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The impact of former iron ore mining on the transformation of vegetation cover of the Gielniowski Hump (Małopolska Upland)

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Abstract: The impact of the 17th-19th century iron ore mining on the current state of vegetation cover of the Gielniowski Hump, an upland region situated within the Old Polish Industrial Region (a former centre of mining and smelting), was studied. In the course of the research, the detailed floristic lists were compiled using the cartogram method (ATPOL grid) and phytosociological relevés were made according to the Braun-Blanquet method. Relevés were taken both at the post-mining sites (on spoil banks) and, for comparative purposes, in the adjacent, not affected areas. The obtained results show significant differences between the flora and vegetation of the sites affected and unaffected by mining. These differences result from the changed mineralogical composition of soil in the post-mining areas, which has lead to an increase in the proportion of mesophilous forest communities and in the number of species of the class *Querco-Fagetea* as compared to the unaffected sites. Overall, the former iron ore mining activity has increased the biodiversity level in the Gielniowski Hump mesoregion due to an increase in the total number of species in the area, brought about by the formation of a mining-related habitat mosaic.

Key words: vegetation cover transformation, iron ore mining, Gielniowski Hump, Małopolska Upland, Poland

1. Introduction

According to the physical and geographical regionalisation of Poland (Kondracki 2000), the Gielniowski Hump mesoregion is situated in the northern part of the Małopolska Upland sub-province. The whole area of this mesoregion is situated within the former Old Polish Industrial Region (Staropolski Okręg Przemysłowy – hereinafter OPIR) – the oldest and, till the end of the 19th century, largest mining and smelting region, located at the confluence of the Vistula, Pilica and Nida rivers (Guldon 2001). The OPIR is one of a few old mining centres, where, after the extraction activity was discontinued, plant succession has occurred, involving the emergence of communities composed mostly of native species. This phenomenon – so interesting from the geobotanical viewpoint – is connected with the aforementioned iron ore mining activities. These activities were very intensive and lasted for the longest time in the northern part of the OPIR, including also the Gielniowski Hump. Some of the most conspicuous remnants of the former iron ore mining industry in the OPIR include groups of old shafts surrounded by small (0.5-3.0 m in height) heaps of earth materials that were discarded from deeper layers in mining operations. Such heaps of waste earth are referred to as 'spoil banks' (Fig. 1). There are numerous studies that refer to the dynamics of plant communities in mining areas, especially in coal-mining regions, both in Poland (e.g. Balcerkiewicz & Pawlak 1990; Kurowski 1993) and worldwide (e.g. Riley 1960; Ottoa *et al.* 2006; Li *et al.* 2008). In the world literature, a considerable body of information concerning iron ore mining can be found, particularly from regions that have a long mining history (e.g. Griffith & Toy 2001; Sweet 2006). There are also papers containing data on the impact of iron ore mining on the natural environment (e.g. Usepa 2006; Hougen 2009). However, transformations of the natural environment caused by iron ore mining in various regions worldwide are different from those observed in the

Fig 1. A small spoil bank (1.5 m in heigth) in the Gielniowski Hump (Old Polish Industrial Region). (Photo M. Podgórska)

OPIR. These differences originate from a different extraction method. In most areas, iron ore is quarried using an open-pit method (e.g. Griffith & Toy 2001; MWH Energy & Infrastructure 2003) or extracted from mountains by drift mining (e.g. Usepa 2006). In contrast, in the OPIR area, iron ore was excavated by deep shafting method (digging numerous narrow, deep vertical shafts – Kleczkowski 1970). At present, every shaft entrance is surrounded by a small heap of refuse material from deeper underground layers. Due to this, these spoil banks do not resemble more commonly found slag or clinker heaps. Therefore, both the origin of spoil banks in the OPIR and plant communities that grow on them make this study area a unique one.

Issues associated with the transformation of the abiotic and biotic environment, brought about by former iron mining practices in the Old Polish Industrial Region, have been addressed in only a few scientific papers published relatively long time ago (Adamczyk 1965a, 1965b; Fabijanowski & Zarzycki 1965; Swałdek 1983). These papers dealt mainly with the transformation of soil cover caused by former mining activity. Adamczyk (1965a) analysed soils of spoil banks in the "Świnia Góra" nature reserve, situated on the Suchedniowski Plateau. He found that anthropogenic soils showed properties of meso- and eutrophic soils. These properties result from the presence of marls and clays brought to the surface during iron ore mining. Fabijanowski & Zarzycki (1965) characterized plant communities of the reserve, in relation to two main groups of soil. The studies of spoil banks were continued by Swałdek (1983). This author investigated transformations in soil cover and the impact of secondary soils of former mining sites on vegetation. The results of his analyses indicated that in forest sites, naturally poorer, the silty post-mining soils of spoil banks improved the quality of original, primary soils and habitats, due to the presence of components from deeper earth layers (e.g. marls) that were carried to the surface (Swałdek 1983).

The question is, how the altered geological and soil conditions resulting from the former iron ore mining practices within the OPIR affected vegetation cover in this area. Previous floristic studies in the Gielniowski Hump showed that mesophilous forests with the character species of the class *Querco-Fagetea* are associated almost solely with the spoil bank sites (Podgórska 2009).

The objective of this study was to present the impact of former iron ore mining on the current state of vegetation cover of the Gielniowski Hump.

