Article

Spoil heaps in Safonovo, Smolensk region: changes in vegetation cover 20 years later

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Abstract. Biodiversity conservation is one of the most important problems facing contemporary botany. These issues are especially relevant in anthropogenic areas with disturbed or even destroyed vegetation cover. For the first time we studied overgrowth of spoil heaps near lignite mines in the town of Safonovo, Smolensk oblast. Geobotanical descriptions were carried out in the territory of the three spoil heaps, 88 species of vascular plants were found, among which meadow and meadow-forest species prevail, and six species are invasive for Smolensk oblast.

Keywords: demutational succession, biodiversity, technogenic landscapes, meadow species, meadow-forest species, invasive species.

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Introduction

The Smolensk Region is located in the western part of Russia, almost in the center of the East European Plain. The Smolensk Region is located in temperate latitudes, in a zone with noticeable influence of air masses from the Atlantic. It occupies a significant part of the watershed of the three largest rivers of Eastern Europe: the Volga, Dnieper and Western Dvina.

These features, the physical and geographical position, determine the main features of the region's nature – the temperate continental climate, the predominance of hills and small rivers, and the widespread occurrence of forests and sod-podzolic soils.

The area of the Smolensk Region is 49.8 thousand km², it includes 25 administrative districts and 2 cities of regional significance: Smolensk and Desnogorsk. About 30 types of minerals associated with the rocks of the sedimentary cover of the Russian

Platform, composed of the Devonian, Carboniferous, Jurassic, Cretaceous, Paleogene, Neogene and Quaternary deposits have been found in this region (Fig. 1). The region is mostly known for its building materials (sand, gravel, loam, clay), carbonate rocks (limestone, dolomite, calcareous tuff, marl), peat, brown coal, fresh, mineral water, and brines. There are also significant reserves of tripolite, opoka, phosphorites, vivianites, rock and potassium salt, medicinal mud, glauconite, ocher, pyrite, martite, and gypsum. Most of the deposits have been explored and exploited. In terms of its mineral resource potential, the Smolensk Region ranks 13th among the subjects of the Central Russian Federal District, and 8th in terms of mineral resources of building materials (Priroda Smolenskoi Oblasti, 2001).

The leading place in the structure of the mineral resource base of the Smolensk Region is occupied by

Fig. 1. Geological map of the Smolensk region (after Priroda Smolenskoy oblasti, 2001).

brown coal, sand and gravel material, refractory clay, cement raw materials, sapropels, peat and building stones (Priroda Smolenskoy Oblasti, 2001). Brown coal deposits are concentrated in four coal-bearing areas in the central and eastern parts of the region: Dorogobuzhsky, Vyazemsky, Elninsky and Vskhodsky, which are part of the Moscow Region Basin. Seven deposits were prepared for industrial development in different years (Safonovskoe, Dorogobuzhskoe, Vadinskoe, Semlevskoe, Elninskoe, Vskhodskoe, and Poldnevskoe) with coal reserves of 719 million tons.

Development of the Safonovskoye field began in 1948 after the Resolution of the Council of Ministers of the USSR on the creation of a fuel and energy base for the North-West economic region of the country. At the end of 1952 mine no. 1 "Smolenskaya" produced a few tons of coal. At the beginning of 1956, 8 mines operated at the deposit. During the first decade of the operation of the mines, it became clear that mistakes were made when assessing the prospects for the industrial development of the Safonovskoye brown coal deposit, which was shortly followed by mine closure and the organisation of industrial enterprises on their basis. While in 1959 there were seven operating mines, in 1962–1963 there were only four (nos. 1, 2, 4 and 7). They were saved from closure at

that time by the introduction of automated cleaning complexes, which significantly increased the efficiency of coal mining. In 1998, the last seventh mine was closed as unprofitable, regardless of the availability of its coal reserves (Yakovleva, 2017).

