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# PINE FORESTS OF ZN-PB POST-MINING AREAS OF SOUTHERN POLAND

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**Abstract**. We studied planted pine forests of the Olkusz Ore Region in southern Poland, an area rich in Zn and Pb deposits. We determined species composition and cover of particular species at 21 study sites (189 plots) on 3 types of substrate (sand, mine waste, sand mixed with mine waste). Seven groups of forest types were distinguished. Only 3 of the 128 species found (*Pinus sylvestris, Festuca ovina, Cardaminopsis arenosa*) were common to all of the groups. Older forests (over 40 years old) occurred on oligotrophic, acidic sandy soils (groups I and II). They were characterized by species typical for coniferous forests (*Deschampsia flexuosa, Orthilia secunda, Vaccinium myrtillus, Moneses uniflora*). Sites on alkaline mine waste, with rocky structure and high concentrations of heavy metals, were covered by younger forests (20–40 years old) (group VII). They were characterized by species typical for grasslands and meadows (*Galium album, Thymus pulegioides, Silene vulgaris, Dianthus carthusianorum, Plantago lanceolata*). Sites on mixed soil (sand with mine waste) were covered by forests of both groups (20–60 years old), with lower or higher dominance of species typical for forest or for open habitats (groups III, IV, V and VI). The floristic diversity of planted pine forests depended on the degree of land degradation, age of stand, type of substrate and proximity to local vegetation.

**Key words**: mine waste, sands, afforestation, forest vegetation

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## INTRODUCTION

Open-cast mining of economically valuable minerals, including Zn-Pb ores, severely damages the natural vegetation, leaving a huge amount of post-mining waste and deep excavations. The local landscape is often drastically transformed and must be restored. The first step is recovery of vegetation cover, as its role is critical. It stabilizes the ground, diminishes wind and water erosion, reduces the danger of groundwater pollution, and has an important role in shaping the landscape. Recreation of vegetation on post-mining waste with nonferrous metals is made difficult by the physicochemistry of those substrates: rocky structure, insufficient nutrients, and high concentrations of heavy metals (Cooke & Johnson 2002).

Various methods are employed to recover the vegetation in post-mining areas (Urbanska *et al.* 1997). Most common is afforestation (Greszta & Morawski 1972; Trafas 1988; Dickinson 2000), which greens those areas quickly. Planted tree stands play a vital role in restoring the biodiversity of degraded areas (Dickinson 2000; Singh *et al.* 2002).

There are rich Zn-Pb ore deposits in the Wyżyna Śląsko-Krakowska upland of southern Poland. The richest deposits are in the Olkusz Ore Region (OOR). They were intensively exploited by open cast mining from the twelfth century to the 1990s. Vast areas degraded by ore exploitation have been intensively restored by afforestation, and are now covered mainly by pine forests of various ages. Some smaller areas were spontaneously overgrown by grassland vegetation, called calamine grassland, built of species adapted to high soil concentrations of Zn and Pb (Dobrzańska 1955; Wierzbicka & Rostański 2002).

The botanical data from the OOR post-mining areas refer mainly to grasslands (Dobrzańska 1955;

Grodzińska *et al.* 2000; Grodzińska & Szarek-Łukaszewska 2009). Forests have not been so deeply studied, and only Kaźmierczakowa (1987) and Szarek-Łukaszewska (2009) have characterized them in greater detail.

This study was intended to describe the pine forest vegetation that originated from pine afforestation in the OOR post-mining areas. We determined its species composition and the frequency and dominance of particular species, and we discuss the factors influencing the species composition.

## Study area

This work was done in the southeastern part of the Wyżyna Śląsko-Krakowska upland, in fragments of the Olkusz Ore Region (OOR) (50°17′N, 19°29′E) (Fig. 1).

The area is geologically heterogeneous, built of Paleozoic and Mesozoic formations of the Middle Triassic, mainly shell limestone (Pasieczna & Lis 2008; Cabała 2009). They are built of Zn-Pb ore-bearing dolomites and dolomite limestone. A depression of the Mesozoic paleosurface in the OOR is filled with fluvioglacial and eolic deposits of the Pleistocene and Holocene, mainly sand.

Huge amounts of waste accumulated in the OOR during 800 years of ore exploitation. Waste originating from the late nineteenth and early twentieth centuries occupies the largest area (Girczys & Sobik-Szołtysek 2002; Liszka & Świć 2004). It is composed of cap rock covering ore deposits, mixed with the deposit material and the products of ore enrichment processes. The mine waste is rocky, of diverse granularity, and with admixture of metals, mainly Zn and Pb.

Soils arising on waste are often shallow, with large amounts of skeletal material and high concentrations of heavy metals, mainly Zn (1.66%) and Pb (0.34%), as well as Ca (2.23%) and Mg (0.87%). Those soils are poor in nutrients, especially N (0.22%) and P (0.004%), and mainly alkaline, pH 7.39 (G. Szarek-Łukaszewska, unpubl.). Soils on sands are deeper and of finer texture, and the concentrations of heavy metals and nutrients are lower, as is the pH (Zn 0.14%, Pb 0.07% Ca 0.13%, Mg 0.06%, N 0.13%, P 0.02%, pH 6.09).

