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Research Paper

An investigation into the long-term effect of soil transplant in bare spoil heaps on survival and migration of soil meso and macrofauna

Jabbar Moradi[a,*], Fabio Vicentini[a], Hana Šimáčková[a], Václav Pižl[b], Karel Tajovský[b], Josef Stary[b], Jan Frouz[a,b,c]

[a] *Institute for Environmental Studies, Faculty of Science, Charles University, Benátská 2, 12801 Prague 2, Czechia*
[b] *Biology Centre, Na Sácdkách 7, 37005, České Budějovice, Czechia*
[c] *Environment Center, Charles University, José Martího 407/2, 162 00 Prague 6, Czechia*

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ABSTRACT

To study the effect(s) of soil transplantation on survival and colonization of post-mining spoil heaps by soil fauna, we transplanted blocks of topsoil (3 × 10 × 0.4 m) from a well-developed meadow into the bare post-mining heap in Sokolov coal mining region (Czechia) in 1995. The soil meso and macrofauna were studied in two periods, namely 1995–1997 (initial period) and 20 years later in 2015–16 (follow-up period). We sampled transplanted blocks (Transported), overburden at a 2-m distance from the blocks (Adjacent), and overburden at a 30-m distance from the blocks (Control). The number of mites was highest in the Transported, in the initial period, and at the Control 20 years after- i.e. in the follow-up period. Judging by their higher densities, for Lumbricidae, and most of the miscellaneous macrofauna, Transported was favored in both time periods. The high macroarthropod densities in the Transported position, even after 20 years, and the low microarthropod densities in the Adjacent position together suggest a limited role of transplanted soil blocks in the colonization of the spoil overburden, signifying that soil development of the spoil overburden might be even more critical than the migration barrier.

1. Introduction

Mining activities have had one of the most substantial impacts on the land surface since the last glacial period (Wiegleb and Felinks, 2001). Extensive open-cast mining operations, among others, have created extreme conditions for invertebrates while completely removing previous biological communities (Curry and Good, 1992; Bröring et al., 2005). Lack of suitable food, adverse physicochemical conditions, unfavorable moisture condition, and surface temperature fluctuations (Curry and Good, 1992) are some of the harsh conditions found in such environments. Nevertheless, even on such surfaces, primary succession occurs (Brändle et al., 2003; Bröring et al., 2005; Doblas-Miranda et al., 2008) accompanied by a gradual development of soil fauna communities (Frouz et al., 2008).

Faunal dispersal and local environmental factors are important in the soil community assembly (Bröring and Wiegleb, 2005; Caruso et al., 2012). Colonization, especially for the soil arthropods, is the crucial step in the assembly of soil communities within the spontaneous successions (Brändle et al., 2003) as well as within the restorations (Meloni and Varanda, 2015) and is a long-term process (Bröring and Wiegleb, 2005; Skubała,2004). Colonization is affected by distance from the source, the vegetation architecture and the plant species composition of the sites as well as the abiotic environmental factors (Bröring and Wiegleb, 2005). Those factors also affect the establishment of soil fauna during succession, which is also affected by other factors such as soil development or various biotic interactions (Holec and Frouz, 2006; Roubíčková and Frouz, 2014).

Some scientists suggested introducing mature topsoil transplantation to facilitate the colonization of the disturbed surfaces, as well as the colonization of the fragmented landscapes for which distance could be a significant barrier to colonization (Curry and Good, 1992; Brady et al., 2002; Grimbacher and Catterall, 2007). Nevertheless, in general, only a few studies have documented the invertebrate inoculation (Brady et al., 2002). Moreover, such efforts have been limited to a small number of taxa (Bengtsson, 2011) on small spatiotemporal scales. Much less effort has been used for the re-establishment of whole fauna assemblages (Nakamura et al., 2008) in long-term and large-scale trials. Additionally, there are differences between larvae and adult life stages of some orders, e.g., coleopteran and dipteran, as each life stage could be active in a different part of the soil system (e.g., Frouz, 1999;

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[*] Corresponding author.
E-mail addresses: rojyar.moradi@gmail.com, moradij@natur.cuni.cz (J. Moradi).

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Coleman et al., 2004).

In this study, to explore the influence of inoculation on whole soil arthropod communities, a set of soil blocks, freshly taken from an undisturbed area, were transported to a newly exposed spoil surface. We carried out field scale soil transplant which was monitored for the first three years after the establishment, i.e., “initial period” 1995–1997, and again 20 years after the establishment of the set-up, i.e., “follow-up period” 2015–2016. We expected that the transplanted soil would be a refugium for soil fauna for these periods, and would be crucial to supporting the migration of earthworms and other non-flying invertebrates, namely macroarthropods, in the adjacent soil. Regarding the mesofauna, however, we anticipated that, after 20 years, passive migration in microarthropods (Wanner and Dunger, 2002; Dunger and Voigtländer, 2009) would override any influence that the inoculation sources might have had. We also expected epedaphic springtails to have been dominating on the spoil surface since they are less sensitive as compared to eudaphic and hemiedaphic springtails.

