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Monika Podgórska

Specific remnants of old iron-ore extraction sites as islands of plant species richness

Abstract: In the Old-Polish Industrial Region (Southern Poland, Central Europe), specific remnants of former iron-ore extraction occur. These interesting post-mining habitats influence the plant cover which emerges on them. In this paper, I analyzed the impact of the former iron-ore mining on the increase of plant species richness in forest communities. I analyzed the floristic composition of 100 phytosociological relevés (plots) made in the mining areas, their surroundings and 100 associated soil samples. I found that within the island communities developing in the former mining fields, there was a considerable increase in the number of species of native flora (in comparison with communities of non-transformed areas). This increase in species richness is caused chiefly by the increased proportion of species characteristic of the syntaxa from the *Querco-Fagetea* class – species exclusively attached to the mesophilous forest communities developing in gob piles whose limits are marked by the material extracted and scattered around in ancient times. My research suggested that in this case, mining activity exerted a positive influence on the biodiversity in forested areas, improving the quality of soils and creating mesophilous forest communities growing on remnants of former iron-ore extraction, which are specific islands among acidophilous forest communities growing in the non-transformed areas.

Keywords: Floristic composition, Habitat features, Native forest species, Old iron-ore mining sites, Positive influence, Gob piles

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1 Introduction

In terrestrial ecosystems – most often those occurring in areas where anthropogenic factors were at work in the past – processes of habitat fragmentation can be observed. This phenomenon occurs primarily in natural communities, e.g. in forests where the habitats are often fragmented by interspaced anthropogenic phytocoenoses as a result of human activities. These processes produce patches of vegetation occurring 'insularly'. Depending on the subject of given studies and also on the effects of various habitat variables, these mosaic communities could be considered in two dimensions: as islands of communities representing precursors of new phytocoenoses ('islands'), or as fragments of relict vegetation ('refuges').

Subjects associated with species richness on islands have often been described in the body of global publications [e.g. 1-3]. Some mechanisms governing the colonisation and spreading of species among oceanic islands are similar to those found on 'islands' developing inland – specific habitat types distinguished by their structure and function from the landscape prevailing in the given area, e.g. in relict fragments of forest communities [e.g. 4-6] or in synanthropic habitats created by anthropogenic activities of humans [e.g. 7-9]. These sites have often improved soil conditions, which is considered to be the main factor affecting species richness. This phenomenon is explained by varying environmental factors [e.g. 10,11] or historical and evolutionary processes [12,13].

Gob piles, the object of the studies described in the presented paper, are atypical islands in that they are specific habitats of forest vegetation which show unique properties.

1.1 Origin of gob piles – specific 'forest islands'

The term 'gob piles' refers to the specific remnants of former iron-ore mining. They are built by accumulated material left by old iron-ore extraction which took place in the Old-Polish Industrial Region (*Staropolski Okręg*

Przemysłowy) situated in the interfluve of the Vistula, Pilica, and Nida rivers (Southern Poland, Central Europe). This region was the oldest, and until the end of the 19th century, the largest iron-ore mining and iron-smelting industrial area in Europe [14].

The history of gob piles reaches back as early as the 12th century, which marked the beginning of iron-ore extraction using the deep-shafting method [15]. This method consisted of digging many narrow (0.5-1.5 m wide), fairly deep (several metres to several tens metres) shafts whose shaft-top looked like an ordinary well with a cranked wheel and winch. Iron ore was taken out of the extracted material brought to the surface, and the remaining useless material was piled around the shafts. Therefore, the gob sites are groups of old mine shafts surrounded by small heaps (0.5 – 3 m high), made up entirely of unprocessed material, extracted from deep rock layers. The gob piles are thus different from commonly occurring modification of terrain caused by mining activities, e.g. heaps of post-processing mining waste or large areas of strip mines [e.g. 16-18].

1.2 Study area

The study covered the Suchedniów Plateau (912 km^2) and Gielniów Hummock (700 km^2), two regions situated in the northern part of the Old-Polish Industrial Region. The area is the northern Mesozoic fringe of the Palaeozoic core of the Świętokrzyskie Mountains (Holy Cross Mountains) (Southern Poland, Central Europe) – (Fig. 1).

The mean annual air temperature in this area is 7.2°C, the average temperature in July is 18°C, and –2.7°C in January. The average annual relative air humidity reaches 82% and the average annual precipitation is 590 mm. The average annual number of days with snow cover is 66, and days with fog is 40. Average insolation reaches 6h/day (9-9.5h in summer, and 2-3h in winter).

The area of the Suchedniów Plateau is occupied by broad, flattened or domed hills (270 – 441 m a.s.l.), formed of Triassic sandstones and clays, whereas the hills on the Gielniów Hummock (208 – 408 m a.s.l.) are formed from an alternative series of Jurassic sandstones. On this substrate, poor, acidic, sandy or sandy-loamy soils are found (podzolic soils, or acid brown soils), which emerged from quartz-silicate series. Therefore, the landscape in the area is dominated by natural vegetation with prevalent acid beech forests and pine forests [19].

In deeper layers in both the Triassic formations (chiefly Lower Triassic) and Jurassic formations (Lower Jurassic), there are ore-bearing series, clays and clay shales, clay shales with ore insertions, clay siderites and spherosiderites subject to mining activities [15].

The chief objectives of the presented study include: 1) showing specific features of remnants of former iron-

