Fragm. Flor. Geobot. 45(1–2): 123–145, 2000

Colonization of zinc mine spoils in southern Poland – preliminary studies on vegetation, seed rain and seed bank

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GRODZIŃSKA, K., KORZENIAK, U., SZAREK-ŁUKASZEWSKA, G. AND GODZIK, B. 2000. Colonization of zinc mine spoils in southern Poland – preliminary studies on vegetation, seed rain and seed bank. *Fragmenta Floristica et Geobotanica* 45(1–2): 123–145. Kraków. ISSN 0015–931x.

ABSTRACT: Zinc mine spoils of different ages were studied in southern Poland. Surveyed were *(1)* the species composition and community structure of the resident vegetation, *(2)* the seed rain *(3)* the germinable fraction of the soil seed reserve. The plant cover totalled 93 species; species composition varied between the study plots, and there were between-plot differences in species abundance. The seed rain varied seasonally, with an increase in density corresponding mostly to early autumn. Differences in abundance of seeds between plots (old and recent spoils) were observed. The density of the soil seed reserve varied from 6000 to 20000 in different plots. Species richness differed between plots. The lowest richness (5 species) was noted on recent spoils covered with imported material. The preliminary results suggest that early colonization of mine spoils is basically determined by the availability of seeds for establishment.

KEY WORDS: Zinc mine spoils, southern Poland, seed rain, seed bank, vegetation, restoration

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INTRODUCTION

Poland is one of the richest European countries in terms of mineral resources. All these resources are located in the southern part of the country, which is therefore the most industrialized region. Zinc, lead and silver ores are located in the surroundings of Olkusz (Fig. 1). In this region, lead and silver was mined and processed from the 13th century, while zinc was smelted from the 18th century. These activities continued till the 1990s. Due to economic changes in Poland in the last decade, excavation of ores in the Olkusz region was stopped and smelters with primitive technology were shut down. Spoils of different ages became a permanent part of the landscape in the Olkusz region (Fig. 2). They now cover hundreds of hectares. After mining activity ceased, the mining enterprises were obliged to afforest damaged land and convey it to the State Forest Administration.

Mine spoils provide extreme habitat conditions (dryness, high insolation, low nutrient content and high concentrations of heavy metals). Thermophilous herbaceous plants tol-

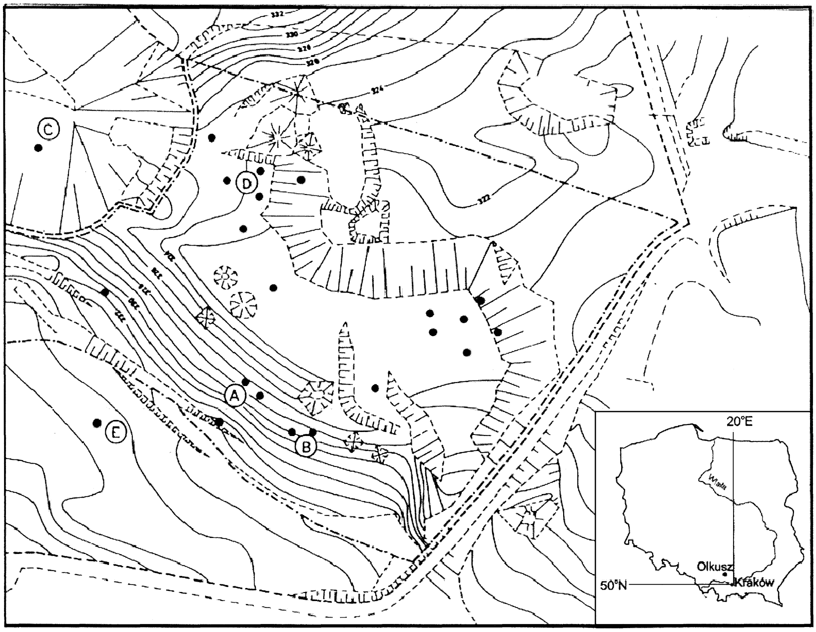

Fig. 1. Location of zinc mine spoils (Olkusz region). • – phytosociological records; A–C – seed rain studied plots; A–E – seed bank studied plots; –•–•–•– – *Biscutella laevigata* distribution. A, B, D – old and C, E – recent spoils.

erate such conditions best; young trees planted on spoils often die (Fig. 3). Unassisted recovery of zinc mine spoils is a slow process, as evidenced by photographs taken at the same sites in the surroundings of Olkusz at the beginning of the 20th century by Wóycicki (1913) and in 1999 by us. The observed differences related mostly to changes in the vegetation mosaic (Fig. 4).

Mine spoils in the surroundings of Olkusz are the only place where *Biscutella laevigata*, a glacial relic in Polish lowlands (Szafer 1972), occurs locally. All remaining localities of the species are in the Tatra Mountains. On the Olkusz spoils, *B. laevigata* is accompanied by some rare xerothermic species (Dobrzańska 1955). To protect this locality a site of ecological interest has been established.

Vegetation dynamics are determined by various population and community processes. To our knowledge, very few parallel studies on resident vegetation, seed rain and seed bank at the same site have been carried out in Poland. One of them was done by Symonides (1986), but it dealt with succession on abandoned crop fields. No similar survey has been conducted on mine spoils. Knowledge of the relation between resident vegetation, seed rain and the seed bank is of fundamental importance for understanding the dynamic regeneration processes of ecosystems, for the restoration of natural ecosystems destroyed by human activity, and for the restitution of rare and threatened species (Bakker *et al.* 1996; Urbanska & Fattorini 1998a–b; Urbanska *et al.* 1999). Zinc mine spoils in the surroundings of Olkusz offer a prime research subject in this respect.

Fig. 2. Zinc mine spoils of various ages in the Olkusz region (1998).

Fig. 3. Afforestation program for zinc mine spoils in the Olkusz region (1998). Arrows indicate dead pines.

