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Research article

Rough wave-like heaped overburden promotes establishment of woody vegetation while leveling promotes grasses during unassisted post mining site development

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ABSTRACT

Geodiversity plays an important role in species establishment during spontaneous succession. At post-mining sites in the Czech Republic in 2003, we established plots in which the surface of the heaped overburden was either kept wave-like or leveled. Based on surveys conducted from 2006 to 2015, leveled plots were increasingly dominated by grasses and herbs (and especially by the grass *Calamagrostis epigejos*) while the wave-like plots were increasingly dominated by the trees *Salix caprea* and *Betula pendula*.

In 2015, a detailed survey was conducted of the dominant species. Both *S. caprea* and *B. pendula* occurred more often in wave-like plots than in leveled plots; this was particularly true for trees taller than 1 m, which were absent in leveled plots. In wave-like plots, leaf and root biomasses of both woody species were higher on the wave slopes than on the wave depressions. Nitrogen content was higher but content stress indicating proline in leaves of *S. caprea* was lower in wave-like plots than in leveled plots. In wave-like plots, both woody species occurred mainly on wave slopes but *C. epigejos* occurred mainly in the depressions. We speculate that trees were more abundant in wave-like plots than in leveled plots because the waves trapped tree seeds and snow and because the soil porosity was greater in wave-like than in leveled plots. Grasses may have preferred the leveled plots because soil porosity was lower and clay content was higher in leveled than in wave-like plots.

1. Introduction

In areas where mining is conducted, original ecosystems are excavated or buried under a layer of overburden, deposited on the soil surface (Bradshaw, 1997). Overburden properties often differ substantially from those of well-developed soils, and recovery of soil and vegetation is the basic pre-condition for the recovery of a functional ecosystem (Bradshaw, 1997). Several studies have demonstrated that spontaneous processes can lead to ecosystem recovery of industrial and post-mining sites where overburden has been deposited on the surface, especially when the substrate or climatic conditions do not limit plant growth (Frouz et al., 2008; Prach and Hobbs, 2008; Tropek et al., 2010; Alday et al., 2012; Baasch et al., 2012; Prach et al., 2014). On the other hand, numerous studies show that the poor tree establishment in post mining sites occurring even with detailed soil separation and respreads (Simmons et al., 2008; Skousen et al., 2009; Zipper et al.,

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2011). Older post-mining sites that have experienced spontaneous succession are in some cases similar to technically reclaimed sites in terms of many ecosystem properties such as biomass production, soil development, and soil water-holding capacity (Cejpek et al., 2013; Frouz, 2013). Young successional sites, on the other hand, support substantial biodiversity due to their geodiversity (Prach et al., 2001; Tukiainen et al., 2017). Despite this, spontaneous succession has only rarely been used as a tool in ecosystem recovery mainly because of its low predictability. Successional processes might be predictable on a broad scale (Baasch et al., 2012; Foster and Tilman, 2000), but this scale is usually larger than is needed for restoration planning (Mudrák et al., 2016a). Several studies suggest that site heterogeneity may greatly affect the establishment of individual plant species and consequently the successional trajectory (Frouz et al., 2011a; Nichols et al., 2008). The wave-like pattern generated by the heaping of overburden is common to many post-mining sites around the world, and especially to sites that previously experienced open-cast mining (Frouz, 2013). Anecdotal observation suggests that rather than developing into forests, post-mining sites that are leveled support a dense cover of grass (Frouz, 2013) (Supplementary S1). In Sokolov *Calamagrostis epigejos*, is a grass dominating in levelled sites, which suppresses succession for many years (Frouz, 2013). This is consistent with observations that site leveling promotes grasses and suppresses trees in post-mining sites in the eastern USA (Ashby, 1998; Franklin et al., 2012; Gilland and McCarthy, 2014; Zeleznik and Skousen, 1996).

Understanding factors that affect the grass-tree interactions may be useful for understanding key ecosystem processes in many other sites. The grass-tree interaction is often explained by water availability (Zhang et al., 2001); soil conditions receive less attention, although has been shown that grasses prefer finer textured soils and that trees preferred coarser textured soils (Fernandez-Illescas et al., 2001).