As a result of the brown coal mining, spoil heaps were formed (Fig. 2, 3), the vegetation of which is the subject of this study. In technogenic territories, the proximity to natural phytocenoses, which are a source of seeds and have a significant impact on the species composition, number and distribution of seedlings is of decisive importance for the formation of the initial vegetation cover (Kupriyanov and Manakov, 2016; Manakov et al., 2011). Also, the overgrowing of spoil heaps is influenced by many environmental factors, among which the features of the microrelief stand out (Kupriyanov and Manakov, 2016). The purpose of this study was to perform a floristic and ecological-cenotic analysis of the vegetation cover of three spoil heaps, on which coal mining ceased at different times.

Materials and methods

We have studied the vegetation of spoil heaps of three mines on the territory of Safonovo, which stopped their work at different times. Earlier, coal mining was stopped at mine no. 1 (spoil heap no. 1 in

Fig. 2. Spoil heaps nos. 1 and 2 (Safonovo).

Fig. 3. Spoil heap no. 3 (Safonovo, Gorniy District).

Table 1. Geobotanical descriptions of spoil heaps in Safonovo. The density of tree crowns is indicated as a total for all species; «+» – the view is present on the site, «–» – species not found.

Description no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Spoil heap							1									2					3			
Site no.	1	2	3	4	5	6	7	8	9	10a	10b	11	12	13	14	15	16	17	18	19	20	21	22	23
Position in relief	top	east face slope 5° near the top	southwest face slope 40°	southwest face slope 30°	west face slope 40	South face slope 30°	north face slope 50°	north face slope 50°	foothill, east face slope 20°	foothill, south face	foothill, southwestern face	foothill, west face	foothill, north face	southwest slope 40°	northwestern slope 30°	top	north slope 45°	top	south slope 40°	top	northwestern slope 40°	southeast slope 30°	foothill	
Species	Projective cover (%), for trees – crown density, taking into account transparency (%)																							
Tree tier	–	–	1	1	–	40	1	–	15	20	–	–	25	–	40	5	–	–	–	–	–	–	10	
Betula pendula Roth	–	–	+	+	–	+	+	–	+	+	–	–	+	–	+	+	–	–	–	–	–	–	+	
Populus tremula L.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	
Salix caprea L.	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
Shrubs and undergrowth	1	1	3	10	10	15	5	3	20	10	10	<1	25	4	15	15	25	7	5	10	5	10	25	
Amelanchier spicata (Lam.) K. Koch	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	3	–	–	–	–	–	–	–	
Betula pendula Roth	1	<1	2	10	10	12	4	3	10	10	10	–	15	3	5	12	20	7	3	10	3	9	22	
Elaeagnus rhamnoides (L.) A. Nelson	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	5	–	2	–	–	–	–	
Frangula alnus Mill.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	
Lonicera xylosteum L.	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	<1	
Physocarpus opulifolius (L.) Maxim.	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	<1	
Pinus sylvestris L.	–	–	–	–	–	–	–	–	–	–	–	–	<1	–	–	–	–	–	<1	–	–	–	–	

