result in an increase of species functional traits similarity due to the specific environmental conditions. Therefore, we hypothesized that the functional richness of the communities on the reclaimed part of the spoil heap will be lower than on the more heterogeneous non-reclaimed part. We also hypothesized that after technical reclamation, the community will not be determined by stochastic drift, but that the extreme and uniform abiotic conditions will encourage the establishment of species with similar traits (generalists).

2. Methods

2.1. Study area

The study was conducted in the north-eastern Czech Republic in the Upper Silesian industrial region, the largest conurbation in central Europe. Deep underground mining has been conducted here since the 1850s. The area is characterized by intense devastation of the landscape, caused mainly by black coal mining and iron metallurgy. The study took place on the Bezruc spoil heap in the city of Ostrava. The Bezruc spoil heap (49°50′29.5″N 18°18′49.6″E, 305 m above sea level) was begun in 1920, and its elevation above the surrounding terrain is nearly 60 m. This spoil heap was created by the accumulation of spoil after deep underground mining for black coal. Spoil depositing ended in the late 1950s to early 1960s. Bezruc was partially reclaimed in the 1980s, which makes it a suitable location for comparison of succession on a reclaimed and non-reclaimed site. The south-western part of the heap was covered by 20 cm of topsoil and planted with different tree species (e.g. *Quercus robur*, *Quercus rubra* and *Picea pungens*). The north-eastern part of Bezruc was left to spontaneous succession and was colonized by pioneer species of plants and woody species (e.g. *Populus × canadensis*, *Betula pendula* and *Fraxinus excelsior*). No specific permission was required to enter the locality, because the spoil heap is publicly accessible.

2.2. Study group and sampling

For our model arthropod group, we chose epigeic beetles because they represent a very abundant and taxonomically diverse group with important ecological functions in ecosystems (Krooss and Schaefer, 1998; Schulze et al., 2004; Gerisch et al., 2012; Gerisch, 2014). To test changes in functional groups of beetles and functional diversity, we chose the family Carabidae. Carabids are effective indicators in the ground layer because they are sensitive to landscape changes, show a large range of responses to those changes and their taxonomy and ecology are well known (Rainio and Niemelä, 2003; Kotze et al., 2011; Gerlach et al., 2013).

We used pitfall traps to capture beetles. Each trap consisted of a 0.3 L plastic cup with the diameter of 7.5 cm. The pitfall traps were covered by small tin roofs and filled with a 2% formaldehyde solution. They were installed in a line 10 m far from each other. Material was collected from 1993 to 1995 (five pitfall traps on reclaimed part and five on non-reclaimed part of the spoil heap), and from 2006 to 2007 (five pitfall traps on each part of the spoil heap completely on the same spots, as in the previous period). In total, we had data from 5 years (1993, 1994, 1995, 2006 and 2007) within a 15-year period. The number of traps was chosen to minimalize the effect of the sampling effort to the structure of the communities (Obrtel, 1971; Slezak et al., 2010). We tried to work with the representative sample of the beetle communities in a way which would not influence the next years of the sampling. Sample-based rarefaction curves showed that for the reclaimed part of Bezruc less than 600 specimens are enough to cover the species richness efficiently (we caught 1751 specimens) and for the non-reclaimed part of Bezruc it is less than 800 specimens (we caught 1812 specimens). Analy-