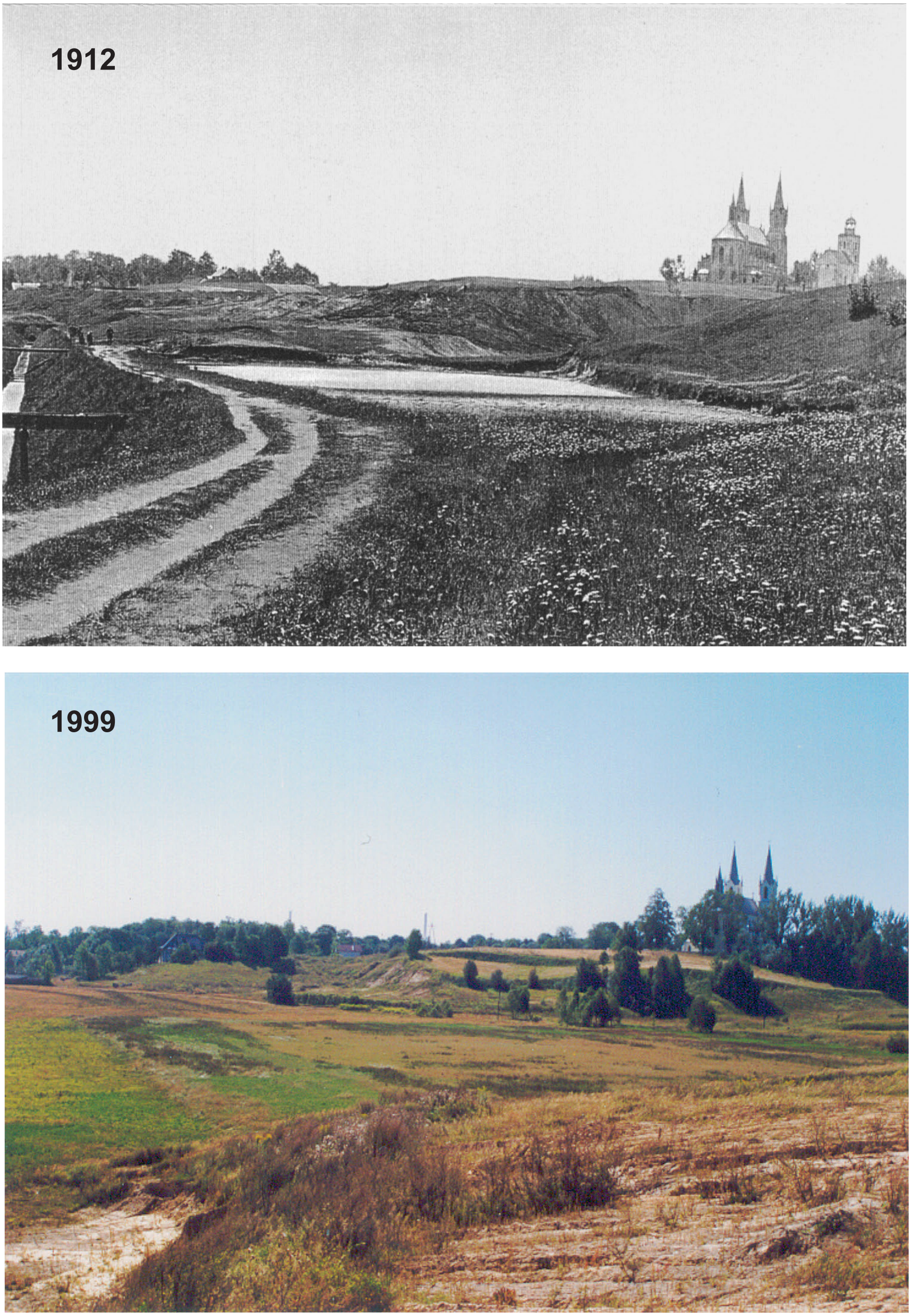

Fig. 4. Zinc mine spoils in the Olkusz region at the beginning and end of the 20th century.

The aims of our preliminary study were to determine *(1)* the species composition and community structure of resident vegetation, *(2)* the germinable fraction of the soil seed reserve and *(3)* the species composition and abundance of seed rain, *(4)* and to propose ways to restore spoils and conserve rare species.

Materials and methods

Site description

The study area is located in the Olkusz region (lat. 50°17′52″N, long. 19°28′35″E) northwest of Kraków in southern Poland. It is composed mainly of the Triassic limestone and metalliferous dolomite from the mined ores. The soil of the mine spoils is stony and except for a thin humus layer associated with densely vegetated turfs. It is not differentiated into horizons. The soil pH of the uppermost 20 cm is neutral. The total concentrations of metals (mg kg^{-1}) are Zn 40000, Pb 1700 and Cd < 200. Forms available to plants account for 2–25% of these elements (Godzik 1991).

Mine spoils of different ages form small hills, often with steep slopes overgrown with thinly scattered bushes and trees (*Pinus sylvestris, Betula pendula*). These spoils add much to the diversity of the landscape, making it more attractive for tourists. They are surrounded by pine woods and some adjoin meadows and crop fields.

Studies on vegetation, seed bank and seed rain

The composition of the vegetation on spoils sites of different ages was determined following the Braun-Blanquet method (1964); 27 phytosociological records were made. The cover of each species was scored on a scale of six (Szafer & Zarzycki 1972).

The species in the tables were listed according to their frequency of occurrence in the phytosociological material. The constancy of the species in the table was scored on a scale of five (Szafer & Zarzycki 1972). To estimate the importance of particular species growing on spoils, their cover indices were calculated using the following formula:

$$J_I = \frac{\sum_{n=1}^{n} \bar{p}}{N} \times 100$$

where: *n* – number of records with a given species

p – average percent of cover of a given species in all records in the table

N – total number of records in the table.

The nomenclature follows Mirek *et al.* (1995) for vascular plant species, Ochyra and Szmajda (1978) for moss species, and Nowak and Tobolewski (1975) for lichen species.

Seed rain was studied at three sites. Two of them represented old mine spoils, and one represented recent spoils. Two 25 m^2 experimental plots were established at each site. Five dry seed traps (14.9 cm dia.) were placed in each plot, with a plastic net (2.5 × 2.5 cm mesh) and dug into the ground. The traps were emptied every three weeks between April 1 and November 30, 1997. Their contents were segregated and the seeds were separated from the debris, counted and identified as to species whenever possible. Seed numbers were converted to density (number of seeds per square meter).

Soil samples for the seed bank study were collected at three sites on old mine spoils and at two sites on recent ones. Samples were taken using a cylinder (5 cm dia.) from soil to a depth of 5 cm. Five samples were collected at each site and then pooled. Samples taken in September were stored at 8–10°C for three months (October-December). Soil samples were transferred to a greenhouse and kept at an average 20°C under natural daylight without additional lighting, in plastic seed trays on a 2 cm layer of sterilized sand, and regularly watered. Emergent seedlings were counted and identified as to species every week. After two months all the seedlings were removed and the upper soil layer was mixed to bring up seeds of heliophilous species to the soil surface. Counting and identification of emergent seedlings continued over the next three months. Shannon-Wiener's coefficients of diversity and equitability were calculated for data on the seed bank (Weiner 1999).

Results

Vegetation

The vegetation of the mine spoils (7 ha in area) was characterized on the basis of 27 phytosociological records; 20 records represented the vegetation of old spoils ranging in age from some decades to a century, and 7 represented the vegetation of recent spoils, from a few to 10–20 years old (Table 1). The number of vascular plant species registered in all records was 93, ranging from 18 to 36 in particular records. The most frequent were 17 species scored at the 5th (81–100% of the records) or 4th (61–80%) degrees of constancy. The 3rd (41–60% of the records) and 2nd (21–40% of the records) degrees were reached by 8 and 12 species, respectively. Sporadic species at the 1st degree of constancy (less than 20% of the records) were represented by 56 species. Mosses were represented by 12 species and lichens by 14 species.

The bulk of species overgrowing recent spoils were similar to those of the old ones. The most frequent species were *Galium album, Thymus pulegioides, Lotus corniculatus, Festuca ovina, Ranunculus serpens* subsp. *nemorosus, Dianthus carthusianorum, Scabiosa ochroleuca* and *Anthyllis vulneraria* (Table 1). However, these species did not always dominate. Among the species of old spoils (Table 1, records 1–20) two groups were distinguished. The first of them (Table 1, records 1–15), which was most frequent in the surveyed area, represented rather dense grasslands dominated mostly by *Festuca ovina* and less frequently by *Armeria maritima, Erysimum odoratum* and *Potentilla arenaria*. Mosses (*Tortella tortuosa*) and lichens (*Cladonia pocillum, C. pyxidata*) were also important components of these grasslands. Scattered trees (*Pinus sylvestris, Betula pendula*) occurred as well. The number of species in this group of records varied between 21 and 30 (vascular plants) and between 2 and 9 (mosses and lichens). The second group (Table 1, records 16–20), which occurred only rarely on the surveyed spoils, represented very dense grassland dominated by sedges, mostly *Carex hirta* and *C. spicata*. The number of species in particular records was generally lower than in the first group, amounting to about 20 (vascular plants) and 3 (mosses and lichens).