Description no.	1	2	3	4	5	6	7	8	9	10	10a	10b	11	12	13	14	15	16	17	18	19	20	21	22	23	
Spoil heap	1												2											3		
Site no.	1	2	3	4	5	6	7	8	9	10a	10b	11	12	13	14	15	16	17	18	19	20	1	2	3	4	
<i>Cerastium fontanum</i> Baumg.	–	<1	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	
<i>Centaurea jacea</i> L.	1	<1	10	–	–	–	–	–	–	–	5	<1	–	–	–	–	<1	–	–	<1	–	–	–	–	–	
<i>Dactylis glomerata</i> L.	4	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–	3	–	–	–	–	2	
<i>Deschampsia caespitosa</i> (L.) P. Beauv.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	
<i>Elymus repens</i> (L.) Gould	–	–	3	–	1	–	–	5	–	–	25	–	–	–	–	–	–	–	–	–	–	–	–	5	–	
<i>Epilobium angustifolium</i> L.	7	2	10	–	1	5	–	2	<1	–	–	–	–	4	–	2	2	1	<1	1	–	–	–	–	1	
<i>Equisetum arvense</i> L.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	–	–	–	–	–	–	
<i>E. pratense</i> Ehrh.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	<1	–	–	–	–	–	–	
<i>Festuca pratensis</i> Huds.	1	–	10	5	–	10	–	5	–	–	–	–	–	1	<1	–	–	1	<1	–	3	2	–	–	–	
<i>Fragaria vesca</i> L.	–	–	–	–	–	2	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	
<i>Galium aparine</i> L.	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
<i>G. mollugo</i> L.	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	2	–	–	–	–	–	–	–	–	
<i>G. verum</i> L.	5	5	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	<1	1	5	–	–	–	–	
<i>Geum urbanum</i> L.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	<1	–	–	–	–	
<i>Hieracium umbellatum</i> L.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	1	–	–	
<i>Hypericum perforatum</i>	–	–	–	–	–	–	–	–	–	–	<1	–	–	–	–	–	1	<1	–	–	1	–	–	1	–	
<i>Impatiens parviflora</i> DC.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	
<i>Imperata cylindrica</i> (L.) Raeusch.	–	10	–	–	–	–	–	5	–	–	2	–	–	–	3	–	5	5	–	10	50	1	10	–	–	
<i>Juncus</i> sp.	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	
<i>Lathyrus pratensis</i> L.	3	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	

Description no.	1	2	3	4	5	6	7	8	9	10	10a	10b	11	12	13	14	15	16	17	18	19	20	21	22	23
Spoil heap							1											2					3		
Site no.	1	2	3	4	5	6	7	8	9	10a	10b	11	12	13	14	15	16	3	4	5	6	1	2	3	4
<i>Leucanthemum vulgare</i> (Vail.) Lam.	-	-	<1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
<i>Linaria vulgaris</i> Mill.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<1	-	-	-
<i>Lupinus polyphyllus</i> Lindl.	-	-	-	-	-	-	-	-	-	-	-	-	-	30	-	-	5	1	-	2	-	-	-	-	-
<i>Lysimachia vulgaris</i> L.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<1	-	-	-
<i>Matricaria</i> <i>discoidea</i> DC.	-	-	-	-	-	-	-	<1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Medicago falcata</i> L.	-	1	-	-	-	-	-	-	-	-	-	<1	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>M. lupulina</i> L.	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	4	-	<1	1	-	-	-	3	1
<i>Melampyrum</i> <i>nemorosum</i> L.	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-
<i>Myosotis arvensis</i> (L.) Hill	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<1	-	-	-
<i>Phleum pratense</i> L.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	-	-	-	-	-	-	-	-	25	60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20
<i>Poa pratensis</i> L.	-	-	-	2	1	5	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	2	-	2
<i>Potentilla recta</i> L.	1	2	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	<1	2	-	-
<i>Pyrola rotundifolia</i> L.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-
<i>Ranunculus repens</i> L.	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
<i>R. sceleratus</i> L.	-	-	-	-	-	-	-	-	-	-	-	<1	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Rubus idaeus</i> L.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-
<i>Rumex acetosa</i> L.	-	1	<1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-	1	<1	-	-	-
<i>Seseli libanotis</i> (L.) W.D.J. Koch	-	-	-	-	-	-	-	-	-	-	<1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
<i>Silene latifolia</i> subsp. <i>alba</i> (Mill.) Greuter & Burdet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<1	-	-	-	-
<i>Solidago canadensis</i> L.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<1	-	-	-	-	-	-	<1	-	-	-

