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THE FLORA AND VEGETATION OF AN OLD SOLVAY PROCESS TIP IN JAWORZNO (UPPER SILESIA, POLAND)

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ABSTRACT

This paper demonstrates the flora, plant communities and substrates of an old solvay process spoil tip in Upper Silesia, Poland. In an area of 15 000 m^2 there are growing 136 vascular plant species. The flora is characterised by the preponderance of Asteraceae – species and long-lived perennial herbs, many of them coming from meadows and grasslands. Ninety-five percent of species are apophytes despite the anthropogenic origin of the site. A majority of species are associated with moderately dry, base-rich soils with low or moderate levels of nitrogen. The site is shown to be an important refuge for some protected species, montane species and other elements uncommon in the local flora.

An analysis of a series of samples used a methodology based on the assessment of percentage cover of particular species and multivariate analysis based on TWINSPAN. Both suggested a relatively high overall similarity between the samples with minor variations associated with moister substrates.

Elemental analysis and pH determinations of soil samples associated with the relevés revealed a narrow range of pH and an absence of any strong concentrations of heavy metals. A redundancy analysis of the soil-plant relationships suggested that the strongest trend of differentiation was most closely associated with a phosphate gradient, and the next strongest was pH and possibly waterlogging. The most species-rich vegetation was associated with low phosphate and high pH levels.

The results could be interpreted to suggest that processes of soil development and plant succession are slow but nevertheless perceptible, with implications for future loss of diversity. The vegetation constitutes an assemblage essentially of one type showing only weak relationships with described vegetation types such as *Molinio-Arrhenatheretea* meadow, *Festuco-Brometea* grassland and *Caricetalia davallianae* mire. The results also suggest that the vegetation of the site is of considerable value for nature conservation. The site should be protected and be the subject of further research.

KEY WORDS: Solvay process spoil, flora analysis, vegetation analysis, rare, protected and mountain plant species, nature conservation evaluation.

INTRODUCTION

Various types of waste land cover a significant area in industrial Upper Silesia. Each site represents an unusual and often unique set of chemical and physical conditions for the establishment of colonising organisms. Man-made habitats such as these present important opportunities for scientific investigation. Many have already been the subject of biological and ecological investigation e.g. Ash et al. (1994), Rostański (1998), Shaw (1992, 1998), Tokarska-Guzik et al. (1991), Turnau and Rybka (1991) and Woźniak (1998).

Many authors have considered and assessed the role of anthropogenic habitats in the process of establishing and maintaining biodiversity (Buszman et al. 1993; Hind 1956-57; Trzcińska-Tacik 1966; Tokarska-Guzik and Rostański 1996). Many examples show that these waste lands can be covered with interesting vegetation and that even rare plant species can be found there. The importance of many post-industrial sites has already been recognised as refuges for protected and rare plants (Greenwood and Gemmell 1978; Hind 1956-1957; Kelcey 1975; Tokarska-Guzik 1991a). This seems to be particularly true for lime waste heaps. Tokarska-Guzik (1996) commented on the significance of 6 lime waste tips in Poland and England as refugia for protected and regionally rare species. Wilkoń-Michalska and Sokół (1968) reported 249 species of flowering plants from lime spoil mounds in the Noteć valley in Poland, including many uncommon species. Lee and Greenwood (1976) described species-rich vegetation characteristic of base-rich habitats which are otherwise absent from the county, on calcareous waste from salt and chemical industries in Cheshire, UK. Vegetation on calcareous waste from the Leblanc process at Nob End in Greater Manchester, UK was given protected site ("Site of Special Scientific Interest") status in 1988 on account of its unusual flora (Shaw and Halton 1998).

The solvay process tip or "soda heap" at Jaworzno, Upper Silesia seems to be another example of this phenomenon (Tokarska-Guzik 1991a, 1996). The aim of the present study was to describe, characterise and determine the nature conservation value of the vegetation of the Jaworzno site and to relate the floristic composition of the vegetation and its variation to soil characteristics. A range of approaches have been used in the survey and analysis of the vegetation, allowing a comparison of phytosociological methods and multivariate computer analyses. The site at Jaworzno has been the subject of systematic observation for some time (Tokarska-Guzik 1991a, 1996, 1999) with the first botanical records made in the 1980s (Celiński et al. 1982; Tokarska-Guzik 1991b). This period of observation allows the present analysis to be placed in the context of dynamic changes in the vegetation and its persistence.