2. Material and methods

In the years 2004-2008, the Gielniowski Hump area was subject to floristic studies (Podgórska 2010a) based

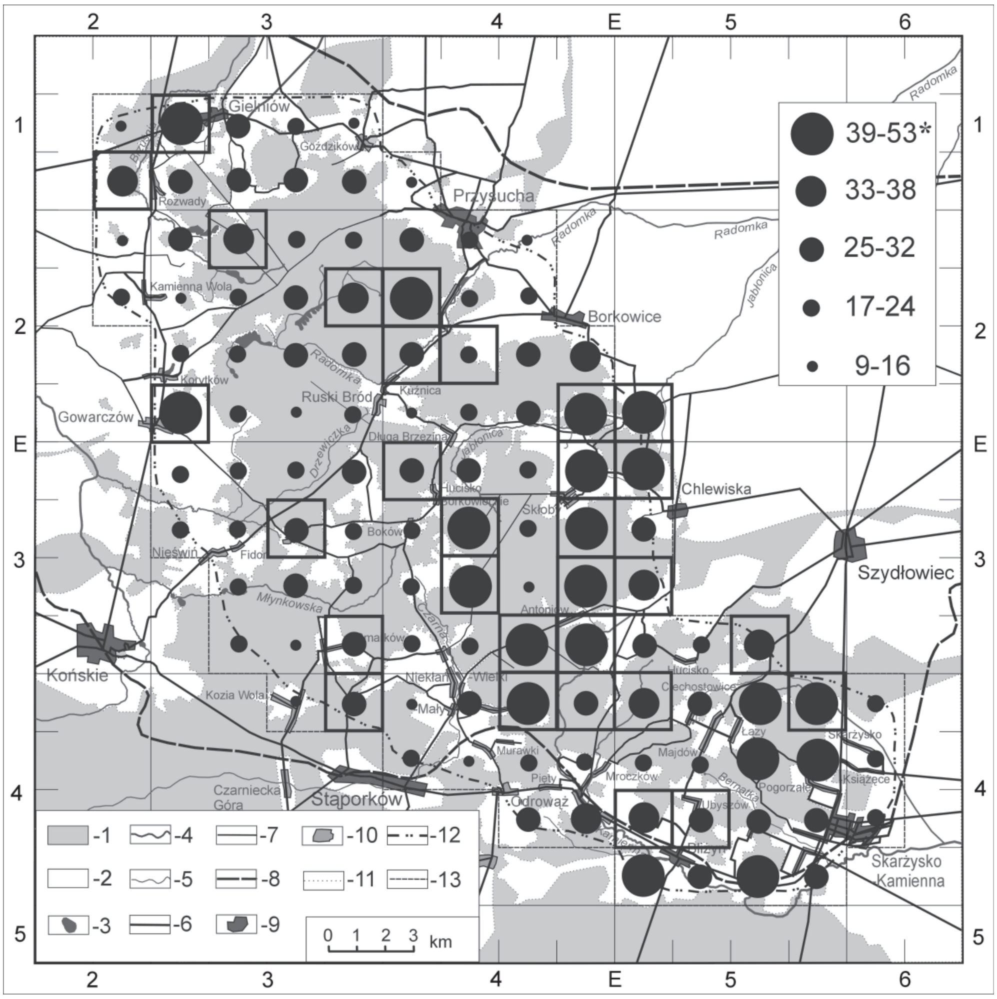

Fig. 2. A quantitative cartogram showing the number of character species of the class *Querco-Fagetea* in particular cartogram units; boldface squares indicate cartogram units including old mining sites with spoil banks
Explanations: 1 – forests, 2 – deforested area, 3 – ponds, 4 – rivers, 5 – streams, 6 – main roads, 7 – secondary roads, 8 – railway, 9 – towns, 10 – villages, 11 – boundary of meadows, 12 – boundary of the Gielniowski Hump, 13 – boundary of the Gielniowski Hump in ATPOL squares, * – the number of character species of the class *Querco-Fagetea* – sizes of rings correspond to the number of species

on the cartogram method (Faliński 1990). Division into the basic cartogram units followed the ATPOL grid (Zając 1978; Zając & Zając 2001) – the study area was divided into 111 squares of 2.5 x 2.5 km.

The main purpose of the present study was to evaluate the impact of several hundred years of iron ore mining on the vegetation cover in this mesoregion. In order to illustrate changes to the flora of the Gielniowski Hump caused by former mining activities, a quantitative cartogram was prepared on the basis of complete floristic lists, which were compiled for every ATPOL square (each square of 6.25 m^2 in area). To evaluate changes in plant communities, phytosociological records (relevés), according to the Braun-Blanquet method (Pawłowski 1977), were completed for the post-mining spoil banks that are relatively evident in the study area (Fig. 1). Phytosociological relevés on the spoil banks were distributed in a way that allowed to capture the maximum diversification of plant communities growing on them. For comparative purposes, phytosociological records were compiled also in the adjacent areas, not directly affected by mining.

In total, 31 phytosociological records (each relevé of 100 m^2) were made and used to make a synthetic phytosociological table (Dzwonko 2007). Nomenclature of species was adopted according to Mirek *et al.* (2002) and Ochyra *et al.* (2003) and their phytosociological affiliation was identified according to Matuszkiewicz (2001).

3. Results

A total of 183 plant species were recorded in the relevés made at the former mining sites, i.e., three times more compared with the number of species found in the relevés made in the unaffected areas (63 species).