Description no.	1	2	3	4	5	6	7	8	9	10	10a	10b	11	12	13	14	15	16	17	18	19	20	21	22	23
Spoil heap							1											2					3		
Site no.	1	2	3	4	5	6	7	8	9	10a			11	12	13	14	15	16	17	18	19	20	21	22	23
<i>S. gigantea</i> Alton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<1	-	-	3	-	-	-	-	-	-
<i>S. virgaurea</i> L.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<1	-	-	-	-	<1	7	-
<i>Sonchus arvensis</i> L.	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	1	-	-	-	-	-	-	-	-	-
<i>Stellaria graminea</i> L.	20	6	7	2	-	-	-	5	-	-	-	-	-	-	-	-	-	3	<1	-	-	-	-	3	-
<i>S. nemorum</i> L.	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Tanacetum vulgare</i> L.	1	2	3	-	-	1	-	-	-	-	-	15	-	-	-	-	-	1	1	1	-	1	<1	-	-
<i>Taraxacum campylodes</i> G.E. Haglund	7	3	1	-	-	-	-	-	-	-	-	5	<1	1	1	-	1	<1	-	1	-	-	-	1	-
<i>Thalictrum</i> <i>aquilegifolium</i> L.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
<i>Trifolium hybridum</i> L.	-	-	3	-	-	-	-	1	-	-	-	-	-	-	1	-	-	1	-	-	1	-	-	2	-
<i>T. pratense</i> L.	-	3	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	1
<i>T. repens</i> L.	6	3	-	-	-	1	-	-	-	-	-	-	3	-	-	<1	-	-	-	-	-	-	-	-	-
<i>Tripleurospermum</i> <i>inodorum</i> (L.) Sch. Bip.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<1	-	-	-	-	-	1	-	-	-
<i>Tussilago farfara</i> L.	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
<i>Typha latifolia</i> L.	-	-	-	-	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-
<i>Urtica dioica</i> L.	-	-	3	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
<i>Veronica</i> <i>chamaedrys</i> L.	20	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	10	-	-	-	-	1	-
<i>Vicia cracca</i> L.	2	5	5	-	-	-	-	-	-	-	-	-	-	-	1	-	-	2	1	-	-	-	-	2	-
<i>V. sepium</i> L.	3	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
<i>Viola arvensis</i> Murray	-	-	-	-	-	<1	-	<1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Moss-lichen tier	-	7	-	-	-	-	-	5	-	-	-	-	5	-	-	-	5	-	-	-	-	-	-	5	-

this study) in the mid-1980s (the coal mining operation had been gradually reduced). In the early 1990s, mine no. 2 (spoil heap no. 2) was closed. At the last of the mines no. 7 (spoil heap no. 3), coal mining continued operating until 1997 (Prokhorov et al., 2004).

In total, 23 geobotanical descriptions were conducted in accordance using the standard technique (Lavrenko and Korchagina, 1965) on test plots 5×5 m in size. The test plots were chosen in such a way as to include in the work all plant associations presented on the slopes, peaks and at the foot of the spoil heaps. We took an unequal number of trial plots for each spoil heap, since spoil heaps differ in area (Fig. 2), and in addition, in some areas at their foot, there are municipal facilities and construction sites.

Results and discussion

In total, 88 species of vascular plants were found on 23 test plots, 15 of which are trees and shrubs, and 73 species belong to the herb-shrub layer. Geobotanical descriptions are given in Table 1, species names are given in accordance with modern taxonomic data (The Plant List, Tropicos Databases).

The species found belong to 32 families, which is unusually high for technogenic territories. A possible reason for the high taxonomic diversity is that the Safonovskoe mineral deposit is located in the subzone of coniferous-deciduous forests (Smolensko-Privolzhsky deciduous-coniferous forest biome (Biomy Rossii, 2018)), and not in the forest-steppe zone, like most coal deposits in the European part of Russia and in neighboring states. In particular, for other spoil heaps of the Moscow Region coal basin, the floristic composition is poor (Motorina and Izhevskaya, 1973), but most of its deposits are also located in the forest-steppe zone, in the Tula and Kaluga regions (Potapenko, 2000), in the Dnieper-Volga broad-leaved biome. The families of Asteraceae (15 species), Rosaceae (10 species), Poaceae (10 species) and Fabaceae (9 species) are most widely represented on the spoil heaps studied, the remaining families are represented by fewer than five

species. This is consistent with the literature data; as a rule, in such habitats, the majority of species belong to a few families (Tokhtar, 2003).