Recent spoils (Table 1, records 21–27) with a skeletal substratum and sparse plant cover were distinguishable from old ones by the more frequent and more abundant occurrence of *Agrostis stolonifera, Rumex thyrsiflorus, Reseda lutea* and *Cardaminopsis arenosa*. Mosses and lichens were scarce. The species number in these young unstable grasslands was higher than in the above-discussed groups, varying from (21) 27 to 36 species in particular records.

Table 1. Zinc mine spoils vegetation.

Record number in the table	1	2	3	4	5	6	7	8	9 B*	10 A	11	12	13	14	15 D	16	17	18	19	20	21 E	22	23	24	25	26	27 C	Constancy
Record number in the field	2	4	7	8	10	11	12	13	16	17	20	1	15	5	6	9	14	3	18	19	21	22	23	24	25	26	27	
Date	11.07. 1997	11. 07.	11. 07.	11. 07.	11. 07.	29. 07.	29. 07.	29. 07.	29. 07.	29. 07.	29. 07.	11. 07.	29. 07.	11. 07.	11. 07.	11. 07.	29. 07.	11. 07.	29. 07.	29. 07.	18. 08.	18. 08.	18. 08.	18. 08.	18. 08.	18. 08.	18. 08.	
Exposition	–	–	W	NNE	SE	SE	SE	–	–	SE	S	SW	–	S	SSW	NNE	E	–	E	SE	W	W	W	S	N	NW	–	
Inclination (o)	0	0	20	35	45	25	10	–	–	25	3	–	–	35	30	5	15	0	25	25	10	5	20	15	15	25	–	
Cover of vegetation layers (%)																												
herb layer (c)	90	70	60	70	90	50	70	80	95	95	100	90	80	80	70	100	100	100	100	100	40	50	70	30	50	50	60	
moss layer (d)						50	60	70	10	70	10		60				80		5	5	40	40	30	20	30	20	40	
Area of record (m^2)	10	10	10	40	50	10	10	10	10	10	10	10	10	20	10	10	10	10	5	5	60	80	100	100	200	100	150	
Galium album	1	+	1	+	1	1	+	+	+	+	+	+	1	1	+	1	3	4	3	3	2	2	2	+	+	+	+	V
Thymus pulegioides	+	+	1	+	1	2	2	1	2	2	2	+	+	1	1	1	2	+	+	+	2	3	3	2	2	3	1	V
Lotus corniculatus	+	1	1	2	2	+	+	2	2	2	+	3	+	2	+	1	+	+	.	.	2	2	2	+	3	2	1	V
Festuca ovina	4	4	3	3	3	4	4	4	3	3	1	2	4	2	4	3	1	.	.	+	+	2	1	2	+	+	.	V
Ranunculus serpens subsp. *nemorosus*	+	+	+	+	+	.	+	+	+	+	1	+	+	+	.	+	2	3	1	+	+	+	1	+	1	.	1	V
Dianthus carthusianorum	2	.	+	1	1	1	1	1	2	2	2	1	1	1	1	2	1	1	+	+	+	+	1	.	+	.	.	V
Scabiosa ochroleuca	+	+	+	+	+	+	.	.	2	1	2	1	1	1	+	+	+	+	1	1	.	1	2	1	1	1	.	V
Anthyllis vulneraria	1	+	+	1	2	.	+	+	+	+	+	4	+	1	+	+	.	.	.	.	1	1	2	1	+	1	1	V
Campanula rotundifolia	+	+	+	.	+	2	1	2	1	1	1	+	+	.	.	.	+	.	+	+	1	2	1	+	+	+	.	IV
Gypsophila fastigiata	+	2	1	1	.	2	2	.	2	2	+	2	1	2	1	.	+	.	.	.	+	2	1	2	2	1	2	IV
Potentilla arenaria	3	1	1	1	.	.	+	2	.	1	.	3	3	3	3	.	+	.	.	.	2	2	+	.	1	2	1	IV
Leontodon hispidus subsp. *hastilis*	+	.	.	1	+	+	+	1	2	2	2	1	+	.	.	.	+	.	.	+	+	+	2	+	2	2	1	IV
Rhinanthus minor	+	.	+	+	1	+	+	+	+	2	+	1	+	+	1	+	+	+	+	+	.	1	.	.	.	.	.	IV
Silene vulgaris	+	+	+	.	.	+	2	2	+	+	+	+	.	1	.	.	.	.	.	.	+	1	3	2	1	2	2	IV
Cardaminopsis arenosa	.	+	+	.	.	1	.	.	.	+	.	+	.	+	+	+	.	.	+	.	1	1	1	1	1	+	1	IV
Euphrasia stricta	+	+	.	.	+	2	2	1	1	1	+	+	+	+	+	.	+	.	.	.	+	1	2	.	.	.	.	IV
Pimpinella saxifraga	1	+	.	+	1	1	2	2	+	2	.	+	1	+	.	.	2	1	1	.	1	.	2	.	.	.	.	IV
Achillea millefolium	.	.	.	.	.	+	.	.	+	.	2	.	.	+	.	+	3	2	+	+	1	1	1	+	1	+	+	III
Biscutella laevigata	+	+	1	1	1	2	1	1	+	2	.	.	+	+	.	.	+	.	+	.	.	.	.	+	.	+	.	III
Leontodon hispidus subsp. *hispidus*	.	.	+	1	2	+	+	+	1	+	+	+	+	+	+	1	.	.	.	.	.	.	+	.	.	1	1	III
Pinus sylvestris	+	+	.	2	.	+	+	.	+	+	.	+	+	+	.	.	.	+	.	.	+	+	+	+	+	.	.	