Up to the 1980s the Olkusz Ore Region was exposed to strong emissions of $SO_2$ and dust with high heavy metal concentrations. Dust emissions from smelters (ZGH Bolesław) reached 500 tons/year, and $SO_2$ 5000 tons/year (Szarek-Łukaszewska 2009). Currently the dust emissions reach 1.5 tons/year and $SO_2$ 400 tons/year.

The study area is in the climatic zone of the Wyżyna Śląsko-Krakowska upland. Average annual precipitation is 750 mm, and average annual temperature 8°C. The growing season lasts 200–210 days (after *Program Ochrony Środowiska dla Powiatu Olkuskiego* 2004).

## Materials and methods

The vegetation was surveyed at 21 sites, each 400 $m^2$ square (Fig. 1). All of them were planted pine stands. The study sites were on sandy substrate, rocky mine waste (mainly dolomite) and mixed sand-waste substrates. Nine circular plots (each of 4 $m^2$) were demarcated at each of study sites, evenly distributed on a 10 × 10 m grid. In each plot (n = 189) the vascular plant species were inventoried and cover-abundance was graded on a 6-point Braun-Blanquet scale (= phytosociological relevés; Medwecka-Kornaś *et al.* 1972) in 2008 and 2009. Plant species nomenclature follows Mirek *et al.* (2002), and the syntaxonomic positions of particular species follow Matuszkiewicz (2002) and Zarzycki *et al.* (2002).

Variability of vegetation on the study plots was described numerically. The relevé and species vectors were normalized to unit length. Before normalization the raw data were square-root transformated and species scalar vectors were replaced by $\log(x{+}1)$. To produce a species resemblance matrix the van der Maarel's distances were calculated, and the Euclidean distances were calculated to produce a relevé resemblance matrix. Both matrices were used in minimum variance clustering (Ward's clustering) to classify species and relevés. An arbitrary number of species and relevé groups was set. To order dense groups along the diagonal, concentration analyses employed an eigenvalue procedure which measures fit by the mean square contingency coefficients. Correspondence analysis was done to rearrange relevés and species within groups. Finally, the species set was reduced to Jancey's ranking based on F statistics, and species with $F<2$ were eliminated from the table. All

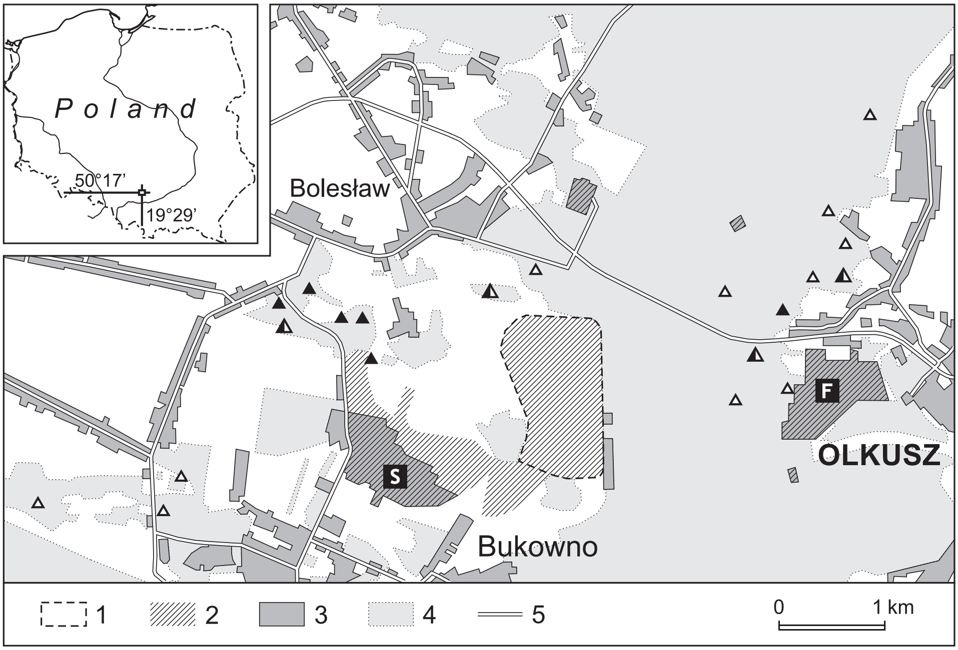


**Fig. 1**. Location of 21 study sites in the Olkusz Ore Region. Study sites: on mining waste – black triangles, on sand – white triangles, on mixed sand and waste – half-black triangles. 1 – flotation tailings ponds, 2 – industrial area including tailings ponds, mine shafts, smelting dumps and ore processing plant (F), smelting plant (S), 3 – built-up area, 4 – forests, 5 – roads.

the calculations were done with MULVA-5 software, according to the methodology of phytosociological classification by Wildi (1989).