SITE, MATERIALS AND METHODS

Site description

The study area is located within a 20 ha site called Wapniówka, which could be translated as "lime place", after the lime heaps which cover 50% of the site with an average height of 4 m. The site, shown in Fig. 1, lies in the Jaworzno Hills in the Silesian Upland (Grid Ref. 50° 18'; 19° 10') and is an abandoned solvay process slurry tip from a former soda factory.

The Szczakowa window glass factory, formerly an Austrian soda factory, to the west of the site produced soda until 1911 using the Solvay process. The process produced "white seas" of calcium chloride as an aqueous suspension and the present day heaps probably represent the places where it was deposited.

Attempts to assess the potential of the waste material either as a fertiliser or to fill nearby dolomite extraction pits have shown that the material contains too high concentrations respectively of lead and sulphate ions for these two purposes (unpublished material gathered by the existing window glass factory Szczakowa S. A.). On the other hand, research carried out by the Institute of Fertilisation in Puławy for the glass factory (unpubl.) showed that the lime waste had the following properties:

– very good deacidification potential, particularly for soils poor in lime and magnesium
– a significant proportion of magnesium
– higher chemical activity compared with ordinary lime fertilisers
– no NaCl addition as an admixture
– low levels of heavy metals
– a paste-like consistency throughout the depth of the heaps

The study area

The part of the site which was the subject of the current investigation is a c. 2 ha. 'D'-shaped plateau c. 200 × 100 m. It is isolated on all sides by steep, more or less bare, vertical eroded banks c. 3 m high. The study area as a whole is more or less horizontal with an undulating microtopography, mostly within the range of 20 cm, varying in moisture content but

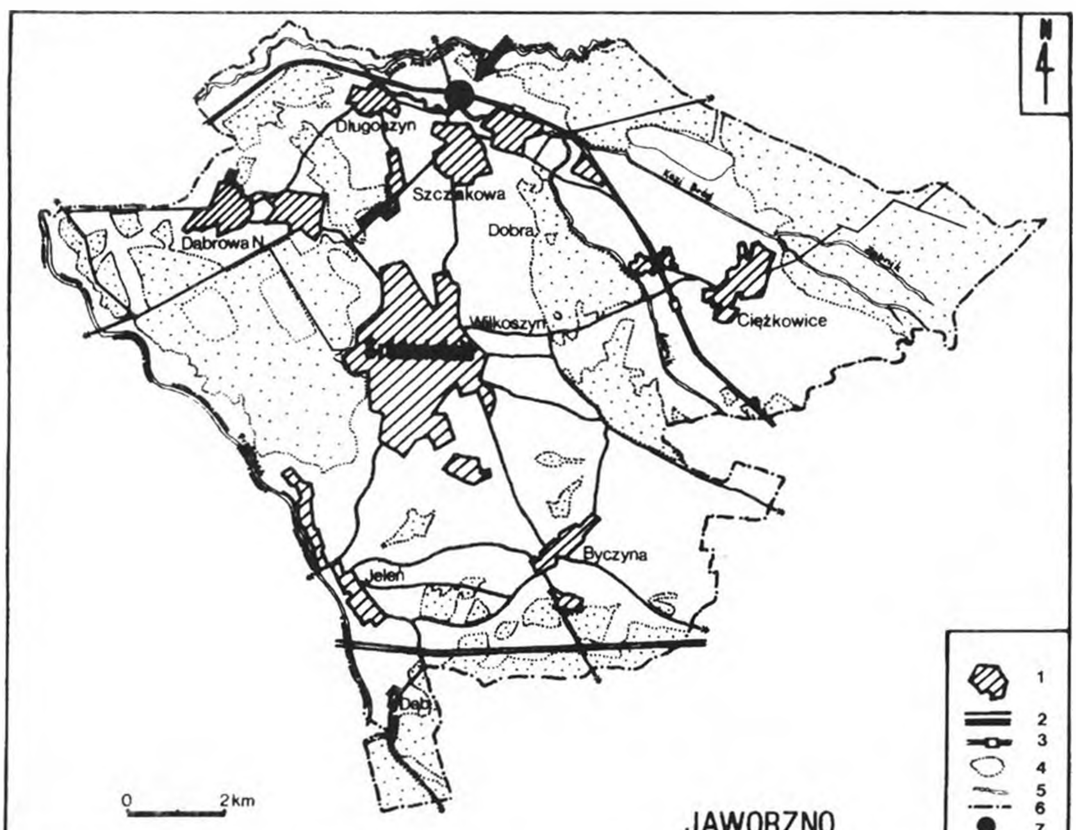

Fig. 1. Localisation of a solvay process tip in Jaworzno.
1 – build-up areas; 2 – roads; 3 – railways; 4 – forests; 5 – rivers and reservoires; 6 – town border; 7 – solvay process tip.

generally moist. The edges are dished as though there has been some shrinkage on the site.