Plantago lanceolata	1	.	.	.	.	.	.	+	+	+	1	+	+	.	+	.	+	.	.	.	.	.	1	+	1	1	1	
Rumex thyrsiflorus	.	.	+	+	+	.	.	.	.	+	+	.	.	.	.	+	+	.	+	+	.	.	2	1	2	2	+	III
Linum catharticum	+	+	+	+	+	1	1	.	+	+	.	+	.	.	.	+	.	.	.	.	.	1	.	.	.	+	+	III
Agrostis stolonifera	.	.	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.	+	+	2	2	2	2	1	1	2	III
Carex hirta	+	+	.	.	+	.	.	.	.	.	.	.	.	+	+	1	1	5	5	5	.	.	.	.	.	.	.	II
Daucus carota	.	.	.	.	+	.	.	.	.	.	+	.	.	.	.	.	.	.	.	+	2	2	2	1	+	2	2	II
Rumex acetosa	+	.	.	.	.	.	+	1	.	+	+	.	+	.	.	.	+	.	+	+	.	+	.	.	.	+	+	II
Viola tricolor	.	.	+	.	.	.	.	.	.	+	.	+	.	+	+	.	+	+	+	+	.	.	.	.	.	.	.	II
Armeria maritima	+	.	.	.	.	.	+	+	+	.	.	4	2	.	.	.	+	+	.	.	.	.	.	.	.	.	.	II
Carlina acaulis	.	.	.	1	1	.	.	.	.	+	+	.	.	+	+	1	.	.	.	.	.	+	+	.	.	.	.	II
Agrostis sp.	+	.	+	+	.	.	.	.	.	.	.	.	.	+	+	+	.	+	.	.	.	.	.	.	.	.	.	II
Carex caryophyllea	+	+	+	.	.	.	.	.	.	.	+	1	1	.	+	.	.	.	.	.	.	.	.	.	.	.	.	II
Reseda lutea	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	1	1	1	3	II
Carlina vulgaris	.	.	.	+	.	.	.	.	+	+	+	.	+	.	.	.	.	.	.	.	.	.	+	.	.	.	.	II
Gentianella germanica	1	.	.	+	.	.	.	+	+	+	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	II
Verbascum nigrum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	+	+	II
Mosses and Lichens																												
Tortella tortuosa	2	4	1	1	3	3	3	4	+	3	+	2	4	+	2	.	2	.	.	.	.	.	.	.	.	.	.	III
Bryum pallens	.	.	+	.	+	1	.	1	.	.	.	+	.	+	+	.	.	.	+	.	.	.	.	.	.	.	.	II
Cladonia pocillum	2	1	+	1	.	3	2	1	2	+	+	+	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.	III
Cladonia pyxidata	2	2	.	.	2	.	2	1	.	.	+	2	+	1	1	.	.	.	.	.	.	.	.	.	.	.	.	II

Sporadic species (I class of constancy): *Acer pseudoplatanus* (27)+; *Agrostis capillaris* (2)+; (3)+; *Alyssum montanum* (9)+; (14)1; (15)1; *Angelica sylvestris* (26)+; *Arabidopsis thaliana* (2)+; *Arenaria serpyllifolia* (21)+; (22)+; *Artemisia* sp. (27)+; *Astragalus glycyphyllos* (5)+; (26)+; *Betula pendula* juv. (25)+; shrub (25)3; *Calamagrostis epigeios* (22)+; (23)+; *Carex ericetorum* (1)1; (4)+; (14)3; (16)+; *Carex flacca* (8)+; (12)+; (22)+; (25)+; 27)+; *Carex pairae* (14)+; (16)+; (19)+; (20)2; *Carex spicata* (17)3; *Cerastium holosteoides* (5)1; (18)+; (21)+; *Chamaecytisus ratisbonensis* (4)1; (9)+; (16)4; (20)+; *Chamaenerion angustifolium* (21)+; (22)+; *Chamaenerion palustre* (5)+; (16)+; (21)+; (17)+; *Cornus sanguinea* (5)+; (20)+; *Echium vulgare* (27)+; *Erysimum odoratum* (14)3; (15)3; (18) +; (21) +; (27) 1; *Euonymus verrucosus* (17)+; *Euphorbia cyparissias* (19)+; *Frangula alnus* juv. (16)+; *Heracleum sphondylium* (18)+; *Herniaria glabra* (21)+; *Knautia arvensis* (16)2; *Leontodon autumnalis* (17)+; *Melilotus alba* (27)+; *Melilotus officinalis* (27)+; *Molinia arundinacea* (15)2; (20)+; *Ononis spinosa* (5)+; *Parnassia palustris* (10)+; *Peucedamum oreoselinum* (5)+; *Picea abies* (6)+; *Pimpinella major* (3)+; (11)3; (17)+; *Pinus sylvestris* shrub (3)+; (4)2; (16)1; *Potentilla erecta* (17)+; *Rhamnus catharticus* (26)+; *Rumex acetosella* (6)+; (21)+; *Sanquisorba minor* (21)+; (22)1; (23)1; *Senecio jacobaea* (23)+; *Solidago gigantea* (21)+; *Sorbus aucuparia* (22)+; *Taraxacum officinale* (22)+; (25)+; *Trifolium pratense* (4)+; (21)+; (22)+; (25)+; (27)+; Trifolium repens (17)+; (21)+; (23)+; (26)+; (27)+; *Tussilaga farfara* (16)+; (21)+; (22)+; (26)+; 27+; *Urtica dioica* (21)+; (22)+; *Valeriana sambucifolia* (5)+; (16)+; *Verbascum lychnitis* (141; (15)+; *Verbascum thapsus* (21)+; *Veronica chamaedrys* (11)2; (17)+; (21)1; (22)+; 23)+; *Vicia cracca* (27)+; *Viola canina* (9)+; (10)+; (13)+; *Viola rupestris* (22)+; *Viola* sp. (22)+.

Mosses: *Amblystegium serpens* (20)+; *Brachythecium rutabulum* (19)+; *Campyllum calcareum* (5)1; (6)+; (10)+; (11)+; (12)+; *Ceratodon purpurens* (11)+; *Eurynchium pulchellum* (20)+; *Plagiomnium cuspidatum* (19)+; *Pleurozium schreberi* (17)+; *Pohlia nutans* (10)1.

Lichens: *Bacidia bagliettoana* (11)+; *Cetraria aculeata* (12)+; *Cetraria islandica* (2)+; (9)2; *Cladonia cariosa* (1)+; *Cladonia cervicornis* (9)+; (10)+; (12)+; (13)+; *Cladonia fimbriata* (15)+; *Cladonia furcata* (1)+; (7)+; (8)+; (13)+; (17)+; *Cladonia* sp. (6).

* A–E – plots where actual vegetation, seed rain and seed bank were studied simultaneously.

The plants colonizing spoils were tentatively assigned to taxa of *(1)* dry habitats, *(2)* sites poor in nutrients, *(3)* meadows and *(4)* ruderal sites. The two most frequent types of spoils vegetation, represented by records 1–15 (old spoils) and records 21–27 (recent spoils), were chosen for analysis (Table 2). Thermophilous species, recorded mostly among the class *Festuco-Brometea*, represented the most constant and most abundant group on both old and recent spoils. Species of nutrient-poor habitats from the class *Sedo-Scleranthetea* and the order *Nardetalia* were frequent on both old and recent spoils but their abundance was greater on old ones. The presence of meadow species from the class *Molinio-Arrhenatheretea* as well as synanthropic and ruderal species from the class *Rudero-Secalietea* was characteristic of more recent spoils, where their number and abundance were greater than on older ones (Table 2).

The vegetation of zinc spoils in the Olkusz region approximated *Festuco-Koelerietum glaucae* from the class *Sedo-Scleranthetea*. Taking into account the frequency and abundance of species, one should recognize *Festuca ovina*, *Potentilla areanaria*, *Dianthus carthusianorum, Biscutella laevigata* and *Armeria maritima* as distinguishing species of old spoils, while *Thymus pulegioides*, *Silene vulgaris*, *Gypsophila fastigiata, Cardaminopsis arenosa*, *Agrostis stolonifera* and *Reseda lutea* would distinguish recent spoils (Table 2).

Seed rain

The mean density of seed rain varied from 120 to 2800 seeds per m^2 depending on the season. From April to June the seed rain density was relatively small, and from July to November it was relatively high (Fig. 5). On the whole, more seeds fell on old mine spoils than on recent mine spoils (1192–11491 seeds/m^2 vs. 769 seeds/m^2, respectively).

