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Differentiation of herb layer vascular flora in reclaimed areas depends on the species composition of forest stands

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ABSTRACT

Spoil heaps, resulting from open-pit mining, are deprived of soil cover. A common method of reclamation for such sites is afforestation aimed at creating whole forest ecosystems. Forest stands planted on soilless areas make it possible to determine the effects of different tree taxa on the species composition of flora. The study focused on the vascular species of herb layers in young forest stands formed by *Alnus glutinosa*, *Betula pendula*, *Pinus sylvestris*, *Quercus petraea* and *Robinia pseudoacacia*, and mixed stands dominated by *Acer pseudoplatanus* or *Betula pendula*. The study included 227 randomly selected plots across the afforested Bełchatów Brown Coal Mine spoil heap. Species composition of the herb layer was composed mainly of synanthropic species (over 70%), and was clearly related to the overstory tree species composition of forest stands. TWINSPAN divided sample plots into two groups that developed under the canopy of stands formed by: (1) *Betula pendula*, *Pinus sylvestris* or *Quercus petraea*, or mixed stands with *Betula pendula*, or (2) *Alnus glutinosa* or *Robinia pseudoacacia*, or mixed stands dominated by *Acer pseudoplatanus*. The first group was dominated by meadow species (25.8%), while the second had higher richness of ruderal (18.6%) and forest-edge species (14.1%). Plant species associated with fertile and moist forest habitats were more frequent in the second group (*Alnus-Robinia*), whereas species of acidic and dry forests occurred only in the first group (*Betula-Pinus*). Non-parametric tests on Ellenberg's indicator values showed that forest stands of *Betula-Pinus* group created habitat conditions for light-demanding species with low fertility requirements, whereas forest stands of *Alnus-Robinia* group created habitat conditions for nitrophilous and shade-tolerant plant species. Our data revealed that tree species composition of forest stands is a key factor shaping herb layer conditions and – as a consequence – herb layer species composition despite of initial habitat variability on the spoil heap. These results highlight a key role of forest stand composition in the development of herb layer richness on post-industrial habitats.

1. Introduction

In the second half of the 20th century, a dominant method of open cast mine reclamation was afforestation of post-mining areas, preceded by technical and biological reclamation treatments (Prach, 2013). Such areas provide opportunities for observation of initial ecological processes in soil-free areas and give us a chance to enhance our knowledge of ecosystem restoration (Hendrychová, 2008; Horodecki and Jagodziński, 2017; Kałucka and Jagodziński 2016; Prach, 2013). Also, dozens of published studies have described the flora of human disturbed sites (Jagodziński et al., 2015, 2018; Rahmonov et al., 2013; Siciński and Sieradzki, 2009; Woch et al., 2013). These researchers showed the dominance of ruderal species in plant communities of post-industrial areas, a higher contribution of Fabaceae species, compared to the surrounding landscape, and the presence of many rare species, especially associated with poor soils. Some studies investigated spontaneous successional changes in post-industrial vegetation (Frouz et al., 2008; Kompała-Bąba and Bąba, 2013; Moreno-de las Heras et al., 2008; Prach et al., 2014). Results of these studies indicated that the rate and direction of succession depended on soil fertility and habitat moisture, as well as on climatic factors, a pool of available species and the degree of transformation of a given area.

Many investigations have shown that the majority of post-industrial areas might be successfully vegetated with woody plants through natural succession. Better results of natural succession as compared to planting, such as, among others, higher species diversity and overgrowth rate of vegetation, as well as lower costs, argue for using spontaneous succession in the reforestation of post-mining areas (Bradshaw 1997, 2000; Doležalová et al., 2012; Jochimsen, 1996; Pensa et al., 2004; Prach et al., 2011, 2013; Prach and Hobbs, 2008;

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Šnajdr et al., 2013). Hodačová and Prach (2003) have shown that reclamation treatments, such as thickening and fertilizing the soil, contributed to the expansion of *Calamagrostis epigejos* – an inhibitor of woody plant succession. However, relying only on natural succession in the reclamation process has some limitations. These limitations may result from the lack of diaspores and developed soil structure or from substrate toxicity (Bradshaw, 1983, 1997, 2000).

Recent studies of forest and post-industrial areas indicate a habitat-forming role of forest stands (Dunger and Voigtländer 2009; Frouz et al., 2001, 2008, 2013; Hendrychová et al., 2012; Hobbie et al., 2006; Kałucka and Jagodziński, 2016; Mudrák et al., 2010; Reich et al., 2005). Thus far, this role was not taken into account in reclamation planning. Studies conducted in forests (Augusto et al., 2002, 2003; Hobbie et al., 2006; Reich et al., 2005) or in arboreta (Jagodziński et al., 2011; Kasprowicz et al., 2011; Skorupski et al., 2011, 2012; Wojterska et al., 2012) showed that different tree species growing in homogeneous habitats gave rise to diverse phyto-, zoo- and mycocoenoses. Mudrák et al. (2010) and Pensa et al. (2004, 2008) showed some differences in herb layer composition under different forest stands in artificially regenerated post-mining areas.

Light regime, soil moisture and nutrient availability are the main factors modified by different tree taxa. Additionally, physical effects of litter and phytotoxic compounds of trees significantly affect herb layer vegetation (Barbier et al., 2008). N-fixing trees stimulate forest ecosystem restoration much more than non-N-fixing trees. N accumulation enhances soil organic matter input, nutrient cycling and colonization by native forest species in comparison to non-N-fixing trees (Chaer et al., 2011; Horodecki and Jagodziński, 2017). Parrotta (1995) indicated that moderately closed canopies suppress grass growth while favoring germination of early- and mid-successional forest species. Furthermore, rapid decomposition of nutrient rich litter causes improvements in seedling establishment.