A quantitative cartogram shows the number of character species of the class *Querco-Fagetea* in particular cartogram units (squares), both in the iron ore mining affected and unaffected areas (Fig. 2). The

Table 1. A synthetic table of floristic composition of forest communities that developed on old mining sites and (for comparison) on areas unaffected by mining

Successive column	A	B	C
Number of relevés	16	8	7
Average cover of tree layer a, a_1 [%]	77	73	74
Average cover of tree layer a_2 [%]	11	9	4
Average cover of shrub layer b [%]	46	43	34
Middle cover of herb layer c [%]	71	71	73
Middle cover of moss layer d [%]	2	15	19
Ch. O. Fagetalia:			
Atrichum undulatum d	I^{+}	.	.
Dryopteris filix-mas	I^{+}	.	.
Festuca gigantea	I^{+}	.	.
Galium odoratum	I^{3}	.	.
Lathyrus vernus	I^{+-1}	.	.
Milium effusum	I^{+}	.	.
Paris quadrifolia	I^{+}	.	.
Phyteuma spicatum	I^{1}	.	.
Pulmonaria obscura	I^{1-2}	.	.
Stachys sylvatica	I^{+}	.	.
Stellaria holostea	I^{4}	.	.
Tilia cordata b c	I^{+} I^{+} I^{+}	.	.
Ulmus glabra a c	I^{+} I^{+} I^{+}	.	.
Actaea spicata	II^{+}	.	.
Asarum europaeum	II^{+-2}	.	.
Astrantia major	II^{+-2}	.	.
Galeobdolon luteum	II^{+-4}	.	.
Carex sylvatica	III^{+}	.	.
Polygonatum multiflorum	I^{+}	I^{+}	.
Acer pseudoplatanus b c	I^{+-2} I^{+-2} I^{+}	II^{+} II^{+} I^{+}	.
Eurhynchium angustirete d	II^{+}	I^{+}	.
Padus avium b c	II^{+} I^{+} I^{+}	I^{2} I^{2} .	.
Daphne mezereum b c	II^{+-2} I^{+-1} II^{+-2}	II^{+} II^{+} I^{+}	.
Galium schultesii	II^{+}	II^{+-2}	.
Viola reichenbachiana	III^{+-1}	IV^{+-1}	.
Sanicula europaea	V^{+-4}	IV^{+-3}	.
Carpinus betulus a a_2 b c	IV^{+-5} III^{+-5} I^{3} III^{+-2} III^{+}	I^{+-2} I^{+}. I^{2} I^{+}	I^{+} . . I^{+} I^{+}
Fagus sylvatica a a_1 a_2 b c	IV^{+-5} III^{2-5} I^{2-3} III^{+-2} III^{+-1}	I^{+-3}. . I^{+} I^{+}	III^{+-4} II^{+-4} . III^{+-2} I^{+}
Cerasus avium b	.	II^{+}	.
Ch. Cl. Querco-Fagetea:			
Aegopodium podagraria	I^{+-1}	.	.
Campanula trachelium	I^{+}	.	.
Lathyrus niger	I^{1}	.	.
Lonicera xylosteum b c	I^{+} I^{+} I^{+}	.	.
Melittis melissophyllum	I^{+}	.	.
Ranunculus auricomus	I^{+}	.	.
Hepatica nobilis	III^{+-2}	.	.
Epipactis helleborine	I^{+}	I^{+}	.
Euonymus europaea b c	I^{+} I^{+} I^{+}	I^{+} I^{+} I^{+}	.
Betula pendula b c	I^{+-2} I^{+-2} I^{+}	I^{+-2} I^{2} I^{+}	.
Campanula persicifolia	I^{+}	II^{+-2}	.
Fraxinus excelsior b c	II^{+-2} II^{+-2} I^{+}	II^{+} II^{+} .	.
Corylus avellana b c	III^{+-4} III^{+-4} I^{+}	II^{+-2} II^{2} I^{+}	.
Carex digitata	III^{+-3}	IV^{+}	.
Melica nutans	IV^{+-4}	III^{+-3}	.
Acer platanoides a a_1 b c	II^{+-4} I^{4} II^{+-2} II^{+-2}	II^{+-2} I^{2} II^{+} .	I^{+} . . I^{+}
Anemone nemorosa	IV^{+-5}	V^{+-2}	I^{+}
Poa nemoralis	.	I^{+}	.
Ch. Cl. Vaccinio-Piceetea:			
Picea abies a a_2 b c	III^{+-3} I^{+} I^{+-3} III^{+-3} I^{+}	I^{+} . . I^{+} .	V^{+-3} III^{+} I^{2} IV^{+-3} I^{+}
Pinus sylvestris a a_1 b c	IV^{+-3} IV^{+-3} . I^{+}	IV^{+-4} IV^{+-4} I^{+} I^{+}	V^{2-4} V^{2-4} . .
Vaccinium myrtillus	III^{+-2}	V^{+-3}	V^{1-5}
Vaccinium vitis-idaea	I^{+}	V^{+-1}	IV^{+-1}
Pleurozium schreberi d	I^{+-1}	III^{+-1}	III^{1-4}
Orthilia secunda	I^{+}	II^{+-1}	I^{+}
Melampyrum pratense	.	II^{+-2}	IV^{+}
Trientalis europaea	.	III^{+-2}	II^{1-2}
Dicranum scoparium d	.	II^{+}	I^{+}
Hylocomium splendens d	.	II^{+-2}	I^{1}