The species number in seed rain totalled 25. On the old mine spoils there were 19 and 21 species identified, and only 10 on the recent spoils. Seed rain on the old spoils was dominated by *Euphrasia stricta* and *Festuca ovina,* which represented 36% and 27% in plot A, and 22% and 12% in plot B. In the latter, *Thymus pulegioides* also had a high share (30%) in seed rain. On the recent spoils the dominating species were *Cardaminopsis arenosa* (63%) and *Silene vulgaris* (28%), which together accounted for almost all the seed rain (Fig. 6). The remaining species were represented by single seeds (Table 3).

The sites also differed in the species composition of the seed rain and species abundance through the growing season (Fig. 7). On the old spoils *Festuca ovina* dominated in seed rain in July, but in September *Euphrasia stricta*, *Rhinanthus minor* and *Thymus pulegioides* prevailed. *Campanula rotundifolia* played a less important role. *Biscutella laevigata* appeared only sporadically in seed rain and only on the old spoils. On the recent spoils *Silene vulgaris* and *Cardaminopsis arenosa* dominated in July. The data from September were destroyed.

The species composition of the seed rain was compared with the species composition of phytosociological records (Table 1, records no. 9 [B], 10 [A], 27 [C]). In the case of old spoils (sites A and B) the proportion of species shared between the resident vegetation and seed rain was 50–70% (Fig. 8). Four species present only in the seed rain were

Table 2. Floristical composition of the zinc mine spoils in Olkusz region.

Species	Zinc mine spoils			
	old (15 records)		young (7 records)	
	A*	B**	A*	B**
Thermophilous species (*Festuco-Brometea* class)				
Anthyllis vulneraria	V	639	V	608
Euphrasia stricta	V	338	III	322
Dianthus carthusianorum	V	767	IV	76
Galium album	V	206	V	755
Scabiosa ochroleuca	V	371	IV	535
Thymus pulegioides	V	753	V	2428
Pimpinella saxifraga	IV	486	II	321
Potentilla arenaria	IV	1500	V	894
Carex caryophyllea	III	37	.	.
Carlina vulgaris	II	2.6	I	1.42
Gentianella germanica	II	36	.	.
Alyssum montanum	I	67	.	.
Erysimum odoratum	I	500	II	72.8
Verbascum lychnitis	I	34	.	.
Sanguisorba minor	.	.	III	144
Astragalus glycyphyllos	.	.	I	1.3
Ononis spinosa	.	.	I	1.3
Senecio jacobaea	.	.	I	1.42
Viola rupestris	.	.	I	1.42
Species typical for poor habitats (*Sedo-Scleranthetea* class, *Nardo-Callunetea* class)				
Festuca ovina	V	4433	V	576
Gypsophila fastigiata	V	718	V	1144
Ranunculus serpens subsp. *nemorosus*	V	41	V	218
Campanula rotundifolia	IV	254	V	397
Silene vulgaris	IV	272	V	1430
Carlina acaulis	II	69	II	2.85
Rumex thyrsiflorus	II	3.3	IV	872
Rumex acetosella	I	1.3	I	1.42
Viola canina	I	1.3	.	.
Arenaria serpyllifolia	.	.	II	2.85
Herniaria glabra	.	.	I	1.42
Species typical for meadows (*Molinio-Arrhenatheretea* class)				
Lotus corniculatus	V	1020	V	1608
Rhinanthus minor	V	223	I	71
Leontodon hispidus subsp. *hastilis*	IV	453	V	825
Leontodon hispidus subsp. *hispidus*	IV	189	III	144
Linum catharticum	IV	72	II	7
Cardaminopsis arenosa	III	37	V	430
Plantago lanceolata	III	70	IV	287

(cont.)

Table 2. Continued.

Species	Zinc mine spoils			
	old (15 records)		young (7 records)	
	A*	B**	A*	B**
Rumex acetosa	II	36	I	1.42
Achillea millefolium	I	118	V	290
Agrostis capillaris	I	1.3	.	.
Carex flacca	I	0.6	III	4.28
Cerastium holosteoides	I	0.6	I	1.42
Daucus carota	I	1.3	V	1250
Parnassia palustris	I	1.3	.	.
Pimpinella major	I	250	.	.
Trifolium pratense	I	0.6	IV	5.71
Trifolium repens	.	.	IV	5.71
Veronica chamaedrys	I	117	III	74.2
Taraxacum officinale	.	.	II	2.85
Angelica sylvestris	.	.	I	1.42
Leontodon autumnalis	.	.	I	1.42
Viccia cracca	.	.	I	1.42
Species typical for ruderal habitats (*Rudero-Secalietea* class)				
Agrostis stolonifera	I	1.3	V	1392
Verbascum nigrum	.	.	V	8.57
Reseda lutea	I	1.3	IV	751
Tussilago farfara	.	.	IV	5.71
Viola tricolor	II	2.6	II	2.85
Echium vulgare	.	.	I	1.42
Meliotus alba	.	.	I	1.42
Melilotus officinalis	.	.	I	1.42
Solidago gigantea	.	.	I	1.42
Verbascum thapsus	.	.	I	1.42
Arabidopsis thaliana	I	1.3	.	.
Carex hirta	II	3.3	.	.
Others				
Biscutella laevigata	IV	505	II	2.85
Armeria maritima	II	533	.	.
Pinus sylvestris	IV	122	IV	72.8

A* constancy
B** index of coverage

found in the immediate vicinity of plots where phytosociological records were made. A similar comparison for the recent spoils (site C) showed a much lower fraction of species (about 20%) which the vegetation plots and seed rain had species in common. In this case as well, four species present only in the seed rain grew in the vicinity of the study site.

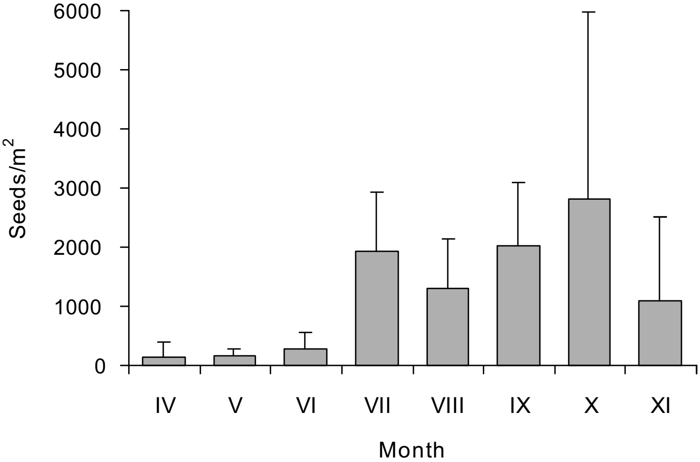

Fig. 5. Seed rain density (April-November 1997). Means ± SD.

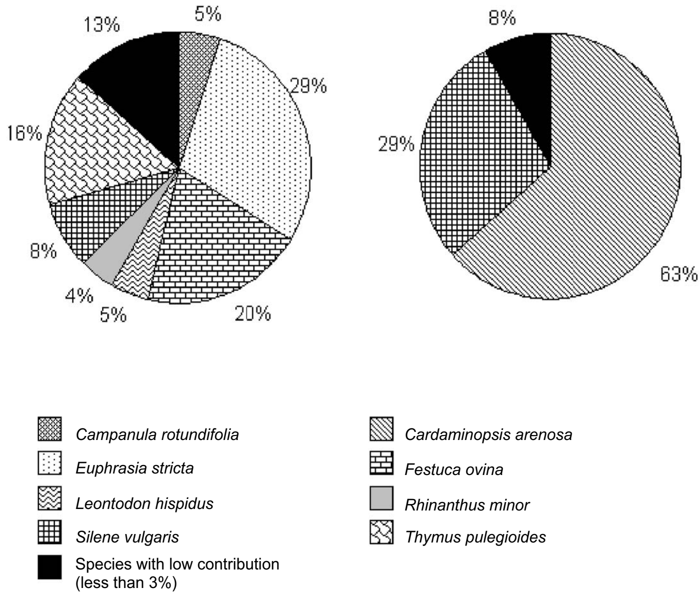

Fig. 6. Contribution (%) of species to seed rain of old (left) and recent (right) mine spoils. Values for old spoils are averages from plots A and B. Species with low contributions (black field) are listed in Table 3.

