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Research article

Influence of surface flattening on biodiversity of terrestrial arthropods during early stages of brown coal spoil heap restoration

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ABSTRACT

Heterogeneity of environmental conditions is the crucial factor supporting biodiversity in various habitats, including post-mining sites. The effects of micro-topographic heterogeneity on biodiversity and conservation potential of arthropod communities in post-industrial habitats had not been studied before now. At one of the largest European brown coal spoil heaps, we sampled eight groups of terrestrial arthropods with different life strategies (moths, spiders, ground beetles, ants, orthopteroids, centipedes, millipedes, and woodlice), in successionally young plots (5–18 y), with a heterogeneous wavy surface after heaping, and compared the communities with plots flattened by dozing. A combination of the standardized quantitative sampling, using two different methods, and a paired design of the plot selection enabled a robust analysis. Altogether, we recorded 380 species of the focal arthropods, 15 of them nationally threatened. We revealed the importance of the micro-topographic heterogeneity for the formation of the biodiversity of arthropods in their secondary refuges. The communities with higher biodiversity and conservation value were detected in the plots with heterogeneous surfaces; exceptions were ground beetles and millipedes. The surface flattening, often the first step of technical reclamation projects, thus suppress biodiversity of most terrestrial arthropods during the restoration of post-mining sites. Since the communities of both surface types differed, the proportional presence on both surfaces could be more efficient in supporting the local biodiversity. We suggest reducing the surface dozing for the cases with other concerns only, to achieve a proportional representation of both surface types. Such a combination of different restoration approaches would, thus, efficiently support high biodiversity of groups with various needs.

1. Introduction

Heterogeneity of environmental conditions is a key factor in forming and sustaining biodiversity (Stein et al., 2014; Tews et al., 2004; Yang et al., 2015). Heterogeneity, in both spatial and temporal scales, is thus commonly used for explaining the biodiversity patterns of diverse communities, as the heterogeneous conditions provide suitable conditions for more organisms, offering a higher chance of survival, coexistence, and more niches to occupy (Frouz et al., 2014; Stein et al., 2014; Williams and Houseman, 2014). Even small-scale environmental heterogeneity has been evidenced to support the local diversity of terrestrial plants (Tamme et al., 2010), as well as invertebrates (Nielsen et al., 2010). Microtopographic heterogeneity of surfaces is responsible for increasing various environmental conditions' heterogeneity, especially water and shade regimes, soil properties, or nutrient availability (Frouz et al., 2011, 2018; Frouz and Nováková, 2005; Kappes et al., 2012; Prach et al., 2011). Hence, supporting the micro-topographic surface heterogeneity is considered an important component of habitat restoration (Prach et al., 2011). Various studies have focused on arthropods, and their primary succession, in post-industrial landscapes (e.g. Hendrychová et al., 2012; Heneberg et al., 2013; Tropek et al., 2012, 2010, Tropek and Konvicka, 2011, 2008). However, the effects of

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heterogeneity, especially surface heterogeneity, on the biodiversity of arthropods in post-industrial landscapes has until now been poorly studied.

Sites affected by surface mining represent an increasing component of many landscapes and are thus chief targets of habitat restoration (Brom et al., 2012; Tropek et al., 2010). Various post-industrial sites were evidenced as essential strongholds of the temperate biodiversity in the current human-affected landscapes despite their numerous negative effects on the environment, including substantial destruction of (semi) natural habitats (e.g. Hendrychová et al., 2012; Heneberg et al., 2013; Tropek et al., 2012, 2010, Tropek and Konvicka, 2011, 2008). Exploring the factors responsible for such high conservation potential, therefore, should precede all restoration projects of post-industrial sites to maximize their conservation outcomes (Tropek and Konvicka, 2011). In this respect, effects of habitat heterogeneity on the biodiversity of post-mining sites are usually studied on large scales (most studies focused on changes in various environmental conditions in few hundreds of metres or kilometres, e.g. Doležalová et al., 2012; Hendrychová et al., 2012; Tichanek and Tropek, 2015; Tropek et al., 2013a,b), whilst the micro-topographic scale (i.e. an influence of the environmental heterogeneity in the scale of a few metres) is rarely studied (Deák et al., 2015; Frouz et al., 2011, 2008; Kappes et al., 2012).

In the Central Europe, as well as in some other regions (Prach and Hobbs, 2008), technical reclamation is still the prevailing approach in the restoration of post-mining sites. As defined by Prach and Hobbs (2008), this practice typically involves surface flattening by heavy machinery, followed by covering the heaped substrate with fertile substrate, sowing a grass/herb mixture, and planting trees. Although technical reclamation is sometimes necessary for avoiding various environmental risks (such as erosion, acid rock drainage, toxin leaks, public safety issues), there is substantial evidence from numerous recent studies (e.g. Hendrychová and Bogusch, 2016; Mudrák et al., 2010; Tropek et al., 2013a, 2012, 2010) that it squanders the potential to protect the terrestrial biodiversity. The cited studies revealed the ruderalisation of the technically reclaimed plots, acceleration of succession into the mid-successional stages, and general decrease of habitat heterogeneity as the main causes of the conservation potential decrease after the technical intervention. Such impoverished habitats do not host a large part of the threatened biodiversity, especially many endangered early-successional species of arthropods and plants, as a result of which those species lose their secondary refuges (Tropek et al., 2010, 2012; 2013a). Nevertheless, the effects of the particular steps of the technical reclamation are not well understood while such knowledge could allow efficient compromises whenever some technical intervention is necessary (Prach and Hobbs, 2008).