## RESULTS

*Pinus sylvestris* was the sole or prevailing species of the studied forests. Average tree height was 18 m, and mean stem diameter between 15 and 20 cm. *Betula pendula* occurred rarely and only on a few studied plots, and *Larix decidua*, *Sorbus aucuparia*, *Populus tremula*, *Alnus glutinosa*, and *A. incana* were noted sporadically. Canopy cover varied, in most cases reaching 70% to 90%. The shrub layer (B) was quite poor (cover 5–10%, occasionally 50%). It consisted mainly of *Frangula alnus*, *Padus serotina* and *Juniperus communis. Pinus sylvestris*, *Betula pendula*, and *Sorbus aucuparia* were found sporadically. The cover of the herb layer (C) varied depending on canopy closure, in most cases reaching 70% to 80%. In the herb layer, numerous seedlings of *Pinus sylvestris* (on 27% of plots), *Quercus robur* (on 22% of plots) and *Frangula alnus* (on 25% of plots) were noted.

On the studied plots (n = 189), 128 vascular plant species were recorded (Table 1). There were 107 herbaceous species and 21 tree and shrub species. Most of them (111 species) were sporadic, with up to 20% frequency. Only 2 species, *Pinus sylvestris* and *Festuca ovina*, were present on over 90% of the plots; *Cardaminopsis arenosa* occurred on 42%, *Orthilia secunda* and *Deschampsia flexuosa* on 30%, and *Galium album*, *Thymus pulegioides*, *Dianthus carthusianorum*, *Potentilla arenaria*, *Silene vulgaris* and *Armeria maritima* on 21 to 28% of the plots (Table 1).

The recorded species represented various syntaxonomic units. Forty species (30% of all noted) were typical for forest habitats (Table 2). There were species typical for coniferous forest (class *Vaccinio-Piceetea*), deciduous forest (class *Querco-Fagetea*) and mixed forest (*Quercetea robori-petraeae*). We noted 42 species (33%) typical for

**Table. 1**. Constancy classes of plant species in seven forest types (see Table 3). Constancy classes: V – 81–100%, IV – 61–80%, III – 41–60%, II – 21–40%, I – up to 20%.

| Constancy class | Forest type | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I–VII | | I | | II | | III | | IV | | V | | VI | | VII | |
| | N | % | N | % | N | % | N | % | N | % | N | % | N | % | N | % |
| V | 2 | 1 | 3 | 6 | 2 | 5 | 1 | 2 | 2 | 7 | 2 | 4 | 3 | 4 | 1 | 1 |
| IV | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 7 | 8 | 15 | 2 | 3 | 7 | 9 |
| III | 1 | 1 | 3 | 6 | 1 | 2 | 7 | 15 | 8 | 27 | 9 | 17 | 6 | 8 | 7 | 9 |
| II | 14 | 11 | 2 | 4 | 4 | 10 | 10 | 21 | 2 | 7 | 12 | 23 | 16 | 22 | 12 | 17 |
| I | 111 | 87 | 42 | 84 | 33 | 83 | 28 | 60 | 16 | 53 | 22 | 41 | 47 | 63 | 47 | 64 |
| V–I | 128 | 100 | 50 | 100 | 40 | 100 | 46 | 100 | 30 | 100 | 53 | 100 | 74 | 100 | 74 | (100) |

xerothermic grassland, including calamine grassland (classes *Festuco-Brometea*, *Violetea calaminariae*), and also for poor xerophytic grassland (classes *Koelerio glaucae-Corynophoretea*, *Nardo-Callunetea*, *Sedo-Scleranthetea*). Also found were 28 species (22%) of fresh, seminatural meadows (class *Molinio-Arrhenathereetea*).

Seven groups of plots were distinguished (Table 3), reflecting substrate type and tree age. Groups I and II comprised sandy plots covered by trees aged more than 60 years, and group VII included mine waste overgrown by younger trees (20–40 years). Other groups were formed by plots with mixed sand and mine waste substrate covered by younger trees (20–40 years) (groups III, V, VI) and by older trees (>40 years).

Only 3 species (*Pinus sylvestris*, *Festuca ovina*, *Cardaminopsis arenosa*) were noted on all plots (Table 3). They reached high abundance in each group.

Groups I and VII differed significantly from the rest (Table 3). The first group was distinguished by *Deschampsia flexuosa*, *Orthilia secunda*, *Vaccinium myrtillus*, *Luzula multiflora* and *Moneses uniflora*. Only in this group, *Vaccinium vitis-idaea*, *Pyrola rotundifolia* and *Luzula luzuloides* were noted on a few plots. All those species are typical for poor, oligotrophic, acidic coniferous habitat types. Group VII was characterized by high quotas of *Galium album*, *Thymus pulegioides*, *Silene vulgaris*, *Dianthus carthusianorum*, *Leontodon hispidus*, *Carex hirta*, *Plantago lan-*

**Table 2**. Distribution of plant species by syntaxonomic class in seven forest types (see Table 3). Syntaxonomic classes (Syntax. class): VP – *Vaccinio-Piceetea*, Qr – *Quercetea robori-petraeae*, QF – *Querco-Fagetea*, VC – *Violetea calaminariae*, FB – *Festuco-Brometea*, MA – *Molinio-Arrhenatheretea*, KC/NC/SS – *Koelerio glaucae-Corynophoretea*/*Nardo-Callunetea*/*Sedo-Scleranthetea*.