Lycopodium annotinum	.	II^{+}	I^{+}
Dicranum polysetum d	.	I^{+}	I^{1}
Leucobryum glaucum d	.	.	I^{+}
Sphagnum girgensohnii d	.	.	I^{1}
Chimaphila umbellata	.	I^{2}	.
Accompanying species:			
Abies alba a a$_1$ a$_2$ b c	V^{+-4} II^{+} I^{+-3} III^{+-4} III^{+}	II^{+-5} II$^{4-5}$. II^{+-3} II^{+}	V^{+-4} III^{+-4} I^{2} V^{+-3} IV^{+}
Calamagrostis villosa	.	I^{+}	V^{+-3}
Luzula pilosa	II^{+}	IV^{+}	V^{+-2}
Maianthemum bifolium	V^{+-2}	IV^{+-2}	V^{+-3}
Oxalis acetosella	IV^{+-2}	IV^{+-3}	V^{+-2}
Polytrichastrum formosum d	I^{+-1}	II^{+-1}	V^{+-1}
Rubus hirtus c	V^{+-5}	II$^{1-4}$	V^{+-3}
Sorbus aucuparia b c	IV^{+-2} III^{+-2} III^{+}	V^{+} IV^{+} II^{+}	V^{+-2} IV^{+-2} III^{+}
Frangula alnus b c	III^{+-3} II^{+-3} I^{+}	V^{+-2} V^{+-2} II^{+}	IV^{+-2} IV^{+-2} III^{+}
Tetraphis pellucida d	I^{+}	II^{+}	IV^{+}
Plagiomnium affine	II^{+}	V^{+-1}	IV^{+}
Plagiothecium curvifolium d	.	II^{+}	IV^{+}
Pteridium aquilinum	I^{+}	II^{+}	IV^{+-1}
Quercus robur a a$_1$ a$_2$ b c	III^{+-3} II^{+-3} I^{+} I^{+} II^{+}	III^{+-4} II$^{3-4}$. III^{+-3} II^{+}	IV^{+-4} IV^{+-4}. III^{+-3} II^{+-1}
Quercus petraea a, a$_1$ a$_2$ b c	III^{+-4} II^{+-4} . II^{+-3} II^{+}	II^{+-3} II^{+-2} I^{3} II^{+-2} II^{+}	III^{+-2} I^{2} . I^{2} II^{+}
Athyrium filix-femina	III^{+-3}	.	II^{+}
Hypnum cupressiforme d	II^{+}	IV^{+-1}	II^{+}
Juniperus communis b	.	III^{+}	II^{+}
Brachythecium salebrosum d	I^{+}	III^{+-1}	I^{+}
Brachytheciastrum velutinum d	III^{+}	IV^{+}	I^{+}
Fragaria vesca	II^{+}	V^{+-3}	I^{+}
Populus tremula a, a$_1$, a$_2$, b, c	II^{+-3} II^{+-3} I^{2} I^{+-3} I^{+}	III^{+-3} II^{+-2} . III^{+-3} I^{+}	I^{+} . . I^{+} I^{+}
Rubus idaeus b c	III^{+} II^{+} I^{+}	II^{+-2} II^{+-2} II^{+}	I^{+} . I^{+}
Rubus nessensis b c	I^{+-2} I^{+-2} I^{+}	III^{+-2} II^{+-2} II^{+-1}	I^{+} . I^{+}
Solidago virgaurea	III^{+}	III^{+-1}	I^{+}
Viburnum opulus b c	V^{+-1} II^{+} IV^{+-1}	III^{+} II^{+} III^{+}	I^{+} . I^{+}
Viola riviniana	III^{+-2}	IV^{+-2}	I^{+}
Ajuga reptans	III^{+-2}	IV^{+-1}	.
Carex pallescens	.	III^{+}	.
Festuca ovina	I^{+}	IV^{+}	.
Hieracium murorum	III^{+}	V^{+}	.
Malus sylvestris a b	I^{+} . I^{+}	III^{+} II^{+} II^{+}	.
Mycelis muralis	I^{+}	IV^{+-1}	.
Pyrus communis a, b, c	I^{+} I^{+} I^{+} .	III^{+} . II^{+} I^{+}	.
Plagiothecium laetum d	I^{+}	IV^{+}	.

Accompanying species with the I degree of constancy: *Alnus glutinosa* a$_2$b, A; *Betula pubescens* b, B; *Cornus sanguinea* bc, A; *Crataegus monogyna* b, A; *Hedera helix* A, C; *Crataegus sp.* c, A; *Larix decidua* aa$_1$, C; *Quercus robur* x *petraea* a, A; *Quercus rubra* b, A; *Rhamnus cathartica* bc, B; *Ribes uva-crispa* c, B; *Rosa canina* c, B; *Rosa sp.* c, A; *Rubus corylifolius* c, B; *Rubus saxatilis* c, A, B; *Rubus sp.* b, C; *Salix caprea* b, B; *Viscum album sp. abietis* a$_1$, A, B; *Astragalus glycyphyllos* B; *Aruncus sylvestris* A; *Betonica officinalis* A; *Chaerophyllum aromaticum* A; *Chamaenerion angustifolium* C; *Leucanthemum vulgare* B; *Carex hirta* B; *Dactylis glomerata* B; *Deschampsia caespitosa* C; *Dryopteris dilatata* A; *Dryopteris carthusiana* A, B; *Epilobium sp.* B; *Equisetum arvense* A, B; *Equisetum sylvaticum* A; *Euphorbia angulata* B; *Galeopsis bifida* A, B; *Galium boreale* B; *Galium uliginosum* A; *Cruciata glabra* B; *Genista tinctoria* B; *Geranium robertianum* A; *Geum urbanum* A, B; *Hieracium lachenalii* A; *Hieracium sabaudum* A; *Hypericum maculatum* B; *Huperzia selago* A; *Hypochoeris radicata* B; *Luzula multiflora* B; *Lysimachia vulgaris* A, C; *Melampyrum nemorosum* A; *Moehringia trinervia* B; *Platanthera chlorantha* A; *Polygonatum verticillatum* A; *Potentilla erecta* A; *Primula veris* A; *Primula sp.* A; *Ranunculus acris* B; *Scorzonera humilis* A; *Selinum carvifolia* A, B; *Serratula tinctoria* A; *Danthonia decumbens* B; *Succisa pratensis* A; *Thalictrum aquilegiifolium* A; *Torilis japonica* B; *Urtica dioica* A; *Veronica officinalis* A, C; *Vinca minor* A; *Brachythecium rutabulum* d, A; *Dicranella heteromalla* d, A; *Orthodicranum montanum* d, C; *Fissidens taxifolius* d, A; *Lophocolea heterophylla* d, A; *Mnium hornum* d, B; *Plagiohila asplenioides* d, A; *Plagiotheciella latebricola* d, A, B, C; *Pseudoscleropodium purum* d, A; *Sphagnum fallax* d, C.