2. Materials and methods

2.1. Study sites

The spoil heaps in the study area were deposited during open-cast coal mining in the western part of the Czech Republic (50.2373572N, 12.6938247E). These post-mining sites were at an altitude of 550 m a.s.l., with a mean annual precipitation of 650 mm, and a mean annual temperature of 6.8 °C. The substrate consisted of tertiary clays (Frouz et al., 2001). The study was carried out on freshly exposed spoil heaps which were denudated due to a landslide in 1994. One year after the landslide (April 1995) six blocks of a developed topsoil, i.e., turf and soil, taken from a meadow located in the forefield of the mine, were used to create rectangular blocks of ca 30 m^2 ($3 \times 10 \times 0.4$ m) and at 10 m distance from each other (three rows and two columns). Blocks were carefully extracted by an excavator and dumped in the new place. Discharging the material from the truck bed was done by slowly forwarding the dump truck while having raised the bed, attempting to keep the original shape and orientation as much as possible. If needed, the blocks' shape was adjusted manually to resemble original shape (Fig. S1). The transported soils deposited in the eastern half of the area with the first two blocks, close to the middle line, were at a 40-m distance from the western edge of the area, and 30 m from the location considered for the control samples (Fig. S2). Almost from the beginning, the dominant component of the plant community established at the study area was *Calamagrostis epigejos*. *C. epigeos*, in Central Europe, is considered one of the most frequent plant species in post-mining landscapes, a competitive grass, and highly resistant to woody species invasion (Wiegleb and Felinks, 2001; Jongepierová et al., 2012). Only a few shrubs grew on the transported soils. The area is surrounded by plantations of evergreen trees, namely pine and spruce; however, the access road from the northern side (6 m wide) is in between the northern plantation and the study area.

2.2. Sampling and processing

Right after the site set-up completion, the sampling campaigns were conducted for three consecutive years, 1995, 1996, and 1997, and were focused on Diplopoda and Oribatidae community composition. Regarding the Lumbricidae (1996 and 1997) and Diptera (1995 and 1996) communities, there were two sampling campaigns each year, in May and September.

Three macrofauna or mesofauna samples were taken from 0 to 5 cm depth, including organic layer. The samples were taken from each block of transplanted soil (18 samples), and in the adjacent overburdens, 1–2 m from the transplanted soil (18 samples). Also, six samples were taken in the control overburden, 30 m from the transplanted soil. Macrofauna and mesofauna samples had a surface area of 625 cm^2 and 10 cm^2, respectively. The faunal communities were extracted from the samples using Tullgren apparatus.

We followed the same sampling design of the initial period in 2015 and 2016. However, in the follow-up period, we focused on more groups of soil meso and macrofauna, in addition to those studied in the initial period. Also, samples for soil chemical analysis were taken in 2016. Six composite samples of soil, 0–5 cm below the litter layer (200 g each), were taken from Transported blocks, Adjacents, and Controls, in 2016. Each composite sample consisted of two subsamples. The samples were transported to the laboratory, homogenized, air dried, and passed through a 2-mm screen for chemical analysis. Part of each sample, before air-drying, was immediately processed for microbial biomass and microbial respiration measurements.

A 1:5 soil:water extract was used for pH determination with a glass electrode and determination of electrical conductivity (EC) with a conductivity meter. Carbon (C) and nitrogen (N) were measured using Elemental Analyser 1108, Carbo Erba (Italy).

We measured microbial biomass using the chloroform fumigation and extraction method (Vance et al., 1987), and microbial respiration based on the CO_2 produced, which was trapped with NaOH in an airtight vial (for two days at 20 °C) and subsequent titration of NaOH by HCl after adding $BaCl_2$.

After extracting the mesofauna and macrofauna from soil samples with a Tullgren apparatus, for one week, we identified mesofauna by their external morphology. Springtails were divided into three functional groups of euedaphics, hemiedaphics, and epedahics, and mites into Oribatidae and other mites. The macrofauna were identified as ‘families’, “orders” or classes (“Coleopteran” and “Dipteran” to families and other “Miscellaneous” fauna to orders and classes) based on their external morphology and counted. Numbers of macrofauna and mesofauna were expressed per m^2. Regarding the macrofauna, we recorded the larvae and adults separately as they can differ in terms of their ecology.

2.3. Data analysis

We determined the associations between dependent variables, sampling year and position (namely Transported, Adjacent, or Control) with two-way ANOVAs using STATISTICA 10 (StatSoft, 2011). When ANOVAs were significant ($P < 0.05$), the means were compared with the Tukey post-hoc test.

To compare the patterns between initial period and follow-up period, we extracted the relevant mean values from the archived data which were the only available values as some gross values were not separated in 1995–1997. When comparing the means with those of the recent years, we only compared initial period and follow-up period mean values of a given position on the site together via paired *t*-test. Hence, it can be considered only as a temporal comparison for a given position, on the studied landscape, to detect the differences.

3. Results

3.1. Soil chemical properties

Among soil chemical properties (Table 1), the C content, C:N ratio, pH and electrical conductivity (EC) significantly differed between Transported and the other two positions. In the case of C and pH, spoil material at the Adjacent and the Control differed significantly. C content was highest in the Control, intermediate in Adjacent, and lowest in the Transported. The same pattern was evident for the C:N ratio. Measured values for pH showed a neutral range for the Transported; however, it was more basic for the Adjacent and the Control; all three positions were significantly different with Transported having the lowest and Adjacent having the highest pH. Electric conductivity was lowest in the Transported compared with the other two positions.

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