| Syntax. class | Forest type | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I–VII | | I | | II | | III | | IV | | V | | VI | | VII | |
| | N | % | N | % | N | % | N | % | N | % | N | % | N | % | N | % |
| VP | 17 | 13 | 13 | 26 | 10 | 25 | 4 | 9 | 4 | 13 | 5 | 9 | 7 | 9 | 8 | 11 |
| Qr | 6 | 5 | 6 | 12 | 5 | 12 | 5 | 11 | 1 | 3 | 6 | 11 | 5 | 7 | 6 | 8 |
| QF | 17 | 13 | 5 | 10 | 6 | 14 | 8 | 17 | 6 | 20 | 5 | 9 | 10 | 14 | 7 | 9 |
| Total | 40 | 31 | 24 | 48 | 21 | 51 | 17 | 37 | 11 | 36 | 16 | 29 | 22 | 30 | 21 | 28 |
| VC | 4 | 3 | 3 | 6 | 3 | 8 | 3 | 7 | 3 | 10 | 3 | 6 | 4 | 6 | 4 | 5 |
| FB | 25 | 20 | 4 | 8 | 5 | 13 | 5 | 11 | 5 | 17 | 13 | 25 | 20 | 27 | 13 | 18 |
| MA | 28 | 22 | 8 | 16 | 5 | 13 | 12 | 26 | 5 | 17 | 12 | 23 | 15 | 20 | 24 | 33 |
| KC/NC/SS | 13 | 10 | 6 | 12 | 5 | 13 | 6 | 13 | 5 | 17 | 7 | 13 | 7 | 9 | 6 | 8 |
| Total | 70 | 55 | 21 | 42 | 18 | 47 | 26 | 57 | 18 | 47 | 35 | 67 | 46 | 62 | 47 | 64 |
| Others | 18 | 14 | 5 | 10 | 1 | 2 | 3 | 6 | 1 | 3 | 2 | 4 | 6 | 8 | 6 | 8 |
| Total | 128 | 100 | 50 | 100 | 40 | 100 | 46 | 100 | 30 | 100 | 53 | 100 | 74 | 100 | 74 | 100 |

*ceolata*, *Lotus corniculatus*, and *Rumex thyrsiflorus*, species typical for open habitats (meadows, grasslands): rather dry, mesotrophic, growing on alkaline soils.

Groups II–VI were less distinct floristically (Table 3). Their species composition was related more or less to groups I or VII, and sometimes to both. Group II was floristically closest to group I. Groups III and IV were represented by species typical for group I (e.g., *Orthilia secunda*, *Moneses uniflora*) as well as for group VII (e.g., *Rumex thyrsiflorus*, *Epipactis atrorubens*, *Galium album*, *Silene vulgaris*, *Armeria maritima*). Groups V and VI were very similar floristically to group VII, as shown by the presence of species typical for grasslands (e.g., *Thymus pulegioides*, *Potentilla arenaria*, *Galium album*, *Dianthus carthusianorum*, *Scabiosa ochroleuca*, *Lotus corniculatus*, *Ranunculus acris*). *Cardaminopsis halleri* (zinc hyperaccumulator) differentiated groups III and IV from the other groups, whereas *Carex caryophyllea*, *Thymus serpyllum*, *Luzula campestris* and *Viola tricolor* distinguished group III from group IV. Group IV was characterized by the common and abundant presence of *Agrostis gigantea*, *Rumex acetosa*, *Galium boreale*, *Carex digitata*, *Viola rupestris* and *Potentilla erecta*. These species were representatives of various habitats, from oligotrophic to rich eutrophic. Worth mentioning is *Agrostis gigantea*, a grass typical for anthropogenic habitats. This species often occurred in groups III and IV. Some species typical for meadows (*Knautia arvensis*, *Veronica chamaedrys*) and grasslands (*Silene nutans*, *Coronilla varia*, *Seseli annuum*, *Phleum phleoides*) distinguished group V from groups VI and VII.

Species richness varied between groups, with species number ranging from 30 to 74 (Table 1). The number of species was highest in groups VI and VII (74 species) and lowest in groups II and IV (40 and 30 species); the other groups numbered from 46 to 53 species (Table 1). Sporadic species quota (constancy class I) varied between 41% and 48% of total species number in a given group; the quota of species of constancy classes IV and V was low in all cases in all groups (Table 1).

In all seven groups of plots the quotas of species typical for open habitats were always higher than those of species typical for forests (Table 2). This predominance was more significant in groups V–VII than in groups I–IV.

## Discussion

The pine forests of the Olkusz Ore Region are floristically diverse. This is connected with the degree of land degradation due to mining activity, also with the substrate type. In the northeastern and southwestern parts of the studied area, on sands, there was no mining activity (according to *Rejestr terenów przekształconych przez Zakłady Górniczo-Hutnicze 'Bolesław'* 2004). That is where the oldest forest stands of the OOR are found. They are characterized by a high degree of canopy closure and a poor herb layer typical for oligotrophic coniferous habitats. Mining activity was very intensive in the center of the studied area. It is covered by mine waste. Pine trees were planted in the 1970s on the shallow, skeletal soils of the post-mining material. Today they form 20–40-year-old forests (T. Zielonka, pers. com.). These forests are thinner, with species typical for nonforest habitats (meadow, grassland) in their herb layer. In other parts of the OOR, forests of various ages occur on sands mixed with mine waste. Old pine forest stands survived at some sites, and other sites were reclaimed by afforestation. They represent younger pine forests. Their canopies are closed to various degrees and the species in the herb layer vary greatly from forest species to grassland species.