Accompanying species with the II degree of constancy: *Betula pendula* a$_1$ a$_2$b, A, B, C; *Crataegus sp.* bc, B; *Larix decidua* aa$_1$, A; *Prunus spinosa* b, B; *Quercus robur* x *petraea* a a$_2$b, B; *Rosa sp.* bc, B; *Sambucus nigra* bc, A; *Agrostis capillaris* B; *Angelica sylvestris* A, B; *Calamagrostis arundinacea* B, C; *Carex flacca* B; *Carex pilulifera* B; *Convallaria majalis* C; *Deschampsia caespitosa* A, B; *Dryopteris dilatata* C; *Galium mollugo* B; *Hieracium lachenalii* B; *Hieracium sabaudum* B; *Hieracium umbellatum* B; *Molinia caerulea* C; *Pimpinella saxifraga* B; *Platanthera chlorantha* B; *Potentilla erecta* B; *Potentilla reptans* B; *Prunella vulgaris* B; *Veronica chamaedrys* B; *Veronica officinalis* B; *Dicranella heteromalla* C; *Herzogiella seligeri* C; *Thuidium tamariscinum* A, B, C.

Explanations: column A – communities of 'oak-hornbeam' spoil banks; column B – communities of 'coniferous' spoil banks, column C – forest communities of areas unaffected by mining practices obtained results indicate that squares representing postmining sites with spoil banks contain a large number of species from the class *Querco-Fagetea* (Fig. 2). There were also observed high differences (over 80%) in the number of species associated with this class across the study area, even between neighbouring cartogram units (e.g. EE 3421 and EE 3422). Outside the sites affected by mining practices, species characteristic of *Querco-Fagetea* were recorded in higher numbers only in the squares representing the valleys of major rivers or other watercourses (EE 2423, EE 4423, EE 4530 and EE 4532) and the hill Skarbowa Góra (EE 4502, EE 4512 and EE 4513), where fertile Carpathian beech forest communities have developed.

A synthetic phytosociological table (Table 1) shows differences in species composition between the studied forest communities that developed as secondary communities in the anthropogenic post-mining sites (Table 1, columns A and B) and the communities found in the areas unaffected by mining practices (Table 1, column C).

Both the column A and B (Table 1) represent communities growing on spoil bank sites, but the column A includes communities more strongly related to the communities of the class *Querco-Fagetea* (hereinafter termed the communities of ‘oak-hornbeam’ spoil banks), whereas the column B – the communities more related to mixed coniferous forests (hereinafter termed the communities of ‘coniferous’ spoil banks). The character species for the order *Fagetalia*, with a narrower phytocoenotic scale, occur primarily in the communities of ‘oak-hornbeam’ spoil banks (Table 1, column A), although a fairly large group of these species was also recorded in the communities growing on ‘coniferous’ spoil banks (Table 1, column B). Some of these species are characterized by a high degree of constancy in both types of communities, e.g. *Sanicula europaea* shows the Vth and VIth degree of constancy and a high degree of coverage. In the areas immediately adjacent to spoil banks and not transformed (Table 1, column C), the character species of this group are conspicuously lacking (except for two tree species – *Carpinus betulus* and *Fagus sylvatica*). In the communities of post-mining spoil banks, both in the group A and B, are species with the largest phytocoenotic scale, characteristic of the class *Querco-Fagetea* (Table 1). These species are practically absent from the communities found within undisturbed areas (Table 1, column C).

An analysis of the character species of the class *Vaccinio-Piceetea* shows that some communities growing on spoil banks display the features of a mixed-coniferous forest (Table 1, column B) and correspond to a certain extent to the communities of unaffected coniferous forest sites. In turn, in the mesophilous communities of deciduous forests with a floristic composition similar to that of oak-hornbeam forests (Table 1, column A), there is only some admixture of conifer tree species and *Vaccinium myrtillus* plants, representing the class *Vaccinio-Piceetea*, with reduced viability and a low degree of coverage.