The vegetation of the site consists mainly of fairly short, species-rich grassland, and can be described as healthy and thriving. The whole plateau bears a scattering of about 100 birch trees, on average around 10 m high, with a circumference around 32-50 cm. There is also a scattering of shrubs in the vegetation, but these seem to be subject to dieback, particularly *Frangula alnus*.

Vegetation survey methods

A preliminary assessment of the study area was made by walking over it and making a list of all vascular plant species present, scoring them on the DAFOR (Dominant, Abundant, Frequent, Occasional, Rare) scale. Broadly four vegetation types were discernible at this stage. There were a number of patches of vegetation in the central areas which tended to be coarser, less species-rich and dominated by *Calamagrostis epigejos* or *Molinia caerulea*. Other facies observed included a variant on the *Calamagrostis* vegetation with *Valeriana officinalis, Medicago sativa, Frangula alnus* and *Rubus caesius*, and a fairly tall vegetation with *Gymnadenia conopsea*. These vegetation types were sampled by recording 2 m × 2 m samples representative of homogeneous areas, as shown in Table 1. In each sample, all vascular plant species and bryophytes were identified and their abundance estimated and recorded on two scales as shown in Table 2. Multivariate computer analysis was performed using the Domin scale, and non-computer tabulation analysis was performed using the other abundance scale shown in Table 2. Total percentage cover of the vegetation and bare ground were also recorded together with the mean height of the vegetation. Slope and aspect of each sample was estimated and microtopographical details were recorded. The area represented by each sample was estimated and recorded (Table 4). Vascular plant nomenclature follows Mirek et al. (1995) and bryophyte nomenclature follows Ochyra and Szmajda (1978).

TABLE 1. Selection of 2 m × 2 m samples.

Vegetation characteristics	Number of samples	Sample numbers
Relatively short	10	1-7, 9-11
Tall vegetation with *Calamagrostis*	4	13, 16, 18, 19
Tall vegetation with *Molinia*	4	8, 12, 17, 20
Vegetation with *Gymnadenia*	2	14, 15

TABLE 2. Comparison of Domin (1905) scale and the non-computer analysis for assessing species abundance.

Species abundance	Domin Scale	The scale used for the non-computer analysis in %
1 or 2 individual plants, <4% cover	1	0.5
Up to 1% cover	–	1
Several individual plants in part of the plot, <4% cover	2	5
Several individual plants scattered throughout the plot	3 (< 4%)	
5-10% cover	4	20
11-25% cover	5	
26-33% cover	6	40
34-50%	7	
51-75%	8	70
76-90%	9	90
91-100%	10	

Substrate survey and analysis

Substrate samples were collected from the centre and towards the four corners of each vegetation sample or relevé. The five samples were taken from 0-5 cm depth following removal of superficial litter and plant material. The samples were combined and thoroughly mixed to provide a single composite sample for each relevé. The substrate samples were then air dried at room temperature for several days. The air-dried soil samples were passed through a 2 mm sieve and the fraction >2 mm was discarded. This comprised roots and other plant material only. The fraction <2 mm was then divided into 3 subsamples for pH testing, elemental analysis and storage.

Substrate pH was determined by mixing a subsample of the air-dried material with twice the volume of distilled water. The mixture was stirred for 1 minute and pH recorded using a pH electrode.

Elemental analysis on the soil was carried out by X-Ray Fluorescence Spectrometry. The air-dried sieved material was oven-dried at 4°C overnight. Samples were then ground to a fine powder in a tungsten teemer mill. Hersh wax was added to the milled soils in a vial in the ratio of 1.5 g wax to 8.5 g soil. Two agate balls were added to the vials to aid mixing and the vials placed on a thrapulator for 20 minutes. Pellets of the soil/wax mixture were made by pressing the mixture into plastic cups at a pressure of 15 tonnes per square inch. All equipment was cleaned with ethanol between samples. Concentrations of elements, as listed in Table 6, in the sample pellets were determined against International Standards of soil sample pellets containing a single element of known concentration using an ARL 8410 X-Ray Fluorescence Spectrometer.