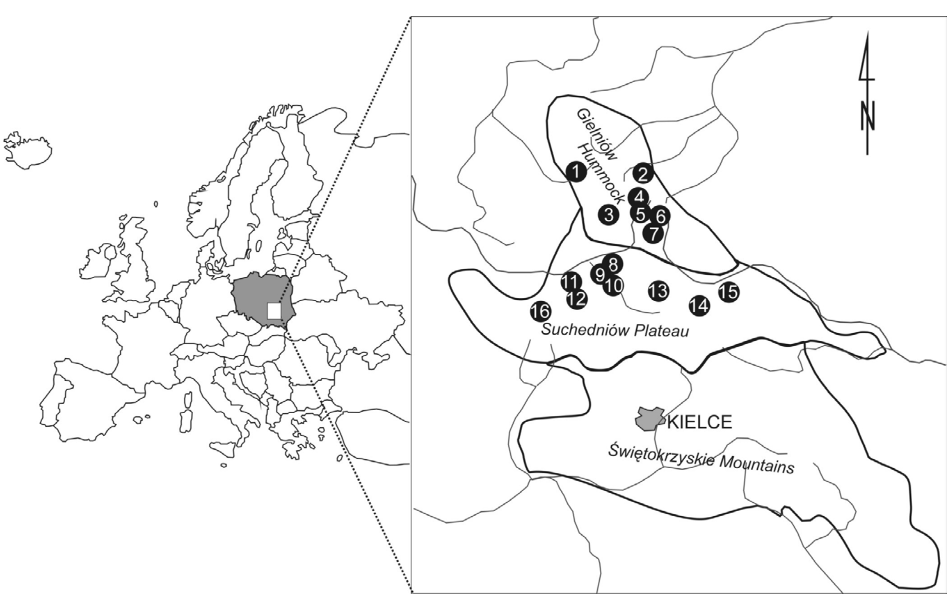

Figure 1: Localization of study area – the northern part of the Old-Polish Industrial Region (the northern part of the Świętokrzyskie Mountains) showing post-extraction fields (1-16), covering concentrations of gob piles; list of localities (numbers of relevés are shown in parentheses): 1 – Gowarczów (75, 76), 2 – Rzuców (47-50, 55-60), 3 – Wielka Wieś (89-92), 4 – Antoniów (19-24, 33-38), 5 – Antoniów 2 (25-31, 39-44, 61- 66), 6 – Borki (17, 18), 7 –Rędocin (11-16, 69-74), 8 – Mokra (45, 46, 51, 52), 9 – Błotnica (53, 54), 10 – Duraczów (1, 2), 11 – Skobelów (3-8), 12 – Adamek (9, 10), 13 – Świnia Góra (93-96), 14 – Dalejów (83-88), 15 – Kamienna Góra (67, 68, 75, 76, 81, 82), 16 – Gliniany Las (97, 98, 99, 100).

ore mining sites (gob piles); 2) indicating the differences in species composition (qualitative and quantitative) between the post-mining sites and non-transformed areas; 3) determining factors affecting the floristic richness in gob piles; 4) characterizing the relationships between selected variables (number of species, habitat parameters) and determining why gob piles result in plant communities rich in species, and which species prefer gob pile habitats; in other words, for which species does the floristic diversity in old mining areas arise?

2 Methods

2.1 Data collection

From 2008 to 2012 I made an inventory of 16 post-extraction fields (sites), covering concentrations of gob piles within an old mining area where iron ore was formerly extracted (Fig. 1). The inventory was based on maps, historical data and my own observations made during field exploration trips.

From 2010 to 2012, I performed 100 relevés (plots) in the study area over three vegetation seasons (July to August) according to the Braun-Blanquet phytosociological method (the area of a single relevé = 100m^2).

In order to determine the maximum floristic diversity of the plant communities developing on iron-ore extraction sites, I did the relevés on gob piles (50 relevés) in communities with different forest management systems and also in communities in which plants were growing spontaneously on the surfaces of relevés. In order to show the differences between insular communities developing on gob piles and the communities growing on unchanged areas, samples were taken from both gob pile plots as well as plots growing proximal to the gob pile plots (3 m from a given pile; resulting in an additional 50 relevés). This study thus includes the analysis of a total of 100 relevés (Fig. 1).

In order to determine the properties of gob pile material composition extracted in the mining process, and also to learn about the species-habitat relationships, I took soil samples in all 100 relevés (humus and mineral layer from a depth of 30 cm – 50 samples on gob piles and 50 in their surroundings). In all soil samples, pH values in distilled water were determined (in humus and mineral layer).

The syntaxonomical nomenclature was determined following Matuszkiewicz [20] while taxonomical nomenclature followed Mirek *et al.* [21].

2.2 Data analysis

I subjected to statistical analyses the floristic composition of 100 relevés made in the study area (each relevé was treated as a single sample).

In analysing the species richness within the communities occurring on gob piles, I took into account the following variables: the total number of species, the number of genera and families represented by the species, and the number of species of the *Querco-Fagetea* class.

The F-test was used to demonstrate the statistical difference between two principal groups of relevés – samples from gob piles (post-mining sites, mining area, iron-ore sites) as well as those from the surrounding areas (non-transformed area, undisturbed area) – with respect to selected variables (total number of species, the number of genera, families and the number of species of the *Querco-Fagetea* class). The differences were considered significant at $p \leq 0.01$.

To demonstrate the statistical difference between considered variables for the species growing on gob piles and in their surroundings, the Mann-Whitney U-test was used. The differences were considered significant at $p \leq 0.05$.

To present the relationship between the floristic richness of vegetation islands developing on gob piles and the habitat conditions provided by the material extracted in mining, regression analysis (Pearson's correlation coefficient) was applied.

The statistical analyses were carried out using 'Statistica 6.1'[22].

3 Results

3.1 General species richness

The analysis of 100 phytosociological relevés on the basis of the total number of species shows that relevés made in communities growing on iron-ore extraction sites have greater floristic richness than relevés made in communities developing in surrounding areas in every pair of relevés (Fig. 2). On the gob piles, the highest number of species was found in relevé 1 (as many as 55 species), the lowest (14 species) – in relevés 39 and 89 (the average number of species was 26). Much lower numbers of species were recorded in the relevés made in non-transformed areas, with the maximum number (22 species) recorded on relevé 2, while the minimum number (just 4 species) was observed in relevé 42 (the average number of species was 12).