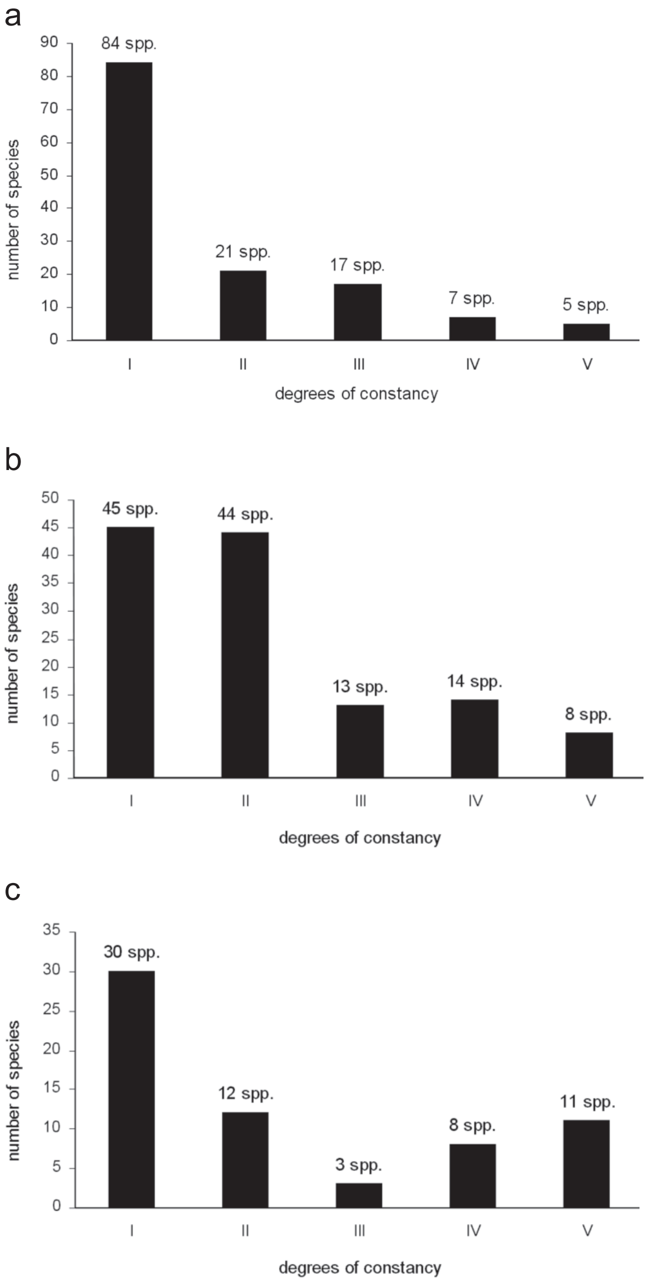

Fig. 3. Distribution of degrees of constancy in the relevés made in: a – forest communities that developed on old mining sites, in the ‘oak-hornbeam’ spoil bank group (Table 1, column A); b – forest communities that developed on old mining sites, in the ‘coniferous’ spoil bank group (Table 1, column B); c – forest communities occurring in the areas unaffected by mining practices (Table 1, column C)

The analysis of graphs illustrating the degrees of constancy in particular groups of relevés shows that the communities of former mining sites (Figs. 3a and 3b) have low proportions of species with the IVth and Vth degree of constancy, very high proportions of species with the Ist and IInd degree of constancy, and a fairly high proportion of species with the III^rd^ degree of constancy. In unaffected communities, the diagram of species constancy (Fig. 3c) corresponds to the distribution described by Raunkiaer's law of frequency (Kershaw 1978).

4. Discussion

In the Gielniowski Hump, the type and geological structure of the soil determines the occurrence of acidophilous forest communities, among them predominantly pine forests of the class *Vaccinio-Piceetea,* with oligotrophic species growing on sandy soils. In these coniferous forests there are peculiar 'isles' of vegetation similar to vegetation occurring in deciduous forests (Fig. 1), with markedly increased proportions of meso- and eutrophic species, characteristic for the syntaxa of the class *Querco-Fagetea* (Fig. 2). The occurrence of these species coincides with the presence of secondary soils of spoil banks (Adamczyk 1965a).

The analysis of relevés (phytosociological records) (Table 1) revealed significant differences between the secondary communities formed at the post-mining sites with spoil banks and the communities of neighbouring unaffected sites. These differences result from the different proportion of species characteristic of the class *Querco-Fagetea* in both types of communities: in the communities formed on spoil banks there is a markedly higher proportion of such species (Podgórska 2009). In most cases, species of the class *Querco-Fagetea* occur exclusively in the communities of spoil banks. This results from the fact that the soil cover of post-mining sites has been considerably changed by bringing calcium-rich rocks (principally marls) onto the surface (Adamczyk 1965a).

The differences found between the communities formed on oak-hornbeam spoil banks (Table 1, column A) and coniferous spoil banks (Table 1, column B) result from the higher content of calcium compounds in the secondary post-mining soils (Adamczyk 1965b). Another significant aspect is the age of spoil banks (Podgórska 2008).

Unambiguous classification of secondary plant communities growing on post-mining soils into specific syntaxa is problematic, because these communities are presently in various stages of succession. Therefore, it seems more appropriate to use broader description, e.g. 'mesophilous forest communities related to the communities of the class *Querco-Fagetea*' (Podgórska 2008). Moreover, the degrees of constancy of species of these communities indicate that these communities are not yet stable (Figs. 3a and 3b). Quite a similar situation has been observed in the Częstochowa Ore Region (*Częstochowski Okręg Rudonośny*), where, as a result of iron ore mining activity and land use that differed from that in the OPIR, meadow communities have developed. These communities are also in the various stages of succession and it is very difficult to perform their phytosociological identification (Kołodziejek 2001).

In the OPIR, forest communities of older spoil banks (dating back to the 18th or early 19th century) demonstrate a substantial level of taxonomic relationship with oak-hornbeam forests, whereas on the 20th century spoil banks, mixed coniferous forest communities still dominate, with barely perceptible initial stages of penetration by species of mesophilous forests. In the field, on such 'younger' spoil banks, a specific mixture of both the oak-hornbeam and mixed-coniferous forest species can often be found, e.g. *Asarum europaeum* and *Hepatica nobilis* between the patches of *Vaccinium myrtillus* and *Orthilia secunda*. This situation may also result from the ecological demands of species of the class *Querco-Fagetea*, which are shade-demanding species (Zarzycki *et al.* 2002). A similar situation has been observed on slag and clinker waste heaps in the mining areas in Ohio, USA (Hougen 2009), where in the intermediate stages of succession shade-demanding species encroached from the surrounding rich deciduous forest communities. This research (conducted 120 years after the decline of industry in south-eastern Ohio) also showed that in the observed stage of succession on the waste heaps of slag, there was a mixture of pioneer species and species of rich deciduous forests (Hougen 2009), similarly as on the spoil banks in the OPIR, where, in most cases, there is a mixture of coniferous and deciduous species.