In this study, we conducted a field experiment to test the hypothesis that leveling and compaction promotes grasses and suppresses trees. We also tested the hypothesis that trees show better performance (establish and grow better and suffer less stress) in sites with an ungraded wave-like surface than in sites with a leveled surface because sites with a wave-like surface have a coarse soil structure that promotes macroporosity and specific habitats that promote seed trapping and tree seedling establishment. As the performance of plants in certain habitat may be manifested by number of individuals, body size and morphology and ecophysiological parameters, we include all these levels of performance. Beside density we also compared growth of both tree and grasses in individual microhabitat using growth analysis, chlorophyll, nitrogen and proline content which are correlated with well-being (chlorophyll or nitrogen) or stress to plants (proline). We also explored haw the species performance corresponds with habitat characteristics, as the experimental sites were created with the same material with the same chemistry we focus mainly on soil physical properties.

2. Materials and methods

2.1. Study sites

The study was conducted on the Podkrušnohorská heap in the Sokolov brown coal-mining area, which is located in the western Czech Republic (Frouz et al., 2008) (Supplementary S1 & S2). The mean annual precipitation and temperature are 650 mm and 6.5°C, elevation 590 m a.s.l. (Frouz et al., 2008). The heap was created by the deposition of overburden from the late 1960s to 2003. The heap consists mainly of alkaline tertiary clays (Frouz et al., 2011b). During the heaping process, overburden was deposited in a parallel series of "waves"; the waves are about 1 m high and several meters apart. During reclamation, these waves are leveled with several passes of caterpillar bulldozer.

In the central part of the heap (50.2379717N, 12.6593433E) in 2003, we created (with mining company assistance) three pairs of plots, each pair consisting of a plot with a wave-like surface and a neighboring plot in which the surface was leveled immediately after dumping (Supplementary S2). The three wave-like plots had areas of 0.7, 0.5, and 0.5 ha, and each leveled plot had the same area as its neighboring wave-like plot. In the wave-like plots, the parallel series of "waves" had a south–north orientation and were about 3 m apart and about 1 m high (Fig. 1, left). As was the case in the other parts of the heap, the dumped material consisted of freshly excavated overburden which have appearance of "mudstones", i.e., rectangular blocks with sides that were 30–50 cm long. The voids between the blocks were in size from few mm to few cm (Supplementary S3). Leveling (Fig. 1, right) broke the mudstone blocks into smaller pieces (with sides that were 15–20 cm long); the voids between these blocks were smaller than those in the wave-like plots and ranged from a few mm to a few cm. Within 2 years, the mudstones in the wave-like plots broke into smaller pieces, and the large voids (those visible with the unaided eye) disappeared. In addition to mudstones, excavated overburden in both kinds of plots contain blocks of carbonate rock mainly containing calcite and siderite. These calcite-siderite concretions were scattered in the material and were about 30 × 30 cm with a width of 5–10 cm. Initially these concretions are embedded in mudstones over time they liberate due to weathering of surrounding clay matrix. The calcite-siderite blocks either remained intact or broke into several smaller pieces, which remained hard and are referred to as stones (Fig. 1) (Supplementary S3). There is no indication that levelling would change material chemistry (Supplementary S4).

2.2. Vegetation survey

In 2003, when vegetation first appeared in the plots, on each of the three paired plots were established three quadrates on each wave like and three on each leveled plot, nine per all treatment replicates, 18 in total. Each quadrat had 3 m × 3 m. In these quadrates, the percentages of cover of vascular plant species were visually estimated at the peak of their biomass production (first half of August) in each year from 2006 to 2015, this was done separately for herbaceous layer as well as for shrubs and tree canopy. In addition, the percentages of cover of the dominant plant species were visually estimated (Kent and Coker, 1992) in the first half of August 2015 in a total of 60 additional 3- x 3-m quadrates that were randomly distributed among all six plots 30 on leveled and 30 on wave like plots (ten per each treatment replicate).

To determine the number of trees, in 2015 we established four 25- x 25-m quadrates in the leveled plots and four in the wave-like plots (two quadrates in each of the larger pair of plots and one in the others). In these plots, all woody individuals including seedlings were counted, identified to species, and measured for height.

2.3. Microhabitat preference and growth of dominant species

In 2015, a survey was conducted to determine the microhabitat preference of the dominant woody species (*Betula pendula* and *Salix caprea*) and the dominant grass (*Calamgrostis epigejos*) in the wave-like plots. One east-west transect about 50 m long was established in each of the wave-like plots. The following microhabitats were designated: wave bottom (depression between waves), east slope of the wave, top of the wave, and west slope of the wave. The percentages of cover of the dominant species in each microhabitat