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Short Communication

How Reclamation Type and Age Influence the Abundance of Earthworms in Anthropogenic Soils

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Abstract

In this study we determined the effects of reclamation type and age on earthworm communities. We focused on forestry and agricultural reclaimed territories in northwest Czech Republic that were recently affected by opencast brown coal mining. We were interested in both the numbers and the biomass of obtained earthworms. The results showed that there was a significant difference between numbers of earthworms in the statistical model with spoil bank age and reclamation type interaction and those in non-interaction statistical models. With regards to the rapid development of earthworm communities, forestry reclamation is more suitable for earthworm communities than agricultural reclamation. However, we can assume that differences between methods of reclamation on the oldest spoils are becoming less evident, and the numbers of individuals become comparable.

Keywords: earthworms, biodiversity, anthropogenic land, reclamation, coal mining

Introduction

Biodiversity is currently understood as the most important natural resource, and biodiversity issues (including nature conservation and environmental quality) are growingly perceived as some of the most critical human global problems [1]. In terrestrial ecosystems one of the key factors that determines biodiversity is soil and its characteristics. Soil has, in addition to abiotic components, live elements that create the soil environment [2]. Soil organisms mix humus with mineral soil and provide soil fertility by enhancing macroporosity, humidification, and mineralization of organic matter [3]. The regulation of soil physical properties and chemical processes is of significant importance [4, 5]. Invertebrates living in soil have often been considered indicators for soil condition investigation due to their ecological demands [6, 7]; earthworms (Lumbricidae) are among the invertebrates used most often [8, 9]. Their popularity as indicator organisms is based on their close connection to the land, limited locomotion, ease of determination and sensitivity to the chemical and physical characteristics of the soil environment [10-12]. Earthworms also affect soil microfauna [13] and other soil organisms [14, 15]. The biomass and population of earthworms in a certain area can determine soil suitability for almost all soil organisms [16].

Man-made soils form a completely new environment that poses a challenge for earthworms. These anthropo-soils ordinarily occur mainly as spoil banks in mining areas.

These new biotopes often provide refuges in anthropogenically impacted landscapes [17]. Spoil banks may be left to spontaneous succession, which is often better in terms of conservation [18], but in most cases reclamation of the affected area is performed due to prevailing economic

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interests. There are various methods of reclamation [19, 20]. The most common reclamation methods in the Czech Republic are forestry and agricultural reclamation [21].

Because the reclamation approach selection crucially affects subsequent area development [17], our aim was to evaluate the influence of the two most common Czech reclamation types (forestry, agricultural) on earthworm abundance and biomass during succession.

Experimental Procedures

The research was carried out throughout 2011 and 2012. Due to the seasonality of select model organisms, sampling took place from April to June in both years. For research purposes, 11 spoil banks in a climatic region of northwestern Bohemia were selected. These spoil banks differ in age (0-15, 15-30, 30 < years) and reclamation type. We chose spoil banks reclaimed by forest – deciduous trees with a dominance of alder (*Alnus glutinosa* L.) with the addition of aspens (*Populus tremula* L.); we choose meadows (permanent grasslands) as agricultural reclamation. Three stands were randomly selected on each spoil bank for soil fauna investigation, and in each stand two square subplots (0.5 m^2) with a distance of 5-10 meters between them were established for earthworm sampling.

Earthworms are found in three different soil layers. For this reason, we used a combination of behavioral and direct methods. The behavioral method involves extraction using a mustard powder diluted in water to "wash out" the earthworms from the soil. Hand sorting of the litter layer and soil monolith (31.7 × 31.7 cm to a depth of 30 cm) was used as a direct sampling method.

The extraction was carried out according to Gunn [22], and Lawrence and Bowers [23], and it consisted of four subsequent applications of 10 liters of mustard emulsion. The first two applications used low concentrations of the expellant; the following two applications used high concentrations. After extraction a square soil sample (31.7 × 31.7 cm to a depth of 30 cm) was taken from the centre of each subplot for hand sorting. Hand sorting was undertaken in a laboratory under uniform light conditions. All collected earthworms were initially conserved in ethanol (70%) and later in formalin (5%). The earthworms from each square subplot were collected and kept in labeled pots. Collected individuals in each sample were counted and weighed with an accuracy of 0.01 g.

To evaluate changes in succession of earthworm communities, two variables were used: biomass and abundance of earthworms. These two variables were mutually correlated ($r = 0.89$, $P < 0.01$), so we decided to use the abundance of earthworms (Poisson distribution) as our main dependent variable. According to the methods of Pekár and Brabec [24], we used data from all 66 square plots, i.e., data from the square subplots were not independent of each other. For this reason we used Generalized Linear Mixed Models (GLMM) and created a new variable assigned as "group," which included data from both square subplots from each of the 33 stands. This variable was used as a factor with a random effect; spoil bank age and reclamation type were used as factors with fixed effects. During the model simplification process, particular models were compared using chi-square tests. The threshold for statistical significance was set at $\alpha = 0.05$. Finally, a minimal adequate model was examined using Cook´s distance [25]. All tests were computed using R statistical software ver. 2.10.1 [26].

Results

During the study 914 earthworms were collected from 11 spoil banks (Table 1). The mean number of earthworms per one square subplot was 13.9±16.3 (SD), ranging from 0 to 72. The average earthworm biomass was 4.43 g±6.84 (SD), ranging from 0.00 to 42.54 g.