Analysis of the flora

The list of vascular plant species for the site, which included all previous known records as described in the Introduction, was analysed in terms of their Raunkiaer life forms, ecological group, Ellenberg indicator values (Ellenberg et al. 1992), geographical-historical group (Kornaś 1981), families and current protection status.

Vegetation analysis

Two different methodologies were used to analyse the samples.

In the first, a tabular arrangement of the samples and species was made based on the identification of widely acknowledged differential or characteristic species with a high degree of fidelity to particular plant communities. The samples were ordered according to similarities in species composition and the frequency of occurrence of particular species.

In the second, computer-based methodology, multivariate analysis methods were used to analyse the abundance records. A hierarchical classification method, TWINSPAN (Hill 1979) based on the ordination of the vegetation records, was used to try to identify vegetation types by classifying samples according to their floristic similarities. The floristic relationships between samples, the ecological relationships between species

TABLE 3. Index of vascular flora species of the solvay process tip in Jaworzno.

LATIN NAME	FAMILY
Achillea millefolium L.	Asteraceae
Agrostis stolonifera L.	Poaceae
Antenaria dioica (L.) Gaertn.	Asteraceae
Anthyllis vulneraria L.	Fabaceae
Arabis hirsuta (L.) Scop.	Brassicaceae
Armeria maritima (Mill.) Willd. P. (=*A. elongata* (Hoffm.) W.D.J. Koch.)	Plumbaginaceae
Asperula cynanchica L.	Rubiaceae
Avenula pubescens (Huds.) Dumort. (=*Avenastrum pubescens* (Huds.) Opiz; (*Avena pubescens* Huds.)	Poaceae
Betula pendula Roth (=*B. verrucosa* Ehrh.)	Betulaceae
Botrychium lunaria (L.) Sw.	Ophioglossaceae
Brachypodium pinnatum (L.) P. Beauv.	Poaceae
Briza media L.	Poaceae
Calamagrostis epigeios (L.) Roth	Poaceae
Cardaminopsis arenosa (L.) Hayek (=*Arabis arenosa* (L.) Scop.)	Brassicaceae
Carex caryophyllea Latourr.	Cyperaceae
Carex flacca Schreber (= *C. glauca* Murray)	Cyperaceae
Carex hirta L.	Cyperaceae
Carex panicea L.	Cyperaceae
Carlina acaulis L.	Asteraceae
Carlina vulgaris L.	Asteraceae
Centaurea jacea L.	Asteraceae
Centaurea phrygia L. (=*C. austriaca* Willd.)	Asteraceae
Centaurea scabiosa L.	Asteraceae
Centaurea stoebe L. (=*C. rhenana* Boreau)	Asteraceae
Centaurium erythraea Rafn subsp. *erythraea* (= *C. umbellatum* Gilib.)	Gentianaceae
Centaurium pulchellum (Sw.) Druce	Gentianaceae
Cerastium arvense L. s.s.	Caryophyllaceae
Cerastium glomeratum L.	Caryophyllaceae
Cerastium holosteoides Fr. em. Hyl. (= *C. vulgatum* L.)	Caryophyllaceae
Chamaenerion angustifolium (L.) Scop. (=*Epilobium angustifolium* L.)	Onagraceae
Coronilla varia L.	Fabaceae
Dactylorhiza majalis (Rchb.) P.F. Hunt & Summerh. (= *Orchis latifolia* L.)	Orchidaceae
Daucus carota L.	Apiaceae