Restoration of degraded post-mining areas consists mainly in afforestation by single planting of trees and shrubs. Later, uncontrolled and independent colonization occurs. Species occurring in the afforested area depend on the habitats in the vicinity, where are the main source of diaspores (Tischew & Kirmer 2007). The presence of species typical for open habitats in the forests was connected with the nearness of grassland and meadows. Those species find good conditions especially in the first stage of shrub and tree development, mainly due to the favorable light conditions. They do not disappear because pine forests

**Table 3**. Species composition of seven distinguished types of forest; constancy classes V – I (see Table 1), coverage classes $^{+-5}$ (Medwecka-Kornaś *et al*. 1972); syntaxonomic classes: VP, Qr, QF, VC, FB, MA, KC/NC/SS (see Table 1). (A) – tree layer, (B) – shrub layer, (C) – herb layer.

| Forest type | I | II | III | IV | V | VI | VII | I–VII | Syntax. class |
|---|---|---|---|---|---|---|---|---|---|
| Number of plots | 57 | 38 | 15 | 12 | 9 | 31 | 27 | 189 | |
| Type of soil | Sand | Sand | Sand/ mine waste | Sand/ mine waste | Sand/ mine waste | Sand/ mine waste | Mine waste | | |
| *Cardaminopsis halleri* (L.) Hayek | . | . | II$^{+-3}$ | III$^{+-1}$ | . | . | . | I | MA |
| *Carex caryophyllea* Latourr. | . | I$^{+}$ | . | III$^{+}$ | . | I$^{+-1}$ | . | I | FB |
| *Thymus serpyllum* L. emend. Fr. | I$^{+2}$ | . | I$^{+}$ | III$^{+-2}$ | . | I$^{+}$ | . | I | KC |
| *Luzula campestris* (L.) DC. | I$^{+}$ | . | . | III$^{+}$ | . | . | . | I | KC |
| *Orthilia secunda* (L.) House | III$^{+-2}$ | III$^{+-2}$ | IV$^{+-2}$ | I$^{+}$ | II$^{1}$ | I$^{+}$ | . | II | VP |
| *Deschampsia flexuosa* (L.) Trin. | V$^{+-4}$ | I$^{+}$ | . | . | . | . | I$^{+-1}$ | II | VP |
| *Moneses uniflora* (L.) A. Gray | II$^{+-2}$ | I$^{+-1}$ | II$^{+-1}$ | I$^{1}$ | . | . | . | I | VP |
| *Vaccinium myrtillus* L. | III$^{+-4}$ | I$^{+}$ | . | . | . | I$^{+}$ | I$^{+}$ | I | VP |
| *Luzula multiflora* (Retz.) Lej. | III$^{+-1}$ | I$^{+}$ | . | . | . | . | I$^{+}$ | I | VP |
| *Viola canina* L. s.str. | I$^{+}$ | . | II$^{+}$ | . | . | . | . | I | KC |
| *Rumex thyrsiflorus* Fingerh. | I$^{+-3}$ | I$^{+}$ | III$^{+-1}$ | IV$^{+-2}$ | III$^{+}$ | I$^{+}$ | IV$^{+-2}$ | II | MA |
| *Pinus sylvestris* L. (C) | I$^{+}$ | II$^{+-1}$ | IV$^{+-1}$ | II$^{+}$ | . | II$^{+}$ | III$^{+-1}$ | II | VP |
| *Epipactis helleborine* (L.) Crantz s.str. | . | I$^{+}$ | II$^{+}$ | III$^{+}$ | . | II$^{+}$ | II$^{+-1}$ | I | QF |
| *Epipactis atrorubens* (Hoffm.) Besser | I$^{+-1}$ | I$^{+}$ | III$^{+}$ | I$^{1}$ | II$^{+}$ | I$^{+}$ | II$^{+}$ | I | QF |
| *Betula pendula* Roth (C) | I$^{+}$ | . | III$^{+-2}$ | I$^{+}$ | . | I$^{+}$ | II$^{+-3}$ | I | Qr |
| *Viola reichenbachiana* Jord. ex Boreau | . | . | II$^{+-1}$ | I$^{+}$ | . | I$^{+-1}$ | . | I | QF |
| *Pinus sylvestris* L. (A) | V$^{1-5}$ | V$^{3-5}$ | V$^{4-5}$ | IV$^{+-5}$ | V$^{1-5}$ | V$^{2-5}$ | IV$^{+-5}$ | V | VP |
| *Festuca ovina* L. s.str. | V$^{1-5}$ | V$^{+-5}$ | IV$^{+-4}$ | V$^{2-5}$ | IV$^{1-3}$ | V$^{+-4}$ | IV$^{+-5}$ | V | VC |
| *Cardaminopsis arenosa* (L.) Hayek | II$^{+-1}$ | III$^{+-1}$ | III$^{+-1}$ | III$^{+-1}$ | . | III$^{+-1}$ | III$^{+-2}$ | III | KC |
| *Quercus robur* L. (C) | I$^{+}$ | II$^{+}$ | II$^{+}$ | . | I$^{+}$ | II$^{+}$ | III$^{+}$ | II | Qr |
| *Viola tricolor* L. s.str. | II$^{+-1}$ | I$^{+}$ | I$^{+}$ | III$^{+-1}$ | . | I$^{+-1}$ | I$^{+}$ | I | KC |
| *Padus serotina* (Ehrh.) Borkh. (C) | II$^{+-2}$ | I$^{+}$ | II$^{+}$ | . | II$^{+-1}$ | I$^{+}$ | I$^{+}$ | I | Qr |
| *Sorbus aucuparia* L. emend. Hedl. (C) | II$^{+-2}$ | I$^{+}$ | I$^{+}$ | . | II$^{+}$ | I$^{+}$ | I$^{1}$ | I | VP |
| *Quercus rubra* L. (C) | I$^{+}$ | II$^{+}$ | II$^{+}$ | . | I$^{+}$ | I$^{+}$ | I$^{+}$ | I | Qr |
| *Pimpinella saxifraga* L. | . | . | . | . | II$^{+}$ | V$^{+-3}$ | III$^{+-3}$ | II | FB |
| *Agrostis gigantea* Roth | I$^{+}$ | . | II$^{1-4}$ | IV$^{+-3}$ | . | IV$^{+-4}$ | II$^{+-3}$ | II | MA |
| *Rumex acetosa* L. | I$^{+}$ | I$^{+}$ | I$^{+}$ | . | . | III$^{+-1}$ | . | I | MA |
| *Galium boreale* L. | . | . | . | . | . | III$^{+-2}$ | I$^{+}$ | I | MA |
| *Carex digitata* L. | I$^{+-2}$ | | II$^{+-2}$ | I$^{+}$ | I$^{+}$ | II$^{+-1}$ | . | I | QF |
| *Potentilla erecta* (L.) Raeusch. | . | . | . | . | . | II$^{+-2}$ | I$^{+}$ | I | KC |
| *Viola rupestris* F. W. Schmidt | . | . | I$^{+}$ | . | . | II$^{+-1}$ | . | I | FB |
| *Euphorbia cyparissias* L. | . | . | . | . | I$^{+}$ | II$^{+}$ | I$^{+}$ | I | FB |
| *Frangula alnus* Mill. (C) | I$^{+}$ | II$^{+-1}$ | I$^{+}$ | . | IV$^{+-1}$ | II$^{+-1}$ | II$^{+}$ | II | Qr |
| *Campanula rotundifolia* L. | I$^{+}$ | I$^{+}$ | I$^{+}$ | . | I$^{+}$ | II$^{+-1}$ | II$^{+-1}$ | I | KC |
| *Molinia caerulea* (L.) Moench s.str. | I$^{+}$ | . | . | . | . | II$^{+-3}$ | . | I | MA |
| *Thymus pulegioides* L. | I$^{+-2}$ | . | I$^{+-1}$ | I$^{+}$ | IV$^{+-2}$ | III$^{+-1}$ | III$^{+-2}$ | II | FB |
| *Potentilla arenaria* Borkh. | . | . | . | I$^{+}$ | III$^{+-1}$ | III$^{+-2}$ | IV$^{+-3}$ | II | FB |
| *Galium album* Mill. | . | I$^{+}$ | III$^{+-2}$ | I$^{1}$ | III$^{+}$ | IV$^{+-3}$ | IV$^{+-3}$ | II | FB |
| *Dianthus carthusianorum* L. | I$^{+}$ | I$^{+}$ | I$^{1-2}$ | II$^{+-1}$ | V$^{+-2}$ | III$^{+-2}$ | II$^{+-4}$ | II | FB |