In terms of numbers of earthworms, from all base models taken in consideration (reclamation, age of spoil bank, reclamation × age of spoil bank) the best explanatory model was the model with spoil bank age and reclamation type in interaction (GLMM: $\chi^2 = 9.81$, df=3, $P < 0.05$) (Fig. 1). The utilized model is more effective than that which has reclamation type and spoil bank age as its independent variables (GLMM: $\chi^2 = 9.00$, df = 2, $P < 0.01$); it is also more effective than the simplest model, which implements none of these factors (GLMM: $\chi^2 = 10.46$, df = 5, $P < 0.05$).

The control test for the factor group shows that the number of collected earthworms was in no way connected to the type of reclamation and spoil bank age, i.e., differences between square subplots of each stand were insignificant during succession in both types of reclamation (GLMM: $\chi^2 = 6.85$, df = 20, $P = 0.97$).

Discussion of Results

Recent studies have dealt with reclamation of affected areas such as dumps, heaps and/or spoil banks. Conservationists often suggest natural succession without

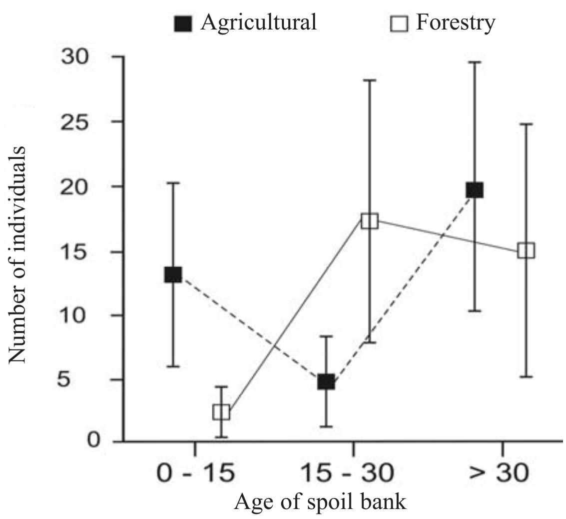

Fig. 1. Relationship between number of earthworms, reclamation method (agricultural, forestry) and spoil bank age (squares represent means, whiskers represent standard deviations).

Table 1. Summary of obtained values of earthworm abundance in spoil heaps under agricultural (A) and forestry (F) reclamation.

Spoil heap name	Reclamation	Abundance (individuals)				
		mean	min	max	SD	Total
Albrechticka	F	27.25	4	72	27.56	109
Albrechticka	A	5	1	9	4	10
Hornojiretinska	F	12.67	3	26	8.52	76
Kopisty	F	21	6	46	13.52	126
Ledvicka	F	2.67	0	8	3.77	16
Pokrok	A	9.5	0	40	14.3	57
Radovesicka	A	21.17	7	41	10.73	127
Ruzodolska	A	10.83	0	31	12.68	65
Strimicka	A	5.33	0	19	6.47	32
Vaclav	F	18.33	0	68	25.62	110
Velebudicka	F	17	0	42	17.56	68
Velebudicka	A	34.5	31	38	3.5	69
Vrbensky	F	8.17	1	20	6.49	49

significant human intervention through reclamation [17]. This is one of the best methods in terms of, among other things, spontaneous soil fauna population development [18].

We studied communities of earthworms in forested areas versus those in agriculturally reclaimed spoil banks with various succession stages. The research study was carried out in former opencast brown coal mining localities in northwest Bohemia, Czech Republic. Based on statistical evaluation of the selected model, interaction between spoil bank age and reclamation type (forestry, agricultural) has a significant effect on earthworm abundance. We postulate a similar effect for earthworm biomass, because biomass and abundance were significantly correlated.

Soil organic biomass (humus layer) is an essential factor for soil fauna vitality [16]. Vegetation plays an important role through the production of biomass, and soil fauna development is closely linked to organic content [27]. This is obvious especially in post-mining sites [27, 28], where decreased litter input has reduced the development of soil biota in sites reclaimed by coniferous forests [29].

This is also apparent from the results of our study, wherein a great increase in the numbers of individuals on forested spoil banks 15 to 30 years after reclamation is visible; there is an opposite trend in agricultural reclamation. In forestry reclamation, earthworm density increases with forest development, and after 30 years the abundance in communities slowly decreases. Pižl [30] reported similar findings at five heap sites representing a chronosequence (3-62 years). Dunger et al. [31] published a comprehensive long-term study (46 years) of soil fauna at forestry reclaimed dumps; it was verified that the rate of colonization is much faster in deciduous forests than it is in other forest types.

The agriculturally reclaimed spoils stay more exposed and prone to erosion, and the soil organic matter content is low (unreplenished from tree or shrub layer) in the primary development stages [30]. There is apparent growth in a number of pioneer species of earthworms in the early successional stages of agricultural reclamation, but due to a lack of organic matter content, abundance slowly decreases during the first two decades. During development on older sites (more than 20 years), the amount of organic matter increases, which in turn increases the number of specimens.

Analogously to our data, Voženílková [32], and Grgić and Kos [33] noted that the number of epigeic fauna of centipedes in the first successional stage is low in afforested spoil heaps. According to Pižl [34], species of endogeic earthworms, which are the largest group among earthworm communities, appeared in afforested sites long after planting. However, changes in agricultural reclaimed spoil heaps are more dynamic and less predictable (Fig. 1). This is most likely influenced by other unobserved factors.

Conclusion

The most common methods of reclamation in the Czech Republic are still forestry and agriculture. With regards to the rapid development of earthworm communities, forestry reclamation is more suitable than agricultural reclamation. However, we can assume that significant differences between these two methods of reclamation on the oldest spoils are becoming less evident, and the numbers of individuals in both methods are becoming comparable.

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