Seed bank

The mean density of germinable seed bank on old spoils varied from 6000 to about 20000 seedlings per m^2. The total species number ranged from 11 to 14 species. In all three analyzed samples the percentage shares of *Cardaminopsis arenosa* and *Euphrasia stricta* were rather high. *Agrostis stolonifera, Campanula rotundifolia* and *Leontodon hispidus*

Table 3. Species contributed less than 3% each to seed rain on the old and young mine spoils. Values for old spoils are averages from plots A and B.

Species	Old		Young	
	Seeds	%	Seeds	%
Achillea millefolium	–	–	1	0.2
Betula pendula	14.5	1	4	0.7
Biscutella laevigata	8.5	0.5	–	–
Cardaminopsis arenosa	22.5	1.4	–	–
Cerastium holosteoides	1	0.1	–	–
Chaenopodium album	–	–	4	0.7
Chamecytisus ratisbonensis	2	0.1	–	–
Daucus carota	10.5	0.7	–	–
Dianthus carthusianorum	9.5	0.6	–	–
Festuca ovina	–	–	13	2.4
Gentianella germanica	5	0.3	–	–
Leontodon hispidus	–	–	2	0.4
Linum catharticum	12	0.8	–	–
Pimpinella saxifraga	3.5	0.2	–	–
Polygonum sp.	4	0.2	–	–
Potentilla arenaria	9	0.6	–	–
Reseda lutea	0.5	0.03	6	1.1
Ranunculus sp.	15	1	–	–
Rumex acetosa	8.5	0.5	7	1.3
Scabiosa ochroleuca	14	0.9	–	–
Thymus pulegioides	–	–	2	0.4
Verbascum nigrum	2	0.1	–	–
Viola sp.	2	0.1	–	–
Non-identified	23.5	1.5	6	1.1

were sizeable in the germinable seed bank (Fig. 9), but many species were represented by single seedlings (Table 4). Shannon's diversity and equitability coefficients calculated for the three sites were similar (Table 5).

On recent spoils the seed bank density varied between 3000 and 81000 per m^2. Emergent seedlings represented 5–11 species. Clearly dominating species were *Cardaminopsis arenosa*, *Agrostis stolonifera* and *Herniaria glabra*; altogether they constituted over 90% of the seedlings (Fig. 10). Shannon's diversity coefficients were 0.96 (plot C) and 1.01 (plot E), and the equitability coefficients were 0.69 and 0.42, respectively (Table 5).

The resident vegetation and seed bank had 30–40% of the species in common on old spoils (Fig. 11). On the recent spoils covered with local material this share was similar (about 30%), while on spoils with imported soil from a distant area the share of species in common was very small, a mere 3%. Species present only in the seed bank were scarce on both old and recent mine spoils.

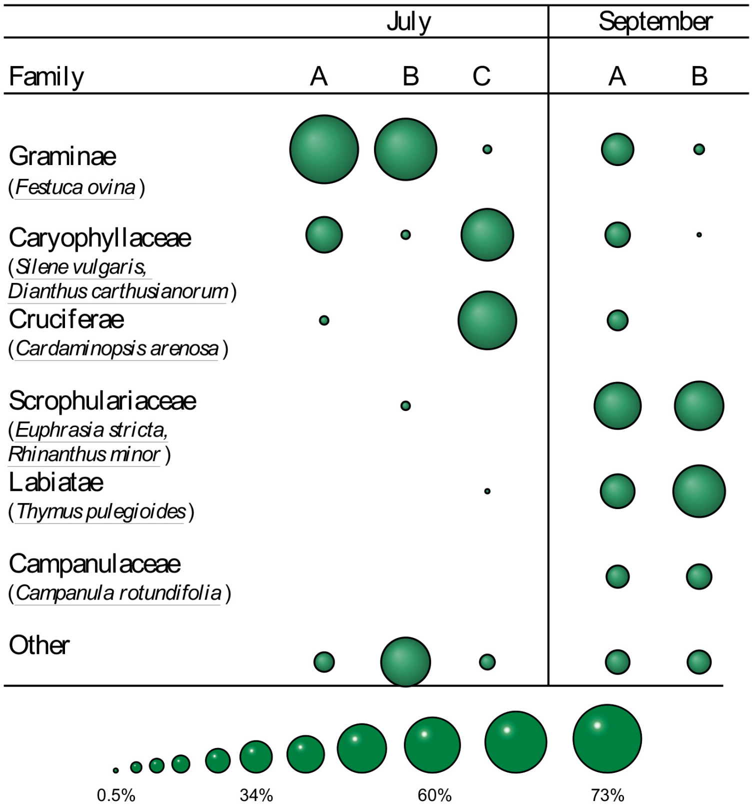

Fig. 7. Species composition (%) of seed rain. A, B – old and C – recent spoils.

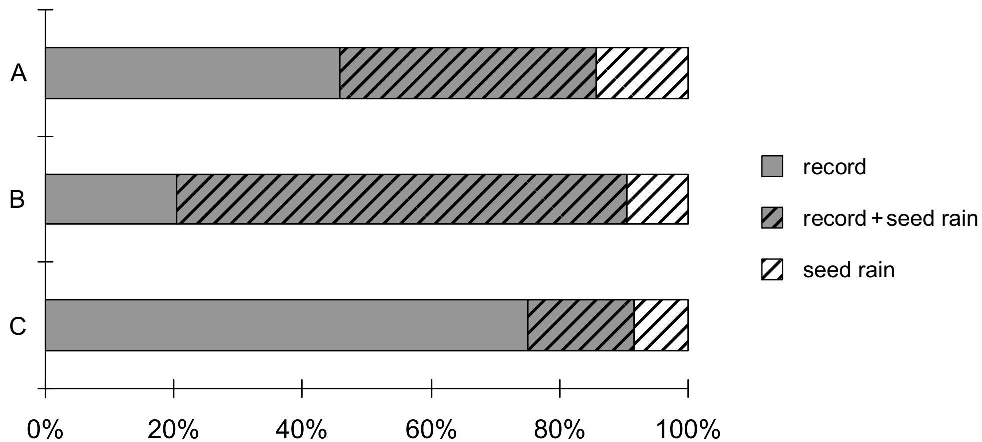

Fig. 8. Contribution (%) of the same species in phytosociological records and seed rain. A, B – old and C – recent spoils.