Dianthus carthusianorum L.	Caryophyllaceae
Dianthus deltoides L.	Caryophyllaceae
Echium vulgare L.	Boraginaceae
Epipactis atrorubens (Hoffm.) Besser (*E. atropurpurea* Raf.; *E. rubiginosa* Gaud.)	Orchidaceae
Epipactis helleborine (L.) Crantz (= *E. latifolia* (L.) All.)	Orchidaceae
Epipactis palustris (L.) Crantz	Orchidaceae
Erigeron acris L. (= *E. acer* L.)	Asteraceae
Eupatorium cannabinum L.	Asteraceae
Euphorbia cyparissias L.	Euphorbiaceae
Euphorbia esula L.	Euphorbiaçeae
Euphrasia stricta D. Wolff ex J.F. Lehm.	Scrophulariaceae
(= *E. stricta* Host)	Poaceae
Festuca ovina L.	
Festuca pratensis Huds.	Poaceae
Festuca rubra L. s.s.	Poaceae
Frangula alnus Mill.	Rhamnaceae
Galium aparine L.	Rubiaceae
Galium mollugo L.	Rubiaceae
Galium verum L.	Rubiaceae
Gymnadenia conopsea (L.) R. Br.	Orchidaceae
Gypsophila muralis L.	Caryophyllaceae
Helianthemum nummularium subsp. *obscurum* (Celak) J. Holub (*Helianthemum ovatum* (Viv.) Dun.)	Cistaceae
Hieracium floribundum Wimm. & Grab.	Asteraceae
Hieracium laevigatum Villd.	Asteraceae
Hieracium pilosella L.	Asteraceae
Hieracium sabaudum L.	Asteraceae
Hieracium umbellatum L.	Asteraceae
Inula salicina L.	Asteraceae
Knautia arvensis (L.) J.M. Coult.	Dipsacaceae
Lathyrus tuberosus L.	Fabaceae
Leontodon autumnalis L.	Asteraceae
Leontodon hispidus L.	Asteraceae
Leucanthemum vulgare Lam. s.s. (*Chrysanthemum leucanthemum* L.)	Asteraceae
Linaria vulgaris Mill.	Scrophulariaceae
Linum catharticum L.	Linaceae
Lotus corniculatus L.	Fabaceae
Malaxis monophyllos (L.) Sw.	Orchidaceae
Medicago falcata L.	Fabaceae
Medicago lupulina L.	Fabaceae
Medicago sativa L.	Fabaceae
Medicago × varia Martyn (= *M. sativa × falcata*)	Fabaceae
Melandrium album (Mill.) Garcke (=*Silene alba* (Miller) E.H.L. Krauze)	Caryophyllaceae
Melilotus alba Medik (= *M. albus* Medik.)	Fabaceae
Molinia coerulea (L.) Moench	Poaceae
Ononis spinosa L.	Fabaceae
Orchis militaris L.	Orchidaceae
Orchis morio L.	Orchidaceae
Parnassia palustris L.	Saxifragaceae
Petrorhagia prolifera (L.) P.W. Ball & Heywood (= *Tunica prolifera* (L.) Scop.)	Caryophyllaceae
Petrorhagia saxifraga (L.) Link (= *Tunica saxifraga* (L.) Scop.)	Caryophyllaceae
Picris hieracioides L.	Astereceae
Pimpinella saxifraga L.	Apiaceae
Pinus sylvestris L.	Pinaceae
Plantago lanceolata L.	Plantaginaceae
Plantago media L.	Plantaginaceae
Poa compressa L.	Poaceae
Poa pratensis L.	Poaceae
Polygala amarella Crantz	Polygalaceae
Polygala comosa Schkuhr	Polygalaceae
Polygala vulgaris L.	Polygalaceae
Polygonum aviculare L.	Polygonaceae
Populus tremula L.	Salicaceae
Potentilla arenaria Borkh.	Rosaceae
Potentilla erecta (L.) Rausch.	Rosaceae
Prunella grandiflora (L.) Scholler	Lamiaceae
Prunella vulgaris L.	Lamiaceae
Ranunculus acris L. (= *R. acer* L.)	Ranunculaceae
Ranunculus bulbosus L.	Ranunculaceae
Ranunculus repens L.	Ranunculaceae
Reseda lutea L.	Resedaceae
Rhinanthus minor L. (=*Alectorolophus minor* (L.) Wimm & Gr.)	Scrophulariaceae

TABLE 3. cont.