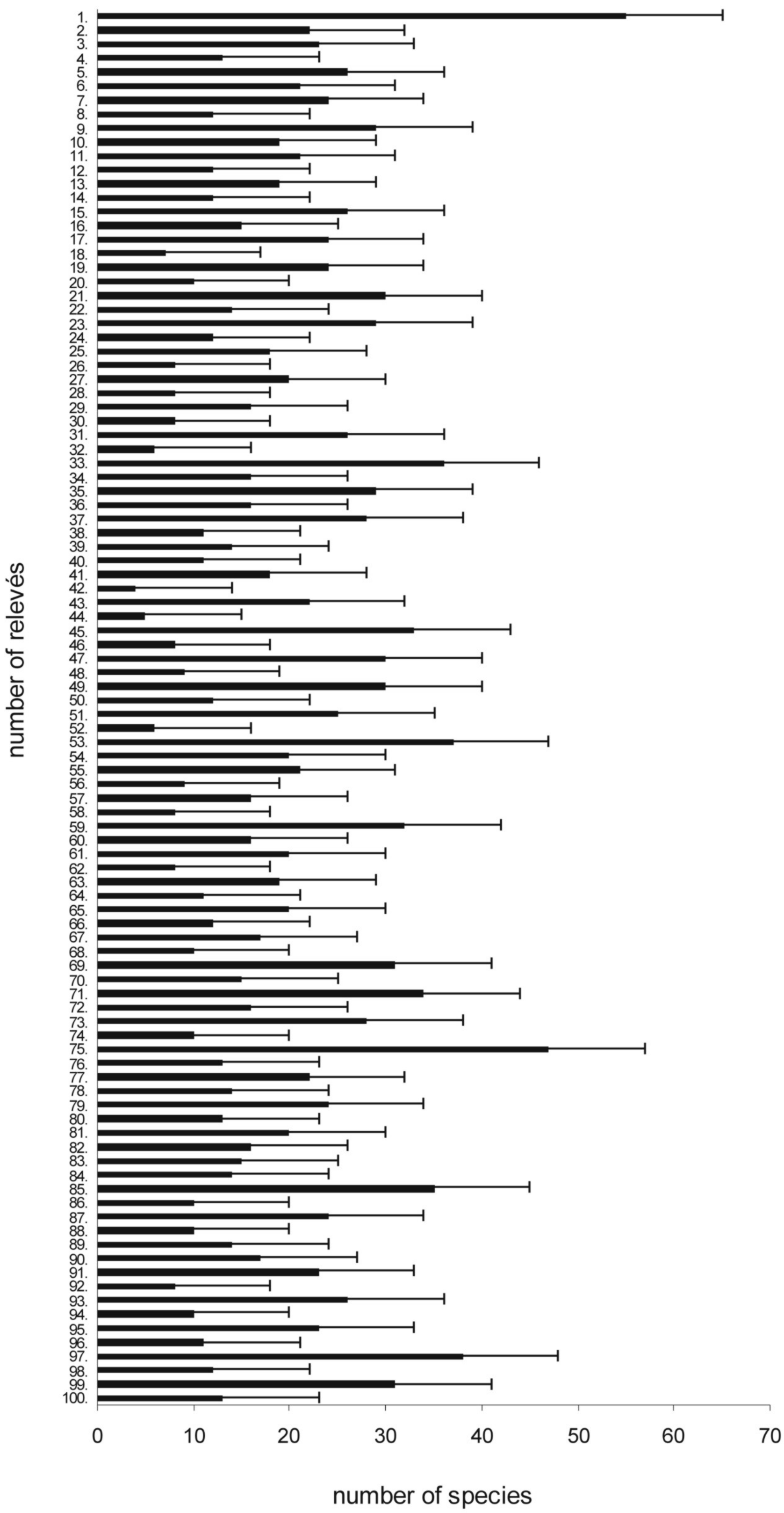

Figure 2: The analysis of 100 phytosociological relevés on the basis of the total number of species; relevés made in communities growing on gob piles are marked by odd numbers; relevés made in communities developing in surroundings are marked by even numbers (e.g. relevé 1 – gob piles; relevé 2 – surroundings of gob pile with relevé 1).

In all relevés made in the study area, a total of 173 species of vascular plants were noted. The analyses indicated that in relevés made in island communities growing on old mining fields, the number of species of vascular flora was over two times higher (169 species) than that found in undisturbed areas (70 species). The F-test (F = 119.745) indicated that the difference between the two groups of relevés was statistically significant as early as at p = 0.000001 (Fig. 3).

The vascular flora of the post-mining sites represents 127 genera of 54 families. The highest species richness was found in genera *Carex*, *Rubus*, *Dryopteris*, *Hieracium* and *Quercus*. The most species-rich families included: *Rosaceae*, *Asteraceae*, *Poaceae* and *Fabaceae*. This flora also contained 31 single-species families (Table 1). In undisturbed areas, vascular flora was represented by 56 genera of 32 families. The highest numbers of species were found in *Rosaceae*, *Poaceae* and *Asteraceae* (Table 1).

The differences in the numbers of families and genera between the two groups of relevés (gob piles and their surroundings) measured with the F-test were statistically significant at p = 0.000001 (for genera; F = 159.75) and p = 0.00001 (for families; F = 33.084).

3.2 Species characteristic of the *Querco-Fagetea* class – the chief factor affecting the increase in biodiversity in vegetation islands on gob piles

On both gob piles and in their surroundings developing forest communities dominated by forest and shrub species. Among them the most numerous groups comprised general forest species and species characteristic of the *Querco-Fagetea* class. However, on vegetation islands, the number of species in these groups was much higher than the number found in areas not transformed by old iron-ore mining activities.

The group of general forest species included plants commonly occurring in various types of forest communities, having a broad range of ecological tolerance (e.g. *Athyrium filix-femina*, *Hieracium murorum* and *Fragaria vesca*). On the old mining sites, 34 species of this group were found, whereas on non-transformed sites, 27 species were noted. Most of them did not show high constancy in the phytosociological relevés, often occurring sporadically, and did not have high degrees of coverage using the Braun-Blanquet scale (except *Ajuga*

