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Local and landscape factors affecting communities of plants and diurnal Lepidoptera in black coal spoil heaps: Implications for restoration management

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ABSTRACT

Post-mining sites have been repeatedly shown as crucial refuges for endangered temperate biodiversity, as they supplement vanishing non-productive and/or early successional habitats. Their effective restoration is thus a key task of applied ecology and should be based on robust evidence. Here, we present a landscape-scale study of black coal spoil heaps in the Kladno mining region, Czech Republic. Surveying vascular plants and diurnal Lepidoptera (butterflies and day-active moths), we analyzed the impact of numerous physical, local habitat, land-use, and surrounding landscape factors on the composition, species richness, and conservation value of the communities established at 11 spoil heaps. We recorded 54 species of butterflies, 37 species of moths, and 203 plant species, including 16 nationally endangered and/or regionally extinct species, which confirmed the high conservation value of postindustrial sites, even in severely industrialized regions. Several factors depending on post-mining management, topography and habitat heterogeneity were revealed as those most important for the conservation value of both plants and invertebrates communities, whereas the surrounding landscape had no effect on the communities. The species richness and the conservation value of the spoil heaps were both mainly related to the initial stages of succession and disturbances supporting these conditions, and to the heterogeneity of the habitats and the topography. On the contrary, biodiversity was suppressed when covered with fertile topsoil, as is often applied in the technical reclamation practice. Following our results, habitat heterogeneity should be created during the spoil heaping and subsequently supported by restoration management, especially by non-intensive disturbances.

1. Introduction

Mining, as a crucial part of the world's economy, affects about 1% of the total land cover (Walker, 1992). Spoil heaps, as an unavoidable by-product of almost every mining activity, represent probably the most common type of post-mining sites in many regions, and thus they have attracted the attention of conservation biologists practically since the establishment of the conservation biology discipline (Primack, 1993; Young, 2000). Recently, it has been repeatedly shown that their heterogeneous surfaces with extreme abiotic conditions and low productivity may offer valuable compensatory habitats for many arthropods and plants rapidly declining in modern human-altered landscapes (e.g., Brandle et al., 2000; Tropek et al., 2012; Dolezalova et al., 2012). This pattern was revealed also for some other postindustrial sites, such as quarries (e.g., Benes et al., 2003; Krauss et al., 2009; Novak and Konvicka, 2006), sand pits (e.g., Lenda et al., 2012; Rehounkova and Prach, 2006; Heneberg et al., 2013), fly ash deposits (Tropek et al., 2013), and brownfields (e.g., Eyre et al., 2003). Therefore, because of accelerating global biodiversity loss, restoring valuable surrogate habitats able to supplement the declining types of environments at locations heavily affected by the mining industry is increasing in importance in restoration ecology (Lundholm and Richardson, 2010; Plieninger and Gaertner, 2011). Additionally, the increasing amounts of financial resources aimed at the restoration of the

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degraded habitats require maximally effective reclamation management for biodiversity conservation (Prach and Hobbs, 2008; Plieninger and Gaertner, 2011).

Recently, numerous studies have dealt with biodiversity patterns and/or the conservation potential of various post-mining sites. Besides studies on fundamental principles of communities' development during spontaneous succession (e.g., Prach et al., 2001; Wiegleb and Felinks, 2001; Strauss and Biedermann, 2008), the majority of research effort has been focused on the direct success of particular restoration management methods (e.g., Martinez-Ruiz et al., 2007; Rydgren et al., 2010; Baasch et al., 2012; Tropek et al., 2010, 2012), and thus these rather technical methods are generally based on well-known principles of active restoration of degraded semi-natural sites. On the other hand, for responsible planning and maximally effective practice, we should follow patterns spontaneously developed in diverse post-industrial sites. A majority of such studies have been restricted to the abiotic conditions, such as the substrate attributes, age or area of the surveyed site, whereas the studies dealing with the suitability and value of particular already established habitats are still rare (e.g., Benes et al., 2003; Krauss et al., 2009; Hendrychova et al., 2012). Additionally, many of these studies are restricted to a single group of organisms or to a single or a few localities. And, finally, almost all multi-taxa and landcape-scale studies use species richness as the only conservation value indicator and generally avoid threatenedness (such as regional rarity or red-list status) of the recorded species, although a focus on threatened species is necessary for maximally effective restoration (Root et al., 2003; Nicholson et al., 2006; Tropek et al., 2008).