LATIN NAME	FAMILY
Rhinanthus serotinus (SCHÖNH.) OBORNY (= *Alectorolophus glaber* (LAM.) BECK)	Scrophulariaceae
Rubus caesius L.	Rosaceae
Rumex acetosa L.	Polygonaceae
Salix acutifolia WILLD.	Salicaceae
Salix caprea L.	Salicaceae
Salix purpurea L.	Salicaceae
Salix repens L. subsp. *arenaria* (L.) HIITONEN (= *S. arenaria* L.)	Salicaceae
Sanguisorba minor L.	Rosaceae
Sanguisorba officinalis L.	Rosaceae
Scabiosa ochroleuca L.	Dipsacaceae
Sedum acre L.	Crassulaceae
Silene nutans L.	Caryophyllaceae
Silene vulgaris (MOENCH) GARCKE (= *S. inflata* (SALISB.) SM.)	Caryophyllaceae
Solidago canadensis L.	Asteraceae
Solidago virgaurea L.	Asteraceae
Sonchus arvensis L.	Asteraceae
Sonchus asper (L.) HILL	Asteraceae
Taraxacum officinale F.H. WIGG.	Asteraceae
Teucrium botrys L.	Lamiaceae
Thymus pulegioides L.	Lamiaceae
Thymus serpyllum L. em. FR.	Lamiaceae
Tofieldia calyculata (L.) WAHLENB.	Liliaceae
Trifolium medium L.	Fabaceae
Trifolium montanum L.	Fabaceae
Trifolium pratense L.	Fabaceae
Trifolium repens L.	Fabaceae
Tussilago farfara L.	Asteraceae
Valeriana officinalis L.	Valerianaceae
Verbascum thapsus L.	Scrophulariaceae
Veronica chamaedrys L.	Scrophulariaceae
Vicia cracca L.	Fabaceae
Viola rupestris F.V. SCHMIDT	Violaceae
Viola tricolor L.	Violaceae

and the relationship between the vegetation and soil characteristics, i.e. pH and the presence of heavy metals and certain other elements, were examined using CANOCO (ter Braak 1988). The data was analysed by Redundancy Analysis, a canonical form of Principal Components Analysis, and Canonical Correspondence Analysis. The significance of the influence of soil variables on the vegetation was examined using a Monte Carlo permutation procedure.

RESULTS

Analysis of the flora

The study site is rich in species considering the small area it covers and its geographical and ecological isolation from other areas with similar physical characteristics. Of the 136 vascular plant species recorded for the site (Table 3), 114 were recorded in the study area, 73 of them in the releves. The best represented families in the flora of the site are:

Asteraceae	(26 species)
Fabaceae	(15 species)
Caryophyllaceae	(11 species)
Poaceae	(11 species)

It is interesting to note that orchids also make a large contribution to the flora. These comprise eight of the nine nationally protected species present on the site (the ninth is *Carlina acaulis*). A further three species are partly protected. *Ranunculus bulbosus* is regionally protected and there are a further seven locally rare species (*Ajuga genevensis, Antennaria dioica, Botrychium lunaria, Inula salicina, Parnassia palustris, Polygala amarella, Teucrium botrys*).

The results of life form analysis of the flora are shown in Fig. 2. They show a clear preponderance of long-lived perennials (hemicryptophytes, geophytes, chamaephytes) which comprise 87% of the flora, while the annuals only contribute 13%.

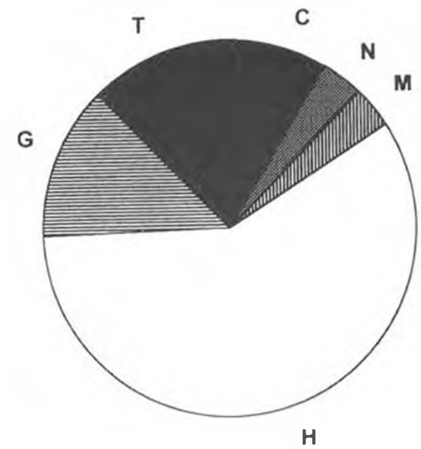

Fig. 2. Raunkiaer's life form – spectrum for Jaworzno tip flora.
M – megaphanerophyte; H – hemicryptophyte; G – geophyte; T – therophyte; N – nanophanerophyte; C – chamaephyte.

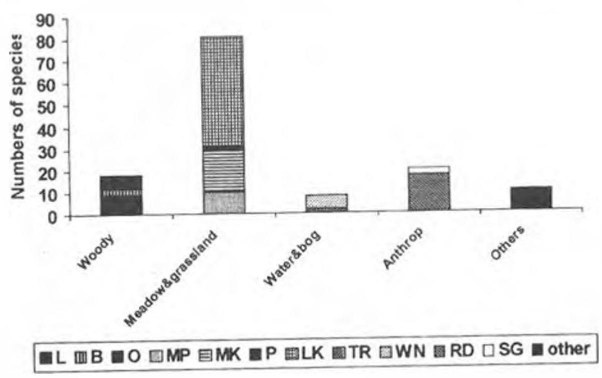

Fig. 3. Numbers of species belonging to ecological groups (after Ellenberg 1992).
Woody plants: L – decideous woodland; B – coniferous woodland; O – shrub edges; Meadow pl.: MP – sandy grasslands; MK – xerothermic grasslands; P – acid grasslands; LK – meadows; Anthropogenic habitats pl.: RD – ruderal pl.; SG – segetal pl.; Water & bog pl.: TR – peat; WN – highwatertable plants; Other plants.