**Table 3**. *Continued.*

| Forest type | I | II | III | IV | V | VI | VII | I–VII | |
|---|---|---|---|---|---|---|---|---|---|
| *Leontodon hispidus* L. subsp. *hastilis* | I$^{+}$ | I$^{+}$ | I$^{+}$ | . | . | II$^{+-1}$ | V$^{1-2}$ | II | MA |
| *Plantago lanceolata* L. | I$^{+}$ | . | . | I$^{+}$ | . | II$^{+-1}$ | IV$^{+-2}$ | I | MA |
| *Lotus corniculatus* L. | . | . | . | . | II$^{+-1}$ | II$^{+}$ | III$^{+-1}$ | I | MA |
| *Silene vulgaris* (Moench) Garcke | I$^{+-3}$ | I$^{+-1}$ | I$^{+}$ | III$^{+-2}$ | . | II$^{+-3}$ | III$^{+-2}$ | II | VC |
| *Ranunculus acris* L. s.str. | I$^{+-1}$ | . | I$^{+}$ | . | II$^{+}$ | II$^{+-1}$ | III$^{+}$ | I | MA |
| *Scabiosa ochroleuca* L. | . | . | . | . | II$^{+}$ | II$^{+}$ | II$^{+-1}$ | I | FB |
| *Carex hirta* L. | . | . | II$^{+-2}$ | I$^{+}$ | I$^{+}$ | I$^{+-2}$ | IV$^{+-4}$ | I | MA |
| *Achillea millefolium* L. s.str. | . | . | I$^{+}$ | . | III$^{+-1}$ | I$^{+-1}$ | III$^{+-2}$ | I | MA |
| *Armeria maritime* (Mill.) Willd. | I$^{+-2}$ | I$^{+}$ | I$^{+-1}$ | V$^{+-2}$ | IV$^{+-1}$ | II$^{+-2}$ | I$^{+-1}$ | II | VC |
| *Anthyllis vulneraria* L. | . | . | . | I$^{1}$ | . | II$^{+}$ | II$^{+-1}$ | I | FB |
| *Leontodon hispidus* L. subsp. *hispidus* | . | . | . | . | I$^{+}$ | I$^{+-1}$ | II$^{+-2}$ | I | MA |
| *Pinus sylvestris* L. (B) | I$^{1}$ | . | . | . | . | I$^{2}$ | II$^{2-4}$ | I | VP |
| *Helianthemum nummularium* (L.) Mill. | . | . | . | . | II$^{+-2}$ | II$^{+-1}$ | . | I | FB |
| *Chimaphila umbellata* (L.) W. P. C. Barton | I$^{+}$ | I$^{+-1}$ | . | . | II$^{+-1}$ | . | . | I | VP |
| *Knautia arvensis* (L.) J. M. Coult. | . | . | I$^{+}$ | . | IV$^{+}$ | II$^{+-2}$ | II$^{+-1}$ | I | MA |
| *Silene nutans* L. | I$^{+}$ | I$^{2}$ | . | . | V$^{+-2}$ | I$^{+-1}$ | . | I | FB |
| *Rhamnus cathartica* L. (C) | . | . | . | . | III$^{+-1}$ | I$^{+}$ | . | I | . |
| *Coronilla varia* L. | . | . | . | . | II$^{+}$ | . | . | I | FB |
| *Rubus caesius* L. | . | . | . | . | II$^{+}$ | . | . | I | . |
| *Seseli annuum* L. | . | . | . | . | IV$^{+-1}$ | I$^{+-1}$ | I$^{+}$ | I | FB |
| *Veronica chamaedrys* L. s.str. | . | . | . | . | III$^{+}$ | . | . | I | MA |
| *Phleum phleoides* (L.) H. Karst. | . | . | . | . | II$^{+-1}$ | . | . | I | FB |

Sporadic species not exceeding 20% of frequency in all of selected groups of forest types. When the cover of these species was evaluated as '+' in all groups this sign is not marked; when its cover was diverse the whole range is presented. Species are arranged according to syntaxonomic classes. **VP**: *Betula pubescens* Ehrh. (C) I; *Larix decidua* Mill. (A) IV:$^{3}$, (B) VI, (C) VII; *Luzula luzuloides* (Lam.) Dandy & Wilmott I:$^{+-1}$; *Monotropa hypopitys* L. s.str. V, VI:$^{2}$, VII; *Picea abies* (L.) H. Karst. (C) II, VII; *Pyrola minor* L. I:$^{+-2}$, II; *Pyrola