As the first step in the technical reclamation, the microtopographic heterogeneity is typically suppressed by surface dozing (Frouz et al., 2018; Prach and Hobbs, 2008; Tropek et al., 2010). The dozing precedes the subsequent supply of nutrients by covering the spoil surface with a layer of fertile topsoil or various fertilizers, which is considered as the main factor responsible for the sites' ruderalisation and the consequent decrease of their conservation potential (Prach and Hobbs, 2008; Tropek and Konvicka, 2011). Nevertheless, surface flattening is known to suppress the heterogeneity of various environmental conditions, to homogenize the habitats, and to cause a higher substrate compaction (Frouz et al., 2018). Moreover, this practice supports a dominance of competitive species such as an expansive grass *Calamagrostis epigejos* in central Europe (Frouz et al., 2018). The dozing can thus be expected to substantially affect the sites' biodiversity. Nevertheless, to the best of our knowledge, no study on the impact of dozing on biodiversity and the conservation potential of terrestrial arthropods in restored post-mining sites exists.

We present the first study focused on the effects of the microtopographic heterogeneity suppression during the spontaneous restoration of a large brown-coal spoil heap on its arthropod conservation potential. We compare the biodiversity of several terrestrial arthropod groups formed in plots with dozed surfaces with the micro-topographic heterogeneous wavy surfaces created during the heaping. Due to the high homogeneity of the spoil heap substrate, and via pairing the neighbouring plots of the same origin and age in our sampling design, we were able to minimize the influence of other factors and thus focus on the surface heterogeneity. As surface flattening is the initial and most important step of the common restoration approach of technical reclamation, it will help us to understand the mechanisms by which this restoration practice influences the biodiversity of restored post-mining sites. Moreover, understanding the impact of micro-topographic heterogeneity will be useful for the efficient restoration of these human-made sites to support the biodiversity of industrial regions. We hypothesize that the suppressing of micro-topographic heterogeneity by dozing is one of the factors responsible for the already-described impoverishment of terrestrial arthropod communities by technical reclamation, even without subsequent provision of nutrients by the addition of a fertile topsoil.

2. Material and methods

2.1. Study site

The study was carried out at the Velká Podkrušnohorská spoil heap, deposited during open-cast brown coal mining in the Sokolov district, western Czech Republic (50°14′N, 12°40′E; 19.6 km^2; 500–550 m a.s.l.; mean annual precipitation 650 mm; mean annual temperature 6.8 °C; Frouz et al., 2011). The heaped spoil consisted of tertiary clays of the high chemical and structural homogeneity (Rojík, 2004).

2.2. Data sampling

For our study, we targeted four pairs of plots (from now on each pair is called a “site”) with wavy and flattened surfaces. The heaping technology created the spoil heap surface in the form of 1 m high waves ca 6 m distance from each other (Frouz et al., 2018, 2011). However, during the heap reclamation, the heterogeneous surface was flattened by dozing with no subsequent addition of topsoil or other fertile substrates. After the reclamation of most parts of the heap, only six relatively small patches (ca 5% of the spoil heap area) were left with the heterogeneous wavy surface (e.g. Fig. 1). The plots within each site were as close as possible (~250 m distance between the paired plots at each site), while the sites were roughly 1 km from each other. All the sites were selected within the spoil heap parts established 5–18 years before our sampling since the early successional stages are reported as the most important for many threatened arthropods in post-mining sites (e.g. Tropek et al., 2013a; Řehounková et al., 2016). Plots in this selected age range also have the highest heterogeneity among particular microhabitats within various environmental parameters (Frouz et al., 2018, 2008), thus making them ideal for the micro-heterogeneity studies. At each of the four sites, we established a pair of one wavy and one flattened plot (each plot ca 1 ha). Within each pair, the plots of the different surface heterogeneity were selected to be of roughly the same age (within the same parts of the heap, the wavy surfaces are 2–3 years older as that is the time needed before dozing), and with as similar environmental conditions as possible. Except the surface dozing, no other restoration effort was performed at any of the studied plots and their vegetation and habitats thus developed spontaneously.

Within each plot, two parallel lines of 5 pitfall traps (i.e. 10 pitfall traps per plot; diameter 9 cm, depth 15 cm; containing 30% ethylene glycol; 1 m between each two neighbouring traps, and ca 50 m between the lines) were exposed from May to September 2014, and emptied seven times fortnightly during the study period. We fixed all the captured material by 80% ethanol for later identification.

In the time of the pitfall traps being exposed and subsequently emptied (i.e., 8 times altogether), two portable light traps (made by Hutur NGO, Hradec Kralove, Czech Republic, with 48 LED lights