Examination of species from the various ecological habitat groups (Fig. 3) show that meadow and grassland species make the largest contributions, while species from forest and anthropogenic habitats are less abundant and wetland species make the smallest contribution. Fig. 4 shows that 95% of the flora are native species (apophytes) and only 5% are alien (anthropophytes).

Selected Ellenberg ecological indicators (Ellenberg et al. 1992) are shown in Figs 5-9. Only a very small proportion of species are associated with shady habitats (Fig. 5). Fig. 6

TABLE 4. Non-computer analysis of the vegetation of the solvay process tip in Jaworzno.

Field No of sample	9	11	15	14	4	1	13	2	10	6	3	8	7	17	5	18	20	12	16	19	frequency
Area of sample in m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	
Area of the patch in m^2	200	200	24	24	250	150	280	200	200	96	20	25	15	200	100	100	50	300	20	100	
Cover of herb layer C in %	100	100	95	98	95	90	95	95	95	95	90	75	80	95	95	95	98	98	100	90	
Cover of mosses layer D in %				2			2		1				25								
No of species in sample	23	21	24	25	23	28	31	26	29	35	26	34	34	24	26	25	20	20	18	17	
List of species with their cover in %																					
The most freq. sp. GR. I																					
Lotus corniculatus	70	70	40	40	40	5	40	40	40	70	5	1	1	40	40	40	40	40	40	1	20
Rhinanthus minor	1	5	1	1	5	0.5	1	1	1	1	1	1	1	0.5	1	1	1	1	1	1	20
Carex flacca	1	0.5	1	1	1	5	0.5	5	5	5	1	5	5	1	1	1	1	1	1	1	20
Epipactis palustris	1	1	1	1	5	1	1	5	1	1	1	1		1	5	1	1	1	1	1	19
Calamagrostis epigejos	1	20	5	1.1	1	1	40	40	1	1	20	1	1	20	20	70		0.5	40	40	19
Festuca rubra	1	1	1	1	1	5	1	1		1	1	1		0.5	1	1	1	1	1	1	18
Ranunculus acris		1	1	1	1	1	1	1	1	1	1	1	0.5	1	1	1	1	1	1	1	18
Trifolium pratensis	1	1	1	1	1	0.5	1	1	0.5	5	1	1	1	1	1	1	1	1			18
Plantago media	1	1	1	1		5	1	0.5	1	1	1	5	5	1	1	1	1			1	17
Briza media	1	1	1	1	40	70	1	40	40	20	40	5	5		20	1	1		1		17
Parnassia palustris		1	1	1	1		1	0.5	0.5	1	1	1		1	0.5	0.5	1	1	0.5		16
Achillea millefolium		1	0.5			1	1	1	1	1	0.5	1	1		1	0.5	0.5	1	5	1	16
species which occure in some samples GR. II																					
Polygala vulgaris	0.5	0.5	0.5	1	1	1	0.5	1	1	0.5	1		1	0.5	.	.	.	.	.	.	13
Carlina vulgaris	1	0.5		1	0.5	5		1	1	1	1	5	1	.	.	.	.	.	.	.	10
Avenula pubescens	1	1	5	5	5		5		1	1	.	0.5		.	.	.	.	.	.	.	9
Sanguisorba minor	.		0.5	.	0.5	1			1	1	1	1	1	.	1	.	.	.	.	.	8
Arabis hirsuta	.			.	.				0.5	0.5	1	0.5	1	0.5	.	.	.	.	.	.	6
Tofieldia calyculata	.			.	.				.	0.5	5	1	0.5	.	.	.	.	.	.	.	4
Potentilla arenaria	.			.	.				.		0.5	1	1	.	.	.	.	.	.	.	3
Gymnadenia conopsea	.		5	5	.				.					.	.	.	.	.	.	.	2
Anthyllis vulneraria	.			.	1	1			.					.	.	.	.	.	.	.	2
Botrychium lunaria	.			.	.		1	1	.					.	.	.	.	.	.	.	2
Molinia caerulea	.			.	.				.			40	0.5	40	.	1	70	70	.	1	7
Valeriana officinalis	.			.	.				.				0.5	0.5	0.5	1			1	1	6
Grassland species GR. III																					
Carex caryophyllea		1	1	5	.		1		1			1	1	1		1	1	1	1	1	13
Thymus pulegioides	1				.	0.5		1	0.5	1	5	1				0.5	0.5	0.5	0.5	.	11
Viola rupestris			1	1	.	1	1		1			1	1			1		0.5	.	.	10
Scabiosa ochroleuca		0.5	0.5	0.5	.			1			0.5	1	1	0.5	1	1			.	.	10
Trifolium montanum				0.5	.	1		1		0.5		1		1					.	.	6
Poa compressa		0.5			.									1				1	.	.	3
Meadow spacies GR. IV																					
Leontodon hispidus	1	1	1	1	1	5	1	1	1	1	5	1			5		1	1	.	.	15
Taraxacum officinale	1		1	0.5	1	0.5	1		1	0.5				1		1	1		1	1	13
Plantago lanceolata	1		1	1		1	0.5		1	1	0.5		0.5		1				.	.	10
Daucus carota						1				0.5		1	1		1				.	.	5
Others GR. V																					
Potentilla erecta	1	.	0.5		1	1	0.5		0.5		5	1		1	1	1			.	.	11
Linum catharticum			.		0.5				.	0.5	0.5	1	0.5	0.5			0.5	0.5	.	.	8
Hieracium sabaudum			.	1			1		.		1		0.5	1	0.5				1	1	7
Euphrasia stricta	0.5		.			0.5		0.5		0.5		1			0.5				.	.	7
Festuca ovina			.					0.5	1			1	5					1	.	.	5