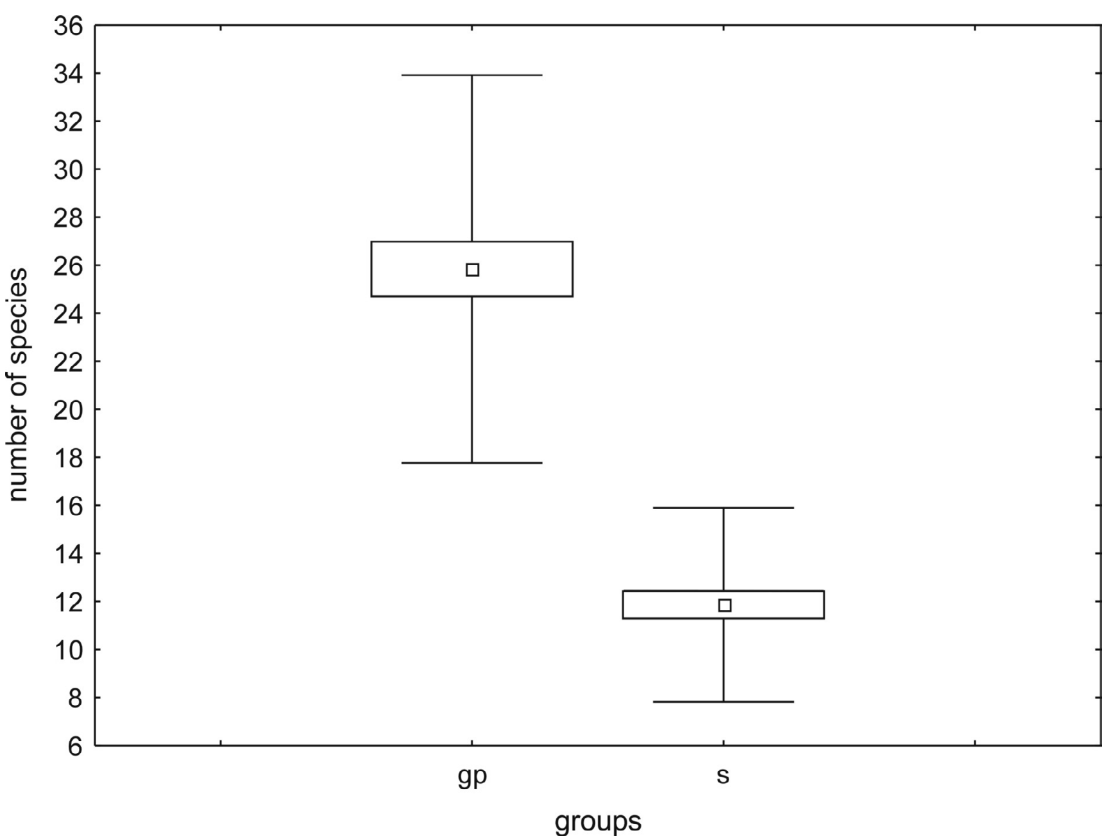

Figure 3: Comparison of total number of species growing on gob piles (gp) and their surroundings (s).

Table 1: Number of genera and species in families occurring on gob piles (gp) and surroundings (s)

Name of family		No. of genera		No. of species	
gp	**s**	**gp**	**s**	**gp**	**s**
Aceraceae	*Aceraceae*	1	1	2	2
Apiaceae	*Apiaceae*	7	1	7	1
Araliaceae	-	1	-	1	-
Aristolochiaceae	-	1	-	1	-
Asteraceae	*Asteraceae*	10	4	14	5
Betulaceae	*Betulaceae*	2	1	3	1
Boraginaceae	-	1	-	1	-
Campanulaceae	-	2	-	2	-
Caprifoliaceae	*Caprifoliaceae*	3	1	4	1
Caryophyllaceae	*Caryophyllaceae*	2	1	2	1
Celastraceae	-	1	-	2	-
Convallariaceae	*Convallariaceae*	2	2	3	2
Cornaceae	-	1	-	1	-
Corylaceae	*Corylaceae*	2	2	2	2
Cupressaceae	*Cupressaceae*	1	1	1	1
Cyperaceae	*Cyperaceae*	1	1	6	3
Dennstaedtiaceae	*Dennstaedtiaceae*	1	1	1	1
Dryopteridaceae	*Dryopteridaceae*	2	2	5	4
Equisetaceae	-	1	-	2	-
Ericaceae	*Ericaceae*	1	1	2	2
Fabaceae	-	7	-	8	-
Fagaceae	*Fagaceae*	2	2	5	4
Geraniaceae	-	1	-	1	-
Hypericaceae	*Hypericaceae*	1	1	1	1
Juncaceae	*Juncaceae*	1	2	1	2
Lamiaceae	*Lamiaceae*	6	2	7	2
Liliaceae	-	1	-	1	-
Loranthaceae	-	1	-	2	-
Lycopodiaceae	*Lycopodiaceae*	1	1	1	1
Monotropaceae	*Monotropaceae*	1	1	1	1
Oleaceae	-	1	-	1	-
Onagraceae	-	3	-	4	-
Orchidaceae	-	4	-	4	-
Oxalidaceae	*Oxalidaceae*	1	1	1	1
Pinaceae	*Pinaceae*	4	4	4	4
Poaceae	*Poaceae*	9	5	11	6
Polygonaceae	-	2	-	2	-
Primulaceae	*Primulaceae*	2	2	3	2
Pyrolaceae	-	4	-	5	-
Ranunculaceae	*Ranunculaceae*	4	1	5	1
Rhamnaceae	*Rhamnaceae*	1	1	1	1
Rosaceae	*Rosaceae*	10	7	17	10
Rubiaceae	-	4	-	4	-
Salicaceae	*Salicaceae*	2	1	2	1
Saxifragaceae	-	1	-	1	-
Scrophulariaceae	*Scrophulariaceae*	2	2	5	3
-	*Thelypteridaceae*	-	1	-	1
Thymelaeaceae	-	1	-	1	-
Tiliaceae	-	1	-	1	-
Trilliaceae	-	1	-	1	-
Ulmaceae	-	1	-	1	-
Urticaceae	-	1	-	1	-
Valerianaceae	*Valerianaceae*	1	1	1	1
Violaceae	*Violaceae*	1	1	2	1
Woodsiaceae	*Woodsiaceae*	1	1	1	1
		N=127	**N=56**	**N=169**	**N=70**

reptans, *Luzula pilosa*, *Maianthemum bifolium*, *Mycelis muralis* and *Oxalis acetosella* – Table 2). Their increased proportions on the post-mining areas are caused by a varied micro-relief of gob piles, and, although they affect the increase in biodiversity, they lack the potential to differentiate communities on post-mining sites (species with higher constancy and cover degrees which co-occur on gob piles grow in communities developing in surroundings, with parallel values).

Regarding the species characteristic of the syntaxa of the *Querco-Fagetea* class, the situation appears to be quite different. Even as early as the fieldwork stage, it was noted that the species of this group appeared in each gob pile relevé with a high degree of coverage (in many cases), but they were almost totally absent in the surrounding areas (Table 2). In the insular communities developing on post-mining sites, as many as 47 species characteristic of the syntaxa of the *Querco-Fagetea* class were found, while only 10 species of this group occurred in non-transformed areas. Additionally, in the surrounding areas, these species had low constancy and cover degrees (beyond *Fagus sylvatica* which in many cases was planted).