rotundifolia* L. I; *Sorbus aucuparia* L. emend. Hedl. (B) I, III, (C) VII; *Trientalis europaea* L. VI; *Vaccinium vitis-idaea* L. I: $^{+-2}$. **Qr**: *Betula pendula* Roth (A) II:$^{+-3}$, IV:$^{3-4}$, VI:$^{+-3}$, VII:$^{4}$; *Frangula alnus* Mill. (B) I:$^{+-1}$, III, VI:$^{1-2}$; *Padus serotina* (Ehrh.) Borkh. (B) I, III:$^{+-2}$, VII:$^{3}$; *Populus tremula* L. (A) VII, (C) I. **QF**: *Acer pseudoplatanus* L. (C) VI, VII; *Brachypodium sylvaticum* (Huds.) P. Beauv. VI:$^{1-4}$, VII; *Dryopteris carthusiana* (Vill.) H. P. Fuchs I, VI; *Dryopteris dilatata* (Hoffm.) A. Gray I:$^{1}$, II, III; *Equisetum pratense* Ehrh. II, III, IV, VI:$^{+-1}$; *Euphorbia esula* L. V, VII; *Luzula pilosa* (L.) Willd. I:$^{+-3}$, II, IV; *Maianthemum bifolium* (L.) F. W. Schmidt III:$^{1}$; *Malaxis monophyllos* (L.) Sw. III, VI:$^{+-2}$, VII:$^{1}$; *Mycelis muralis* (L.) Dumort. V; *Padus avium* Mill. (C) V; *Poa nemoralis* L. II:$^{2-3}$, VII; *Tilia cordata* Mill. (C) VI. **VC**: *Biscutella laevigata* L. VI, VII:$^{1}$. **FB**: *Anthericum ramosum* L. VI:$^{1-3}$; *Astragalus glycyphyllos* L. V; *Carlina acaulis* L. II, VI:$^{+-3}$, VII:$^{1}$; *Carlina vulgaris* L. VI, VII:$^{+-3}$; *Convolvulus arvensis* L. VI; *Euphrasia stricta* D. Wolff ex J. F. Lehm. VII; *Poa compressa* L. III:$^{2}$, VII; *Prunella grandiflora* (L.) Scholler VI; *Ranunculus bulbosus* L. VI. **MA**: *Angelica sylvestris* L. VI:$^{+-1}$; *Agrostis capillaris* L. I:$^{+-2}$, II, III:$^{+-4}$; *Campanula patula* L. s.str. VII; *Cerastium holosteoides* Fr. emend. Hyl. III, VI, VII; *Dactylis glomerata* L. VII; *Daucus carota* L. II, VI, VII:$^{+-2}$; *Deschampsia caespitosa* (L.) P. Beauv. II, III, VII; *Festuca rubra* L. s.str. III:$^{1}$, VII:$^{2-5}$; *Linum catharticum* L. VII; *Prunella vulgaris* L. VII:$^{2}$; *Rhinanthus serotinus* (Schönh.) Oborný VII; *Trifolium pratense* L. V, VII:$^{+-1}$; *Trifolium repens* L. V:$^{2}$, VII. **KC/NC/SS**: *Calluna vulgaris* (L.) Hull VI; *Gypsophila fastigiata* L. VII:$^{+-2}$; *Hieracium pilosella* L. IV, V, VII:$^{+-1}$; *Juniperus communis* L. (B) VI, (C) I, II, III, V, VI; *Koeleria glauca* (Spreng.) DC. II; *Rumex acetosella* L. V. **Others**: *Agrostis stolonifera* L. VI:$^{+-1}$; *Alnus glutinosa* (L.) Gaertn. (A) VII:$^{3}$, (B) VI; *Alnus incana* (L.) Moench (A) VII, (B) VII:$^{1}$, (C) I:$^{1}$; *Cirsium arvense* (L.) Scop. I; *Cruciata glabra* (L.) Ehrend. V:$^{2}$; *Equisetum hyemale* L. IV; *Galeopsis tetrahit* L. I, II; *Phegopteris connectilis* (Michx.) Watt III; *Robinia pseudoacacia* L. (C) VII; *Sambucus nigra* L. (C) VI; *Salix caprea* L. (B) VII:$^{4}$, (C) VII:$^{4}$; *Tussilago farfara* L. III:$^{1}$; *Valeriana officinalis* L. I; *Vicia angustifolia* L. VII; *Vicia hirsuta* (L.) Gray VII; *Vicia tetrasperma* (L.) Schreb. VI.