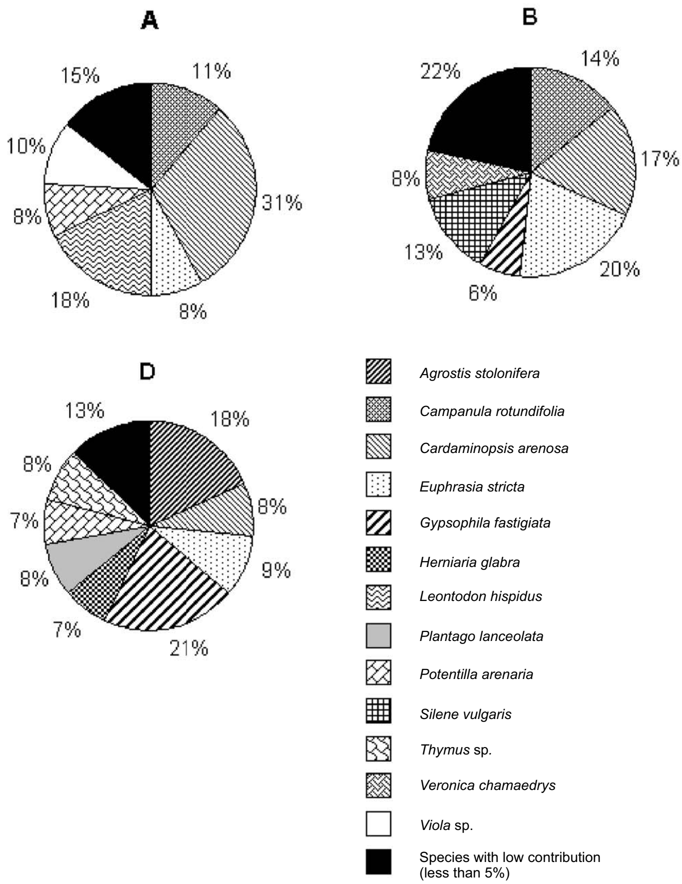

Fig. 9. Contribution (%) of species to germinable fraction of seed bank of old mine spoils. Species with low contributions (black field) are listed in Table 4. A, B, D – studied plots.

Number and species composition in resident vegetation, seed rain and seed bank

Only 5 of the 27 phytosociological records describing the resident vegetation of the spoils were used for this comparison because only these 5 sites yielded phytosociological data and data on the seed rain and seed bank.

On the whole, 66 species occurred in the resident vegetation, 25 species were identified in the seed rain, and 20 in the seed bank. Ten species were shared between the investigated vegetation plots, seed rain and seed bank. The spoils grasslands and the seed rain as well as the grasslands and the seed bank had 19 common species each. The seed rain and seed bank had 10 species in common. Thirty-two species occurred only in the

Table 4. Species contributed less than 5% each to seed bank on the old mine spolis. Non-identified = two undetermined dicotyledonous species.

Species	Plot A		Plot B		Plot D	
	Seedlings	%	Seedlings	%	Seedlings	%
Agrostis stolonifera	–	–	3	1.5	–	–
Atriplex sp.	1	1.6	–	–	1	0.6
Dianthus carthusianorum	1	1.6	6	3.1	–	–
Leontodon hispidus	–	–	6	3.1	–	–
Plantago lanceolata	–	–	1	0.5	–	–
Potentilla arenaria	–	–	9	4.6	–	–
Ranunculus nemorosus	1	1.6	–	0	4	2.5
Rumex acetosella	3	4.8	–	0	–	–
Scabiosa ochroleuca	–	–	7	3.6	2	1.3
Thymus sp.	–	–	5	2.6	–	–
Veronica chamaedrys	–	–	–	–	7	4.4
Viola sp.	–	–	5	2.6	–	–
Non-identified	3	4.8	–	–	1	0.6

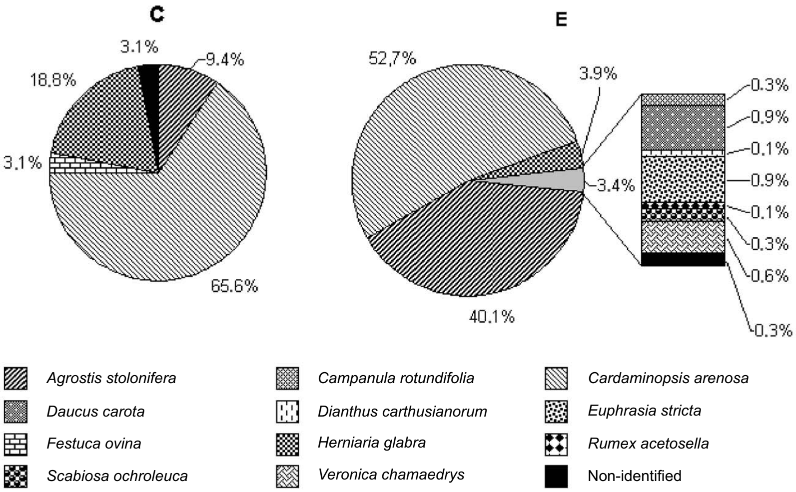

Fig. 10. Contribution (%) of species to germinable fraction of seed bank of recent mine spoils. The non-identified class included 2 species. C, E – studied plots.

resident vegetation, 4 species were present only in the seed rain, and a single species was found exclusively in the seed bank.

The most frequent species among those shared between the resident vegetation, seed rain and seed bank were *Cardaminopsis arenosa, Campanula rotundifolia*, *Silene vulgaris* and *Thymus pulegioides* (Table 6). Of the species present in both the seed rain and

Table 5. Seed bank in the zinc mine spoils in Olkusz region.

Site	Species number	Seedling density (m^2)	Shannon-Wiener index	
			Diversity	Equitability
A	11	6326	2.04	0.85
B	14	19898	2.29	0.87
D	14	16122	2.31	0.88
E	11	81531	1.01	0.42
C	5	3265	0.96	0.69

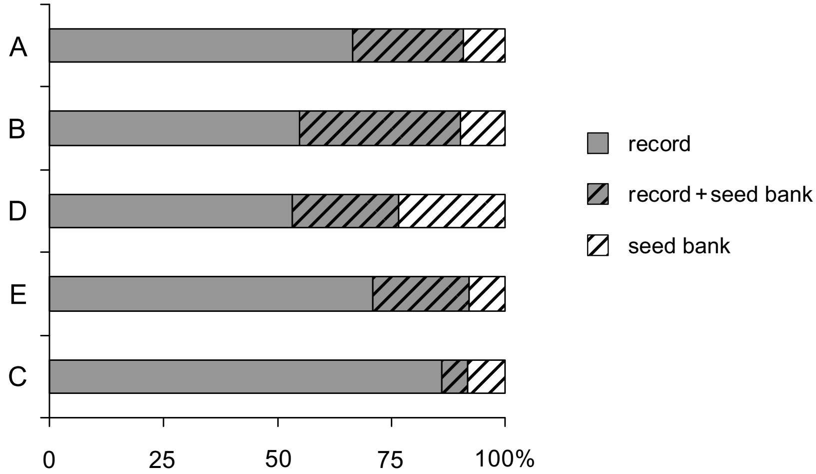

Fig. 11. Contribution (%) of the same species in phytosociological records and seed bank. A–E – studied plots.

phytosociological records, *Campanula rotundifolia, Silene vulgaris, Thymus pulegioides* and *Euphrasia stricta* were most abundant on old spoils, while *Achillea millefolium* and *Leontodon hispidus* prevailed on recent spoils. *Cardaminopsis arenosa* occurred both in the seed bank and in the established vegetation at each examined site. In both cases it occurred abundantly on recent spoils but was also fairly numerous on old ones. Species occurring frequently in both the seed bank and phytosociological records were *Campanula rotundifolia, Euphrasia stricta*, *Thymus pulegioides*, *Gypsophila fastigiata*, *Festuca ovina*, *Silene vulgaris* and *Scabiosa ochroleuca* on old spoils, and *Agrostis stolonifera* and *Daucus carota* on recent spoils.