For the phytosociological relevés made in the communities developing on gob piles, in particular, the number of species characteristic of the syntaxa of the *Querco-Fagetea* class ranged from 2-20 with an average of 9 species per relevé, contributing greatly to the increase in floristic richness in these areas. In non-transformed communities, the number of species per relevé ranged from 0 (in as many as 7 relevés, none of the species of this class was found) to 4 species, with the average number being merely 1 species per relevé.

The difference in the number of sites between the two groups of relevés (gob piles and their surroundings) where the species characteristic of syntaxa of *Querco-Fagetea* class occurred measured by the F-test (F = 153.331) was statistically significant at p = 0.000001 (Fig. 4). In the case of some species, e.g. *Sanicula europaea*, and *Viola reichenbachiana*, the differences measured by the Mann-Whitney U-test were found to be highly statistically significant at p = 0.0000001 (Table 2).

This situation resulted in the remarkable differences between these two types of communities which developed on post-mining areas and in their surroundings.

On gob piles, communities of fertile mesophilous deciduous forests developed with a mosaic of species characteristic of the prevailing syntaxa belonging to the *Querco-Fagetea* class (Table 2, column A and B). On

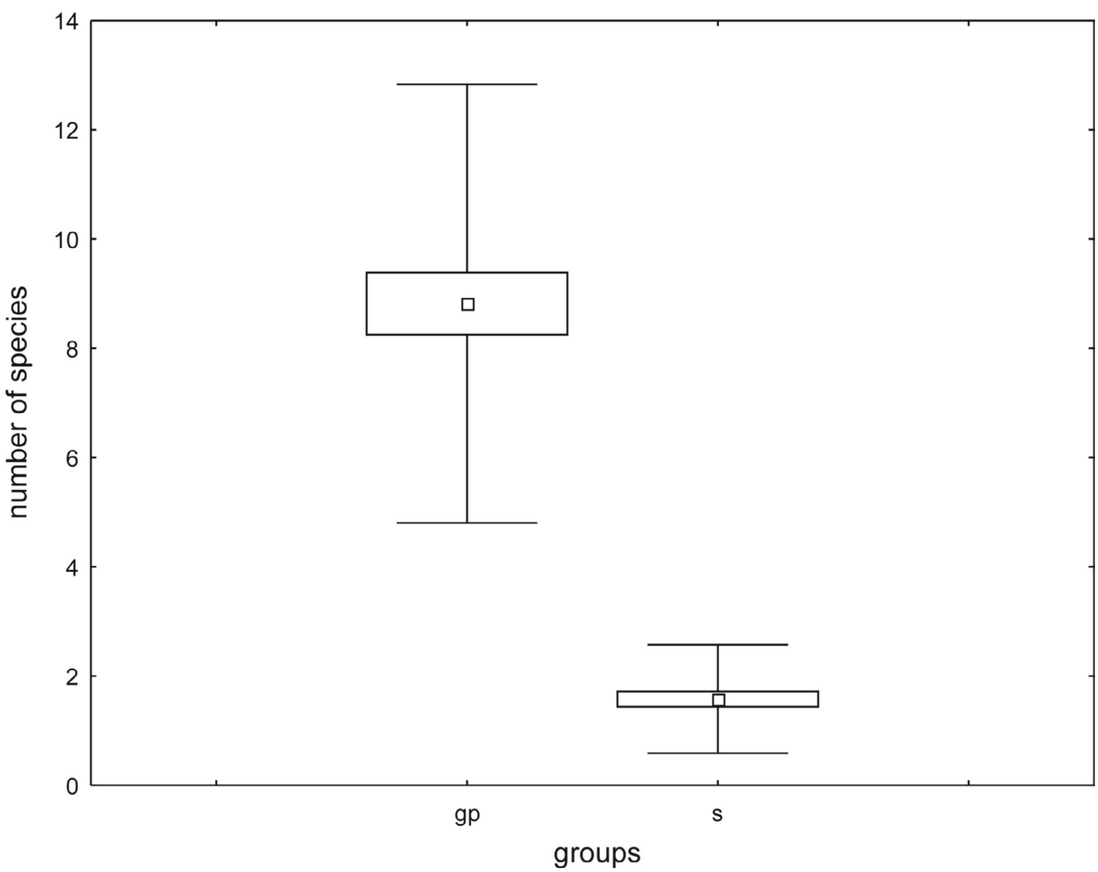

Figure 4: Comparison of number of species characteristic for *Querco-Fagetea* class occurring on gob piles (gp) and their surroundings (s).

Table 2: Comparison of forest communities growing on gob piles (gp; A – spontaneously or with appropriate forest management; B – with trees planted incompatible to habitat) and in their surroundings (s; C) with respect to the floristic composition of species occur in phyto-sociological relevés (without accompanying species with one station only); P denotes the probability of difference in frequency of species (Mann-Whitney U-test)