Here, we present a landscape-scale study of vascular plants and diurnal Lepidoptera (butterflies and day-active moths) communities established at black coal spoil heaps in the Kladno mining region, Czech Republic. Since treeless habitats have been repeatedly revealed as the most valuable parts of many post-mining sites in Europe (e.g., Benes et al., 2003; Krauss et al., 2009; Hendrychova et al., 2012; Lenda et al., 2012), we surveyed all spoil heaps in the region that harbour patches of non-forested habitats. Considering the remarkable diversity of numerous environmental factors, we focused on the following questions: 1/What is the conservation potential of black coal spoil heaps in severely degraded industrial regions for diurnal Lepidoptera and vascular plants? 2/What is the role of local site and surrounding landscape factors for the communities' establishment? 3/Can this knowledge of the studied local site and landscape factors's effect on biodiversity improve the common practice of postindustrial site restoration? For the evaluation of the conservation value of particular components, we concentrated on species richness, abundances of threatened and invasive alien species and their affinities to particular factors.

2. Methods

2.1. Study area and sites

The Kladno mining region (about 100 km^2) is located in Central Bohemia, the centre of the Czech Republic. It is a hilly (250–400 m a.s.l.), mildly warm and relatively dry (mean annual temperatures: 7–8.7 °C; annual precipitation: 450–500 mm) region of intensive agriculture (about 50% of the area are arable fields), production forestry (about 25%), and industry (about 10% of the area; mainly mining and steel industry) (Gremlica, 2005). Such intensive land use has resulted in the severe degradation of almost all natural habitats, a situation typical for the common landscape of many industrial areas in Central Europe.

Until the end of the 20th century, the Kladno mining region had been one of the most important black coal (bituminous) mining areas in the Czech Republic. Non-intensive mining is documented from the mid-18th century, the second half of the 19th century was bound up with its strong intensification. All mines were closed in the 1990s, when mining became unprofitable. Approximately 5% of the region is affected by underground mining, which resulted in the creation of 37 larger (0.2–24.6 ha) black coal spoil heaps, forming hills or hillsides (Gremlica, 2005).

Until the mining activities' cessation, almost all inactive heaps were left to spontaneous succession, gradually forming prevailingly heterogeneous deciduous woodlands (Prach et al., 2011). Species rich grasslands or shrub and forest steppes, however, locally developed in spatially restricted extreme habitats (such as steep slopes, strongly desiccative substrate) or periodically disturbed sites (both human-made and natural; Gremlica, 2005). Mining termination has generated recent pressure for rapid technical reclamation of all spoil heaps in the region, mainly because of a danger of autoignition which, however, has been recently averted (Gremlica, 2005; Prach et al., 2011). Consequently, a majority of the sites are now at least partly technically reclaimed or technical reclamation is underway or planned in the nearest future. In the studied region, similarly to the whole Czech Republic, this reclamation include mainly a fertile topsoil covering supplemented by commercial grass-herb mixture sowing and/or tree planting (Tropek et al., 2012). Only a few spoil heaps still stay abandoned for spontaneous succession outside these technical reclamation pressures.

In this study, we targeted 11 black coal spoil heaps (Table 1); i.e., all spoil heaps in the region with larger (i.e. > 0.1 ha) patches of persisting open habitats. All studied spoil heaps varied highly in all basic characteristics, such as age, area, shape, or disturbances (cf. Tables 1 and 2).

Table 1
Position and basic characteristics of the studied black coal spoil dumps with the sampling efforts, represented by the numbers of relevés for plants and sampling time (min per visit) for diurnal Lepidoptera.

spoil heap	location		age (y)	area (ha)	sampling effort	
					plants	Lepidoptera
Wanieck	50°08′09″N;	14°01′47″E	38	0.7	9	40
Max	50°09′37″N;	14°03′29″E	36	5.4	24	60
Mayrau	50°09′52″N;	14°05′07″E	35	2.8	19	40
Barre	50°09′46″N;	14°05′38″E	88	1.1	10	40
Motycin	50°09′56″N;	14°05′44″E	88	0.5	7	20
Ronna	50°10′39″N	14°07′00″E	26	6.3	21	60
Prago-Tragy	50°09′58″N	14°07′43″E	20	1.7	16	40
Ferdinand	50°10′35″N	14°08′31″E	91	1.4	11	20
Theodor	50°10′54″N	14°08′05″E	73	1.7	10	40
Vitek	50°10′29″N	14°09′36″E	117	0.2	8	20
Teplak	50°10′11″N	14°09′49″E	117	1.5	8	40