Table 6. Species composition of phytosociological records, seed rain and seed bank on zinc mine spoils in the Olkusz region.

Species	Record	Seed rain	Seed bank
Campanula rotundifolia	■	■	■
Cardaminopsis arenosa	■	■	■
Dianthus carthusianorum	■	■	■
Euphrasia stricta	■	■	■
Festuca ovina	■	■	■
Leontodon hispidus	■	■	■
Potentilla arenaria	■	■	■
Scabiosa ochroleuca	■	■	■
Silene vulgaris	■	■	■
Thymus pulegioides	■	■	■
Achillea millefolium	■	■	
Biscutella laevigata	■	■	
Chamaecytisus ratisbonesis	■	■	
Gentianella germanica	■	■	
Linum catharticum	■	■	
Pimpinella saxifraga	■	■	
Ranunculus serpens subsp. *nemorosus*	■	■	
Reseda lutea	■	■	
Rhinanthus minor	■	■	
Rumex acetosa	■	■	
Agrostis stolonifera	■		■
Anthylis vulneraria	■		■
Daucus carota	■		■
Gypsophila fastigiata	■		■
Herniaria glabra	■		■
Plantago lanceolata	■		■
Veronica chamaedrys	■		■
Viola canina	■		■

Discussion

The results of the present studies provide an insight into the processes of succession and are instructive in regard to the maintenance and restitution of natural plant systems. Among the 28 most frequent species recorded on the studied spoils, as many as 14 represent metal-tolerant taxa (Ernst 1974, 1990; Ellenberg 1978; Antosiewicz 1992; Punz 1995; Wierzbicka & Panufnik 1998). They included *Silene vulgaris*, *Dianthus carthusianorum*, *Gypsophila fastigiata*, *Cardaminopsis arenosa*, *Biscutella laevigata* and *Festuca ovina*. The zinc spoils in the Olkusz region are rich in heavy metals, and particularly zinc and lead (Godzik 1991; Pawłowska *et al.* 1996). Because of the neutral or slightly alkaline substratum (pH > 7) only a small fraction of these metals occur in soluble forms that are available to plants. It is well known that metals are largely excluded from metabolic processes in plants by way of accumulation in underground parts, or by binding in vacuoles and cell walls in aboveground parts and beyond the embryonal tissues in seeds (Harmens *et al*. 1993; Chardonnes *et al*. 1998; Mesjasz-Przybyłowicz *et al*. 1999). Therefore, plants overgrowing mine spoils need not necessarily be threatened seriously by heavy metals. However, only the most resistant species have a chance to adapt to the extreme conditions prevailing on zinc mine spoils, including dryness, full insolation and scarcity of nutrients in the soil, combined with the presence of heavy metals.

The seed rain studies show differences between resident and potential vegetation. Because part of the samples were destroyed (seed traps were stolen and dug out), we can discuss only general tendencies. The analyzed samples differed markedly in species composition and abundance. On both the old and recent spoils the seed rain was strongly dominated by a few species; their total share reached even 90% (*Cardaminopsis arenosa* and *Silene vulgaris* on recent spoils). A similar asymmetry in the distribution of species has been reported in many other surveys of seed rain (Hutchings & Booth 1996; Jensen 1998; Urbanska *et al*. 1999; Molau & Larsson 2000). There was more similarity between the resident vegetation and the influx of seeds on the old (50–70%) than on the recent spoils, where it reached a mere 20%. However, almost all species represented in the seed rain (except for *Chaenopodium album* on recent spoils) grew in the immediate vicinity of the investigated spoils. Thus, one can say that the colonization of bare sites is based on the existing pool of species, and long-range transport is apparently of minor importance. The study area is under strong anthropogenic pressure (e.g., dumping, walking, afforestation) which may disturb the process of natural succession by massively introducing ruderal species.

Many previous studies on seed banks have shown that only a few species, and sometimes only one (Molau & Larsson 2000), form the basic permanent seed bank, while other species have less abundant or short-lived banks (Falińska 1998a; Urbanska & Fattorini 1998a–b; Molau & Larsson 2000). Our research demonstrated the expansive character of *Cardaminopsis arenosa*, as it appeared abundantly in the seed bank on recent spoils (53–66%), while on old spoils it attained 31% at most. A species of particular interest to us, *Biscutella laevigata*, did not appear in the germinable seed bank at all (perhaps due to the short period of observations), and in the seed rain only single seeds of this species were found. However, it has been demonstrated that many species from different ecosystems, even species with high seed production (such as *B. laevigata*), do not form a seed bank (Pirożnikow 1983; Diemer & Prock 1993; Milberg & Hansson 1993; Falińska 1998a, 1999; Jankowska-Błaszczuk 1998). Previous studies on the germination of *B. laevigata* seeds from mine spoils populations and Tatra populations (Godzik 1984) and the Swiss Alps (Gasser 1984), carried out in standard laboratory conditions, showed a rather high germination ability in the seeds of this species (88.8%, 57.6% and 86.5%, respectively). Gasser's demographic surveys (1984) revealed that *B. laevigata* seedlings appeared over the whole vegetation period and that its seeds remained viable in alpine soils for several years. Many factors influence the formation of the seed bank in the soil and it is a very complicated process (Simpson *et al.* 1989). Future research, then, should focus on long-term studies of seed banks and on experiments with selected interesting species.

In stable ecosystems a similarity between the resident vegetation and the seed bank is greater than in labile systems (Falińska 1998b and references). In the investigated area we are dealing with ecosystems undergoing succession from grassland to forest. This could help to explain the low similarity between the resident vegetation and the seed bank (30%), but also relevant is the fact that our preliminary studies covered only a short period of time (5 months). Some species with strong seed dormancy may not have appeared in the germinable fraction of the seed bank. It would be well to continue studies along these lines.

The results of the present studies allow one to draw the following conclusions:

(1) The abundance of seeds in the soil and seed rain is sufficient for reestablishment of the local vegetation by way of long-term succession processes.

(2) The process of succession on recent spoils may be accelerated by introducing seeds of dominating plant species such as *Cardaminopsis arenosa, Silene vulgaris, Campanula rotundifolia, Thymus pulegioides, Biscutella laevigata* and/or fragments of grasslands from older mine spoils.

(3) Planting tree species not resistant to extreme habitat conditions on zinc spoils is neither scientifically nor economically sensible (Fig. 3).

(4) At least some mine spoils with the abundant occurrence of *Biscutella laevigata*, whose remaining stations in Poland are only in the Tatra Mountains, and with numerous thermophilous plants, should be excluded from the afforestation program and taken under active protection.

(5) Foreign material originating from distant areas should not be used to level the area or fill in excavations because it does not contain the local seed bank ensuring reestablishment of the local grassland vegetation by way of spontaneous succession.

Acknowledgements. This work was supported by funds from the Polish Academy of Sciences, W. Szafer Institute of Botany (Kraków, Poland). The authors thank Professor Krystyna Urbanska and the anonymous reviewers for their valuable comments and critical remarks.

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