Name of species	Average cover [%]			Constancy			No. of stations		P
	A	B	C	A	B	C	gp	s	
Trees and shrubs:									
Querco-Fagetea									
Fagus sylvatica	892.8	570.3	1265.9	V	III	III	38	29	.
Carpinus betulus	442.6	55.2	125.2	III	II	I	19	6	0.01
Corylus avellana	105.7	45.5	35.4	III	II	I	20	5	0.001
Acer platanoides	55.1	0.1	.	II	I	I	3	.	.
Daphne mezereum	10.8	0.4	.	II	I	.	17	.	0.00001
Cerasus avium	17.8	.	.	II	I	I	4	.	0.05
Euonymus verrucosa	45.1	.	.	II	.	.	7	.	0.01
Acer pseudoplatanus	0.1	.	17.6	I	I	I	1	1	.
Padus avium	0.5	0.1	.	I	I	.	6	.	0.05
Lonicera xylosteum	35.2	17.6	.	I	I	.	6	.	0.05
Ulmus glabra	0.1	10.1	.	.	.	.	4	.	0.05
Fraxinus excelsior	0.1	.	.	I	.	.	1	.	.
Tilia cordata	0.2	.	.	I	.	.	2	.	.
Vaccinio-Piceetea									
Abies alba	323	660.7	843.1	III	V	III	30	25	.
Pinus sylvestris	55.7	258	455.8	II	III	III	22	25	.
Picea abies	.	35.3	0.1	I	II	II	4	1	.
Accompanying species:									
Rubus hirtus	105.6	75.2	143.3	III	II	I	20	14	.
Viburnum opulus	38.3	10.6	0.1	III	II	I	21	1	0.00001
Frangula alnus	130.9	10.8.	91.5	II	III	II	25	21	.
Sorbus aucuparia	0.1	37.5	.	II	III	II	2	.	.
Larix decidua	130.3	0.5	35.5	II	II	I	12	4	0.05
Populus tremula	110.4	17.7	132.8	II	II	I	11	9	.
Betula pendula	55.9	5	105.6	II	I	II	9	11	.
Quercus petraea	148.3	0.1	205.3	II	I	II	11	11	.
Prunus spinosa	88.1	.	72.5	II	I	I	14	3	0.01
Rubus idaeus	0.8	15.3	22.8	I	II	I	14	5	0.05
Quercus robur	108.1	75.2	205.2	I	I	I	12	10	.
Pyrus communis	17.6	.	.	I	I	I	2	.	.
Herbs:									
Querco-Fagetea									
Sanicula europaea	481.4	205.8	.	V	IV	.	46	.	0.0000001
Viola reichenbachiana	71.8	66.4	0.4	V	V	I	45	4	0.0000001
Anemone nemorosa	21.9	88.4	10.7	IV	IV	I	38	9	0.000001
Carex digitata	68.4	83	.	III	III	.	25	.	0.000001
Hepatica nobilis	170.3	42.9	.	III	II	.	19	.	0.00001
Actaea spicata	11.2	5.4	.	III	II	.	19	.	0.00001
Dryopteris filix-mas	10.5	5.3	5	II	I	I	11	1	0.01
Carex sylvatica	53.3	35.2	.	II	I	.	16	.	0.0001
Stachys sylvatica	10.5	0.3	.	II	I	.	10	.	0.001
Epipactis helleborine	10.5	0.1	.	II	I	.	8	.	0.01
Melica nutans	28.1	15.1	.	II	I	.	13	.	0.001
Asarum europaeum	62.8	.	.	II	.	.	8	.	0.01
Galeobdolon luteum	197.7	.	.	II	.	.	12	.	0.001
Pulmonaria obscura	92.6	.	.	II	.	.	7	.	0.01
Lathyrus vernus	10.3	0.2	.	I	I	.	7	.	0.01
Paris quadrifolia	0.5	5.1	.	I	I	.	7	.	0.01
Neottia nidus-avis	0.2	0.1	.	I	I	.	3	.	.
Festuca gigantea	0.3	0.1	.	I	I	.	4	.	0.05

continued Table 2: Comparison of forest communities growing on gob piles (gp; A – spontaneously or with appropriate forest management; B – with trees planted incompatible to habitat) and in their surroundings (s; C) with respect to the floristic composition of species occur in phytosociological relevés (without accompanying species with one station only); P denotes the probability of difference in frequency of species (Mann-Whitney U-test)

Name of species	Average cover [%]			Constancy			No. of stations		P
	A	B	C	A	B	C	gp	s	
Querco-Fagetea (continued):									
Phyteuma spicatum	0.1	5.2	.	I	I	.	4	.	0.05
Brachypodium sylvaticum	0.2	0.1	.	I	I	.	3	.	.
Circaea alpina	0.3	.	.	I	.	.	3	.	.
Carex remota	0.1	.	.	I	.	.	1	.	.
Chrysosplenium alternifolium	0.1	.	.	I	.	.	1	.	.
Circaea lutetiana	0.1	.	.	I	.	.	1	.	.
Galium schultesii	17.6	.	.	I	.	.	2	.	.
Galium odoratum	92.5	.	.	I	.	.	3	.	.
Astrantia major	5.2	.	.	I	.	.	4	.	0.05
Lilium martagon	5.2	.	.	I	.	.	3	.	.
Polygonatum multiflorum	0.4	.	.	I	.	.	4	.	0.05
Aegopodium podagraria	0.4	.	.	I	.	.	4	.	0.05
Milium effusum	0.1	.	.	I	.	.	1	.	.
Campanula trachelium	0.1	.	.	I	.	.	1	.	.
Melittis melissophyllum	5	.	.	I		.	1	.	.
Poa nemoralis	.	0.2	0.1	.	I	I	2	1	.
Vaccinio-Piceetea									
Vaccinium myrtillus	43.2	163.1	805.7	III	V	IV	31	36	.
Dryopteris dilatata	0.3	15.3	0.6	I	II	I	9	6	.
Orthilia secunda	0.2	10.6	.	I	II	.	10	.	0.001
Melampyrum pratense	0.1	0.3	10.1	I	I	I	4	3	.
Pyrola minor	0.1	0.3	.	I	I	.	4	.	0.05
Moneses uniflora	0.1	0.1	.	I	I	.	2	.	.
Monotropa hypopitys	0.1	.	0.2	I	.	I	1	2	.
Lycopodium annotinum	.	0.2	17.6	.	I	I	2	2	.
Trientalis europaea	.	0.3	5.7	.	I	I	3	8	.
Vaccinium vitis-idaea	.	0.3	17.8	.	I	I	3	4	.
Chimaphila umbellata	.	17.5	.	.	I	.	1	.	.
Pyrola rotundifolia	.	0.1	.	.	I	.	1	.	.
Accompanying species:									
Oxalis acetosella	533.5	255.3	218.5	V	V	IV	50	31	0.0001
Maianthemum bifolium	113.6	185.3	244.1	IV	V	IV	41	38	.
Luzula pilosa	21.7	16.2	36.7	IV	IV	III	36	24	.
Ajuga reptans	86.2	25.4	0.1	IV	III	I	33	1	0.000001
Mycelis muralis	36.1	26.1	0.5	III	IV	I	34	5	0.000001
Athyrium filix-femina	38.2	15.9	28.1	II	III	I	24	9	0.01
Dryopteris carthusiana	0.7	31.5	1.4	II	III	II	18	14	.
Hieracium murorum	10.9	38.2	5.4	II	III	I	21	5	0.01
Fragaria vesca	28.4	35.6	5.2	II	II	I	20	3	0.01
Solidago virgaurea	22.9	20.5	5.8	I	III	I	15	9	.
Veronica officinalis	5.3	10.4	0.4	I	II	I	10	4	.
Pteridium aquilinum	0.4	5.1	178.2	I	I	II	6	17	0.05
Carex pilulifera	0.3	0.4	16.1	I	I	II	7	14	.
Deschampsia caespitosa	18	0.2	0.2	I	I	I	8	2	.
Calamagrostis villosa	0.2	5	57.7	I	I	I	3	6	.
Geum urbanum	5.5	0.1	.	I	I	.	7	.	0.01
Platanthera chlorantha	0.1	5.1	.	I	I	.	3	.	.
Senecio ovatus	0.2	10.1	.	I	I	.	5	.	0.05
Veronica chamaedrys	10.4	.	5.1	I	.	I	6	2	.
Cruciata glabra	60.3	.	.	I	.	.	6	.	0.05
Hedera helix	42.8	.	.	I	.	.	5	.	0.05

undisturbed sites, acidiphilous forest communities (which are low in species richness) occurred. Their undergrowth vegetation was dominated by species characteristic of the *Vaccinio-Piceetea* class (Table 2, column C).