are generally thin and sufficiently insolated. The presence of oligotrophic coniferous forest species appearing in pine forests was related to the nearness of remnants of old pine woods.

Brief descriptions of the pine forests of the OOR published at the beginning of the twentieth century (Wóycicki 1913) and in the early 1950s (Dobrzańska 1955) suggest that those forests grew on sandy margins of mining zones and were thin, with a rather poor herb layer, characterized by *Vaccinium myrtillus*, *Pyrola minor*, *Moneses uniflora*, *Orthilia secunda*, *Chimaphila umbellata*, *Deschampsia flexuosa* and *Luzula multiflora*. These are the same forests studied in the current work.

In a paper from a phytosociological study done in the OOR in the 1970s, Kaźmierczakowa (1987) presented forests growing on sandy soils. Their herb layer was composed of coniferous forest species (*Vaccinium myrtillus*, *V. vitis-idaea*, *Orthilia secunda*, *Chimaphila umbellata*, *Moneses uniflora*) and grassland species (*Dianthus carthusianorum*, *Potentilla arenaria*, *Scabiosa ochroleuca*, *Silene nutans*). Those forests were characterized by high variability of species quotas in both groups. The pine forests presented in this study are of the same type. This means that the species composition of the pine forests in the OOR has been stable.

Kaźmierczakowa (1987) identified the pine forests of the OOR as degraded *Vaccinio myrtilli-Pinetum* association, and Wika (1983) regarded them as a *Leucobryo-Pinetum* association of high internal variety. Following Matuszkiewicz (2002), we suggest that the pine forests described in this study should be classified as a community of the *Dicrano-Pinion* alliance. Here we do not analyze or discuss their syntaxonomic position at lower rank.

*Pinus sylvestris* is often used for forest restoration in degraded areas. It is a pioneer species with low edaphic requirements but it is sensitive to atmospheric pollution (especially $SO_2$) (Białobok *et al.* 1993). High emissions of industrial pollution in the 1960s and 1970s seriously inhibited tree growth in the OOR; this is especially evident in the growth depression in those periods (Danek 2008; T. Zielonka, pers. com.). From the beginning of the 1980s, when industrial pollution decreased considerably, average annual radial growth significantly increased, and is now at a level similar to that observed in the 1940s before smelting plants were built in the OOR (T. Zielonka, pers. com.). The health of the pines improved as emissions declined. Pine trees are now expanding in the OOR. They colonize open habitats. Overgrowing of grasslands by pine trees can threaten light-demanding and thermophilous species, and may lead to their disappearance.

The results of our study confirm the usefulness of reclaiming degraded lands by afforesting them (Singh *et al.* 2002). It can produce permanent vegetation cover on vast areas.

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