In the case of the Gielniowski Hump, it is likely that in the course of time, the character species of the class *Vaccinio-Piceetea* will be replaced by oak-hornbeam species. Presumably, all communities in the study area that have developed on the meso- and eutrophic marl-rich secondary soils of post-mining spoil banks will continue their future succession stages toward oak-hornbeam or fertile beech forests. This direction of development seems very likely, when considering similar types of transformation of an abiotic and biotic environment observed in the Świnia Góra reserve (Fabijanowski & Zarzycki 1965), situated on the Suchedniowski Plateau. In the Świnia Góra reserve, where the extraction of iron ore began as early as before the end of the 15th century, Fabijanowski and Zarzycki (1965) distinguished three types of plant communities that were developing on secondary post-mining soils: alder-elm forest *Circaeo-Alnetum* (fragments), mountain beech forest with glandular toothwort *Dentario glandulosae-Fagetum* and 'poor' oak-hornbeam forest *Querco-Carpinetum*.

At the time of old mining activities the extracted iron was accompanied by pelitic formations (clays and silts from the ore-bearing seam with a marl admixture), which were deposited over the psammite formations (sandstones and sands) primarily occurring in the area. In the OPIR, as a result of former iron ore mining, pelitic rocks (clays and silts from the ore-bearing seam, with the admixture of marl) were brought to the surface, over psammite rocks (sandstones and sands) originaly occurring in this area.

The pelitic rocks were also found on one of the hills in the study area, not affected by any extraction activity (Skarbowa Góra hill). They are an effect of the natural erosion of this hill: washing down sandstones and sands of the layers above the ore-deposits that exposes marl-rich ore-bearing layers (Podgórska 2008). A consequence of these processes was the development of a fertile Carpathian beech forest (Podgórska 2010b), (ATPOL squares: EE 4502, EE 4512, EE 4513 – Fig. 2). This is the sole occurrence of this community within the Gielniowski Hump.

The forest phytocoenoses that developed on post-mining spoil banks are the result of spontaneous succession and are formed by plant species native to the Polish flora, with a very minor proportion of anthropohytes. Anthropophytes occur in these communities only sporadically, in the initial stages of succession. A very similar phenomenon has been observed in the Częstochowa Ore Region (Kołodziejek 2001). Meadows that grow in the post-mining areas of this region are composed of native species and contain also some rare species for the Polish flora (Kołodziejek 1999).

5. Conclusions

- Former iron ore mining practices, dating back to the 17th century, have exerted a significant impact on the transformation of vegetation cover in the Gielniowski Hump.
- The richest forest associations, in terms of their floristic composition, developing on the secondary soils of spoil banks are those of mesophilous forests, composed of species related to the syntaxa of the class *Querco-Fagetea*.
- Mining in the Gielniowski Hump has resulted in the permanent deformation of the land surface as well as profound changes in the soil cover. These general changes promoted the development of a habitat mosaic that led to an increase in the total biodiversity level in the mesoregion, particularly, an increase in the number of species from the class *Querco-Fagetea*.
- Former iron ore mining practices have resulted in the combined spread of mesophilous forest communities and native species (the process has not resulted in the disappearance of naturally occurring plant communities, or the emergence of new anthropogenic communities). Changes in the vegetation cover have been similar to the degradation caused by natural factors.
- In the case of the Gielniowski Hump, human activities have affected the vegetation cover of the mesoregion positively, contributing to the increased biodiversity in the area.

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References

Adamczyk B. 1965a. Studia nad kształtowaniem się związków pomiędzy podłożem skalnym i glebą. Część I. Gleby rezerwatu leśnego "Świnia Góra" wytworzone z utworów formacji piaskowca pstrego (dolnego triasu). Acta Agr. Silv., Seria Leśna 5: 3-60.

Adamczyk B. 1965b. Wtórne przekształcenia okrywy glebowo-roślinnej w objętych starym kopalnictwem północno-zachodnich rejonach Gór Świętokrzyskich. Roczn. Gleb. Dod. 15: 437-442.

Balcerkiewicz S. & Pawlak G. 1990. Zarastanie zwałowiska zewnętrznego kopalni odkrywkowej węgla brunatnego w aspekcie analizy florystyczno-ekologicznej występujących tam zbiorowisk roślinnych. Arch. Ochr. Środ. 2: 7-20.

Dzwonko Z. 2007. Przewodnik do badań. In: Vademecum Geobotanicum, pp. 304. Sorus, Instytut Botaniki Uniwersytetu Jagiellońskiego, Poznań-Kraków.

Fabijanowski J. & Zarzycki K. 1965. Roślinność rezerwatu leśnego "Świnia Góra" w Górach Świętokrzyskich. Acta Agr. Silv., Seria Leśna 5: 61-103.

Faliński J. B. 1990. Kartografia geobotaniczna. Cześć 1. Zagadnienia ogólne. Kartografia florystyczna i fitogeograficzna. 284 pp. Państwowe Przedsiębiorstwo Wydawnictw Kartograf. im. E. Romera, Warszawa-Wrocław.