3.3 Factors conditioning the increased proportion of species of the *Querco-Fagetea* class

As a result of analyses of soil samples, major differences were found in both mechanical and chemical composition between the substrates in disturbed and undisturbed sites. The gob piles were built of loamy material (heavy loams, and clays), whereas surrounding areas were composed of sandy formations (chiefly sands, and more rarely sandy-loams). The soils samples from post-mining sites had higher pH values compared with undisturbed sites. They contained material from the ore-bearing horizon (from marl-silicate series) brought to the surface during mining operations (with e.g. marls). In undisturbed areas, poor and acid soils occurred, which emerged from quartz-silicate series.

When analysing the relationship between the number of species of the *Querco-Fagetea* class and soil pH at the sites of relevés taken on gob piles and in their surroundings, a clear difference was noted (Fig. 5). In the non-transformed areas, the pH indicated the strongly acidic reaction of soil in the range from pH = 3.8 to pH = 4.6, whereas on post-mining gob piles the pH indicated equal tendencies for slightly acidic, neutral, or even alkaline soil reactions (from pH = 5.4 to pH = 7.1), which resulted in increased proportions of neutrophytes and calciphilous species of the *Querco-Fagetea* class.

The regression analysis between the pH values and the number of species of the *Querco-Fagetea* class noted in the study area demonstrated a strong positive correlation (Y = -19.4764968 + 7.23141449X; r^2 = 0.765648; Pearson correlation coefficient r = 0.8750 at level of significance p = 0.000001; t = 17.89342) (Fig. 5).

When the properties of soil humus were analysed, it was found that in the mesophilous forest communities occurring on post-mining sites where deciduous tree species prevailed (either spontaneously growing, or planted in accordance with the type of habitat), the humus was slightly acidic (pH = 5.5-6.2) (Table 1, column A). When coniferous trees prevailed (in most cases because of artificial tree-planting), the humus was more acidic (pH = 4.5-5.1) (Table 1, column B; cf. Discussion section).

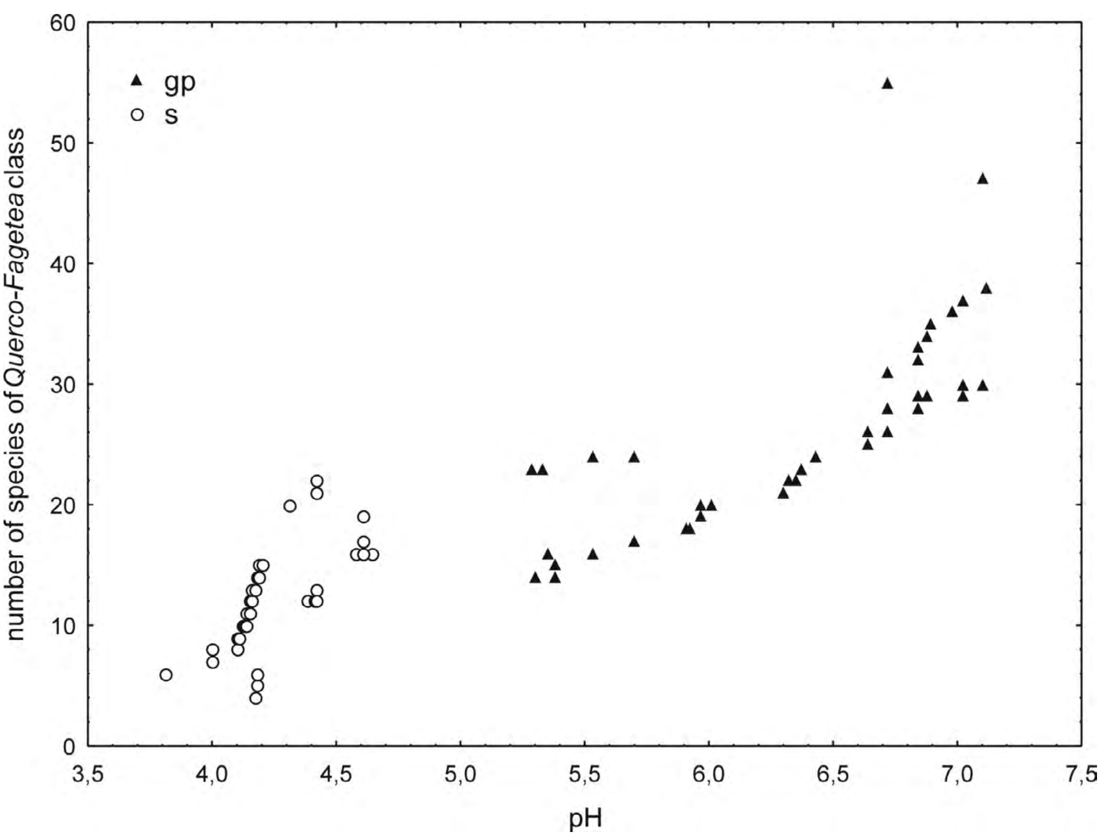

Figure 5: Relationship between the number of species of the *Querco-Fagetea* class and soil pH; gp – sites of relevés taken on gob piles, s - sites of relevés taken in their surroundings.

In the non-transformed sites (Table 1, column C) the occurrence of strongly acidic (pH = 3.2 – 3.8) mor-type humus was found in all samples.