Investigations of pure and mixed stands of soilless post-industrial areas provoke questions about the significance of tree species as promoters of the processes of forest ecosystem succession. Human activities in forest restoration are mainly limited to tree stand management; other ecosystem components undergo spontaneous processes of dispersion and competition.

The aim of the study was to assess the impact of forest stands on the herb layer vascular plant flora of a reclaimed lignite mine spoil heap. We hypothesized that forest stand composition has played the most significant role in herb layer biodiversity. We tested this hypothesis on over 200 randomized sample plots, which allow us to take into account topographic variants and detect even weak ecological relationships.

2. Material and methods

2.1. Study area

The study plots were located at Mount Kamieńsk (51°12′41.28″N, 19°25′50.83″E), which is the largest artificial overlayer spoil heap in Poland (relative height ca. 180 m, ca. 400 m a.s.l.). The external heap of the Bełchatów Brown Coal Mine was formed in the years 1977–1994, by deposition of the overburden lying above the carboniferous layer of the Bełchatów open pit mine. The overburden consisted of unselected Tertiary and Quaternary sedimentary rocks. Quaternary material was dominated by sands with some gravel and lesser quantities of silt, boulder clay and loam, while sands with some silt and loam, often carbonaceous and sulphated, were prevalent in the Tertiary material. The reclamation treatments included: NPK mineral fertilisation (N – 60, P – 70 and K – 60 kg/ha) and sowing with a grass and legume seed mixture on the whole area. Acidic ground (mainly carbonaceous Tertiary rocks) were subject to neutralization using lacustrine chalk mixed into the surface layer to a depth of 40 cm (Krzaklewski, 1990; Pietrzykowski et al., 2009).

Presently, the heap area (with a base surface of ca. 1480 ha) is almost completely occupied by forest stands introduced in the process of reclamation. These stands are mainly dominated by *Pinus sylvestris*, *Betula pendula*, *Robinia pseudoacacia* and *Alnus glutinosa*. A potential type of forest habitat is a fresh mixed coniferous forest (93% of the area) and fresh coniferous forest (7%) (Plan Urządzenia Lasu, 1997). Afforestation was conducted in stages, thus, the age of the majority of forest stands ranged from 11 to 30 years (24 years on average). In the years 1971–2010, according to the data from the nearest meteorological station (in Łódź), the average annual temperature was 8.2 °C, while the average sum of precipitation was 579 mm (Jagodziński et al., 2015; Mały Rocznik Statystyczny, 2015).

2.2. Sampling design

Field studies were conducted in research plots of octangular shape, with apices oriented to the four Cardinal Directions and four primary Inter-Cardinal Directions and 7.28 m distance from the plot center. Each plot was 150 m^2 in area. All forest stands were identified and, next, verified based on an analysis of aerial photographs, satellite images and data obtained during floristic investigations (Jagodziński et al., 2015) and collected by the Institute of Dendrology of the Polish Academy of Sciences, Kórnik, Poland (Jagodziński et al., unpublished). The studied heap was divided into the following five zones of similar area: hilltop and northern, eastern, southern and western slopes (Fig. 1). The area of study was selected based on the premises that 8 research plots were designated for each type of forest stand in each heap zone and each plot met the following criteria:

(a) homogeneity of canopy cover with a minimal cover above 40%, for mixed forest stands an even distribution of different tree species was an additional criterion of selection,
(b) homogeneity (cover and species composition) of the shrub layer,
(c) homogeneity (cover and species composition) of the herb layer.

Results obtained from the detailed field inventory showed that the above criteria were met by 605 plots situated in either single-species forest stands of *Alnus glutinosa*, *Betula pendula*, *Quercus petraea*, *Pinus sylvestris* and *Robinia pseudoacacia*, or mixed stands dominated by *Acer pseudoplatanus* or *Betula pendula*. The mixed stands contained mainly an admixture of *Alnus glutinosa* or *Robinia pseudoacacia* and, less frequently, *Quercus petraea*, *Q. robur* and *Larix decidua*. Based on the criterion that a minimum distance between the plot centers in the same type of forest stand was at least 100 m, 227 research plots were randomly selected from the available pool. Incomplete representation of forest stands in individual zones and a lower number of repetitions (Table 1) results from the lack of sufficient number of stands that met the accepted criteria. In June and July 2013 and 2014, the species composition of each plot was determined (nomenclature according to Mirek et al. (2002)) and the percentage cover of the tree and herb layers was evaluated.

2.3. Floristic analyses

The herb layer was defined as all vascular plant species (all herb species, as well as shrubs and trees up to 0.5 m tall). The species that form forest stands, i.e., *Acer pseudoplatanus*, *Alnus glutinosa*, *Betula pendula*, *Pinus sylvestris*, *Quercus petraea* and *Robinia pseudoacacia*, were excluded from analyses. The binary (0 − 1) data were used in calculations and numerical analyses. In the TWINSPAN analysis (Hill and Šmilauer, 2005), only the species with occurrence frequency ≥ 5% were included. In other analyses, the complete list of species was used. The herb layer flora of the study area was analysed in the following categories:

(a) taxonomical rank (belong to family) of species according to Rutkowski (2006),