Griffith J. J. & Toy T. J. 2001. Evolution in revegetation of iron-ore mines in Minas Gerais State, Brazil. Unasylva 207(52): 9-15.

Guldon Z. 2001. Old Polish Industrial District. In: P. Pierściński (ed.). Old Polish Industrial District, pp. 32-35. Sam-Wil, Kielce.

Hougen K. E. 2009. Long-term effects of industrial history on the forest flora of southeastern Ohio. pp.125. College of Arts and Sciences of Ohio University, Ohio.

Kershaw K. A. 1978. Ilościowa i dynamiczna ekologia roślin. 383 pp. PWN, Warszawa.

Kleczkowski 1970. Rudy żelaza w utworach pstrego piaskowca północnego obrzeżenia Gór Świętokrzyskich. Prace Muzeum Ziemi 15(1): 193-221.

Kołodziejek J. 1999. Rzadkie i interesujące gatunki roślin naczyniowych na górniczo zniekształconych obszarach środkowej części Częstochowskiego Okręgu Rudonośnego. Fragm. Flor. Geobot. 6(39-43): 39-43.

Kołodziejek J. 2001. Roślinność łąkowo-bagienna na górniczo zniekształconych obszarach Częstochowskiego Okręgu Rudonośnego. 169 pp. Wyd. Uniw. Łódzkiego, Łódź.

Kondracki J. 2000. Geografia fizyczna Polski. 441 pp. PWN, Warszawa.

Kurowski J. K. 1993. Dynamika fitocenoz leśnych w rejonie kopalni odkrywkowej Bełchatów. 171 pp. Wyd. Uniw. Łódzkiego, Łódź.

Li S., Yang B. & Wu D. 2008. Community succession analysis of naturally colonized plants on coal gob piles in Shanxi Mining Areas, China. Water Air Soil Pollut. 193: 211-228.

Matuszkiewicz W. 2001. Przewodnik do oznaczania zbiorowisk roślinnych Polski. In: J. B. Faliński (ed.). Vademecum Geobotanicum 3, pp. 537. Wyd. Nauk. PWN, Warszawa.

Mirek Z., Piękoś-Mirkowa H., Zając A. & Zając M. 2002. Flowering plants and pteridophytes of Poland. A checklist. In: Z. Mirek (ed.). Biodiversity of Poland 1, pp. 442. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

MWH Energy & Infrastructure 2003. Best management practices manual: case studies of model zinc, bauxite, iron ore and limestone mining operations. Vol. 2, i-ii+1-53 pp. Ministry of Environment and Forest Government of India, India.

Ochyra R., Żarnowiec J. & Bednarek-Ochyra H. 2003. Census Catalogue of Polish Mosses. In: Z. Mirek (ed.). Biodiversity of Poland 3, 372 pp. Polish Academy of Sciences, Institute of Botany, Kraków.

Ottoa R., Krüsi B. O., Burgac C. A. & Fernández-Palaciosa J. M. 2006. Old-field succession along a precipitation gradient in the semi-arid coastal region of Tenerife. Journal of Arid Environments 65: 156-178.

Pawłowski B. 1977. Skład i budowa zbiorowisk roślinnych oraz metody ich badania. In: W. Szafer & K. Zarzycki (ed.). Szata roślinna Polski, 1, pp. 237-269. PWN, Warszawa.

Podgórska M. 2008. Zagadnienia fitogeograficzne i flora naczyniowa Garbu Gielniowskiego. Ph.D. Thesis, Department of Plant Taxonomy and Phytogeography, Institute of Botany, Jagiellonian University in Kraków.

Podgórska M. 2009. Wpływ dawnego górnictwa rud żelaza na zmiany we florze i roślinności leśnej północnego przedpola Gór Świętokrzyskich. In: M. Staniaszek-Kik & G. J. Wolski (ed.). Dynamika roślinności w warunkach antropopresji i ochrony, 38 pp. Uniwersytet Łódzki, Łódź.

Podgórska M. 2010a. Flora roślin naczyniowych Garbu Gielniowskiego (Wyżyna Małopolska). Zeszyty Naukowe UJ, Prace Botaniczne (in print).

Podgórska M. 2010b. Skarbowa Góra – godny ochrony obiekt przyrodniczy na Garbie Gielniowskim (Wyżyna Małopolska). Roczn. Świętokrz. (in print).

Riley C. V. 1960. The ecology of water areas associated with coal strip-mined lands in Ohio. The Ohio Journal of Science 60(2): 106-121.

Swałdek M. 1983. Przekształcenia pokrywy glebowej i zbiorowisk roślinnych w Staropolskim Okręgu Przemysłowym. Dok. Geog. 4: 1-86.

Sweet P. C. 2006. Bettie Martin iron mine and old's furnance North Garden, Virginia. Virginia Minerals 49(1-2): 1-8.

Usepa O. 2006. Iron Mountain Mine case study. Abandoned Mine Lands. pp. 17 Environmental Protection Agency, USA.

ZAJĄC A. 1978. Atlas of distribution of vascular plants in Poland (ATPOL). Taxon 27(5/6): 481-484.

ZAJĄC A. & ZAJĄC M. (eds.). 2001. Distribution Atlas of Vascular Plants in Poland. xii+714 pp. Edited by Laboratory of Computer Chorology, Institute of Botany, Jagiellonian University, Cracow.

ZARZYCKI K., TRZCIŃSKA-TACIK H., RÓŻAŃSKI W., SZELĄG Z., WOŁEK J. & KORZENIAK U. 2002. Ecological indicator values of vascular plants of Poland. In: Z. MIREK (ed.). Biodiversity of Poland 2, 183 pp. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.