4 Discussion

In different parts of the world, studies carried out on heaps within old mining sites, which may be treated as inland islands because of the different habitat conditions compared with their surroundings, often show an increased number of species [7,16,23]. In these anthropogenic habitats, the increase in species richness is caused primarily by higher numbers of species of alien origin [9,24] which easily colonise new ecological niches devoid of competition.

However, on the studied remnants of old iron-ore extraction sites in the Old-Polish Industrial Region, one can see the increased species richness caused by the increased numbers of species from native flora coupled with an almost total lack of anthropophytes, which is an extremely rare phenomenon in post-mining sites. These native species create mesophilous forest communities. The increase of number of native species is interrelated with specific soil features, which create richer habitats. These new habitats are colonized by species that could not exist in the areas surrounding gob piles because of nutrient-poor soils. A similar phenomenon has been observed on different outcrops which create new, unique ecological niches for species, e.g. serpentine outcrops [e.g. 25-27].

The various types of islands, including inland ones [28], very often show similarity to proximal areas. However, in the study area, major differences were found in the floristic composition between the insular communities of post-mining sites and their nearest surroundings. In the plant communities growing on gob piles, neutrophytes and calciphilous species of the *Querco-Fagetea* class predominated, whereas on non-transformed areas oligotrophic and acidic species of the *Vaccinio-Piceetea* class occurred. Such significant floristic differences led to the emergence of two distinctly different types of vegetation, separated by habitat conditions. In post-mining sites, the communities of mesophilous deciduous forest developed (their substrate is made of loamy material with the addition of marls, extracted by miners many centuries ago), whereas in their surroundings on poor, acid, and sandy soils characteristic of the region, various types of coniferous communities or acid beech forests developed. Therefore, the gob piles constituted the islands of vegetation similar to oak-hornbeam forests among acidophilous forest communities growing in the non-transformed sites in the study area.

The changes which occurred in the habitat under anthropogenic impact (in this case – mining activities) are advantageous as they have led to increases in floristic diversity. A similar phenomenon was observed by Junqueira *et al.* [29] in the Brazilian Amazonia forest, where anthropogenic soils became richer habitat than non-transformed soils. ‘Secondary forests’ developed there, composed of native species showing more floristic richness than the primary forests, which, in the end, led to increased biodiversity.

In different plant communities (especially in forest communities), there is a positive correlation observed between soil pH and species richness [12,13,30].

Pärtel [12] and Ewald [13] hypothesized that in Central European flora the relationship between local species richness and soil pH is determined by the pool of regional species, and it is a result of historical and evolutionary processes that took place on high pH soils. For instance, if alkaline soils are historically common in a region, one would expect a positive correlation between soil pH and plant species richness, whereas if acidic soils are historically common, a negative correlation would be expected.

My research shows that in forest communities growing on gob piles, a large number of species is noted (in comparison to their surroundings). This is primarily because of the higher pH value (Fig. 5), in spite of the fact that the northern foreland of the Świętokrzyskie Mountains is dominated by acidic, oligotrophic soils (in the study area the soils with higher pH occur on post-mining sites only). In this case, the positive correlation between species abundance and soil pH is connected more with the anthropogenic factor, which created more favourable habitat conditions for plant growth, than with the historical and evolutionary processes. As a result of mining extraction, primarily acidic, sandy soil formations were covered by material brought from deep rock layers. This in turn became soil parent material for new, more fertile soils. The soils on gob piles with elevated pH values created considerably richer habitats for the species of the *Querco-Fagetea* class, a condition which did not occur in the areas proximal to the gob piles. The limit of the occurrence of these species is marked by the spread of an extracted overlayer.

Moreover, Schuster & Diekmann [11] claimed that at a pH of about 5 to 6, both acidophilous and calciphilous species may be able to coexist, while at a lower or higher pH the numbers of tolerant species decline. On gob piles, the pH value is in the range of pH = 5.4 to pH = 7.1, which can additionally affect the increase of species richness on mining sites (in some cases on gob piles acidic species e.g. *Vaccinium vitis-idaea* and species which prefer higher pH value e.g. *Asarum europaeum* coincide [31]).

It is worth mentioning that in some cases, forest management practices also affect the floristic composition and physiognomy of newly-developed phytocoenoses on post-mining sites. The gob piles on which no management practices are conducted undergo spontaneous succession resulting in a significant increase in the number of syntaxa characteristic of the *Querco-Fagetea* class. These communities have a species composition very similar to oak-hornbeam forests. The acidophilous species characteristic of the V*accinio-Piceetea* class occur sporadically and are less viable (Table 1, column A). In phytocoenosis with planted tree species incompatible with the habitat (e.g. *Pinus sylvestris*), increase in numbers of acidophilous species in the forest floor vegetation was observed, although herbaceous species characteristic of the *Querco-Fagetea* class still form the principal foundation of the flora in these post-mining communities (Table 1, column B).

Additionally, in phytocoenosis where inappropriate forest management was abandoned several dozen years ago, pines presently constitute only a small addition to the forest stand (Table 1, column A), and acidophilous species are almost completely replaced by species characteristic of the *Querco-Fagetea* class. A similar process of ‘disappearance’ of acidophilous species was observed e.g. by Medwecka-Kornaś [32] in the forests of southern Poland.

5 Conclusions

1) The analyses of phytosociological relevés indicate that within the island communities developing in the former mining fields, there is a considerable increase in the number of species of native flora (in particular species characteristic for the syntaxa of the *Querco-Fagetea* class). These species are almost exclusively attached to the communities developing on gob piles – specific remnants of the former exploitation of iron ores.

2) Forest communities growing on the post-mining gob piles have a floristic composition diametrically different from their surroundings. On transformed areas these phytocoenoses are similar to oak-hornbeam forests, which are dominated by *Querco-Fagetea* class species, whereas on non-transformed areas acidophilous communities dominated by developing *Vaccinio-Piceetea* class species.

3) As a result of mining extraction, primarily acidic, sandy soil formations were covered by clays with marls brought from deep rock layers; these became a new soil parent material for newly forming soils.

4) Remnants of old iron-ore mining sites have improved the quality of soils, and at the same time, generated an increase in floristic diversity and emergence of new communities.

5) In this study, mining activity has exerted a positive influence on biodiversity in forested areas, inducing an increase in the number of native plant species developing on gob piles, specifically, islands of fertile, mesophilous forest communities among acidophilous forest communities of the northern foreland of the Świętokrzyskie Mountains.

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