The species diversity on the three spoil heaps is different – the largest number of species was found on spoil heap no. 1, located near the mine which was closed in the mid-1980s (Table 2), which is not surprising: demutational succession is slow, and 13–15 years in this case gives an indisputable advantage over the spoil heaps of the other two mines. All three spoil heaps are home to invasive species included in the Black Book of Central Russia (Vinogradova et al., 2020) and the list of Top-100 invasive species in Russia (Dgebuadze et al., 2018). Their share in the first spoil heap, with the highest floristic diversity, is small and amounts to only 3.3%. Of the species found, six are invasive: *Amelanchier spicata*, *Impatiens parviflora*, *Lupinus polyphyllus*, *Matricaria discoidea*, *Solidago canadensis*, *S. gigantea*, and they are most represented on spoil heap no. 2. One of the reasons for this is obvious – nearby (300 m) there were thickets of invasive goldenrods, from which seeds penetrated onto heap no. 2, since the conditions of all three spoil heaps are similar. It is worth noting that in studies of spoil heaps of other regions, invasive species were often observed on them, growing there for many years and showing a tendency to expand to nearby territories (Kupriyanov and Manakov, 2016).

It should be noted that the overgrowth of the considered technogenic spaces occurs not only very slowly (in the absence of special measures for the remediation of the territory), but also rather unevenly. Even on spoil heap no. 1, with a relatively high floristic diversity, and where coal mining was stopped more than 30 years ago, there were test plots with an absent grass-shrub layer (Table 1). On the other two spoil heaps, there were areas completely devoid of vegetation. Spoil heap no. 3 has areas where the total projective cover of the grass-dwarf shrub layer reaches 70%, as in the spoil heap no. 1. Uneven overgrowth and depletion of the vegetation cover in this case is caused by intense erosion processes on

Table 2. Floristic diversity in various spoil heaps of Safonovo.

	Spoil heap		
	no. 1	no. 2	no 3
Number of species	61	54	44
Total number of vascular plant species	2	4	2
Number of invasive species	1	3	2
Number of species included in the Top-100 invasive species of Russia	3.3%	7.4%	4.5%

the slopes. Earlier, uneven overgrowth was recorded on spoil heaps of brown coal mines in Kuznetsk Basin (Kupriyanov and Manakov, 2016).

At the foot of the spoil heaps there are meadow-marsh species, on the slopes in places with a relatively high closeness of the crowns of birches – forest and meadow-forest, on dry and well-warmed slopes we found meadow-steppe plants; meadow species. Ruderal species were also recorded on all three spoil heaps; their share hardly differs, despite the different ages of the spoil heaps, and varies from 14 to 16%. The phytocenotic confinement of species for each spoil heap is shown in Fig. 4.

Conclusions

It takes several decades for the spoil heaps to overgrow near the brown coal mines. In the first decades, meadow and meadow-forest species prevail in the vegetation cover of mine spoil heaps. The most widely represented families are Asteraceae, Rosaceae, Poaceae, and Fabaceae, which is typical of many local floras. Despite the high degree of technogenic disturbance of the territory, we found species from 32 families. Depending on the nature of the relief, there are meadow, meadow-steppe and meadow-bog species. So, climatic conditions allow the birch to renew; forest and meadow-forest species gradually appear under the canopy of birch, and the share of ruderal species in all studied spoil heaps is less than 20%. Of the 88 species of vascular plants found, six species are invasive.

Based on the data obtained, it is possible to recommend planting small-leaved trees in technogenically disturbed territories, since there is not a seed bank nearby for the natural settlement of such trees. Under their canopy, meadow-forest and forest species will be renewed, contributing to a higher rate of restoration of zonal vegetation and biodiversity in disturbed landscapes.

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Fig. 4. Phytocenotic confinement of species on three studied spoil heaps in Safonovo.

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