TABLE 4. Description

Sporadic species GR. III : *Asperula cynanchica* 9 (5), 2 (1), 7 (1); *Centaurea scabiosa* 5 (5); *Coronilla varia* 7 (1); *Dianthus carthusianorum* 6 (0.5); *Euphorbia cyparissias* 4 (0.5), 9, 16 (0.5); *Ononis spinosa* 18 (0.5), 19 (70)

Sporadic species GR. IV: *Centaurea jacea* 9 (0.5), 13 (1), 17 (0.5); *Festuca pratensis* 5 (0.5); *Galium mollugo* 18 (1), 16 (5); *Leontodon autumnalis* 6 (0.5), 7 (0.5); *Poa pratensis* 11 (1), 6 (0.5), 20 (0.5); *Rumex acetosa* 13 (0.5), 19 (0.5); *Sanguisorba officinalis* 4 (5); *Trifolium repens* 4 (1), 2 (1), 6 (0.5), 5 (1); *Vicia cracca* 19 (0.5).

Sporadic species GR V: *Agrostis stolonifera* 1 (0.5); *Amblystegium serpens* d 7 (1); *Brachythecium rutabulum* d 14 (1), 13 (0.5); *Brachythecium salebrosum* d 13 (1), 7 (18); *Brachytecium velutinum* d 14 (1), 9 (1); *Bryum cespiticium* d 8 (1); *Carex hirta* 11 (0.5), 6 (0.5), 10 (0.5), 5 (0.5); *C. panicea* 4 (1), 1 (0.5), 2 (0.5), 10 (0.5); *Carlina acaulis* 3 (0.5); *Centaurium pulchellum* 8 (0.5); *Cerastium arvense* 15 (1), 13 (0.5), 7 (1), 16 (1); *Erigeron acris* 7 (1); *Euphorbia esula* 19 (1); *Frangula alnus* c 13 (0.5); 10 (0.5), 17 (1); *Galium verum* 9 (5); *Hieracium floribundum* 6 (0.5); *Hieracium lachenalii* 2 (0.5); *Medicago falcata* 18 (1); *Hieracium pilosella* 6 (0.5), 8 (0.5); *Medicago lupulina* 7 (0.5); *Pimpinella saxifraga* 1 (1), 6 (1), 18 (1), 16 (1); *Plagiomnium rostratum* d 13 (0.5); *Prunella vulgaris* 6 (0.5); *Ranunculus repens* 9 (1); *Silene nutans* 12 (1); *Silene vulgaris* 1 (0.5), 9 (1), 17 (0.5), 20 (1); *Solidago canadensis* 2 (0.5); *Thymus serpyllum* 13 (5).

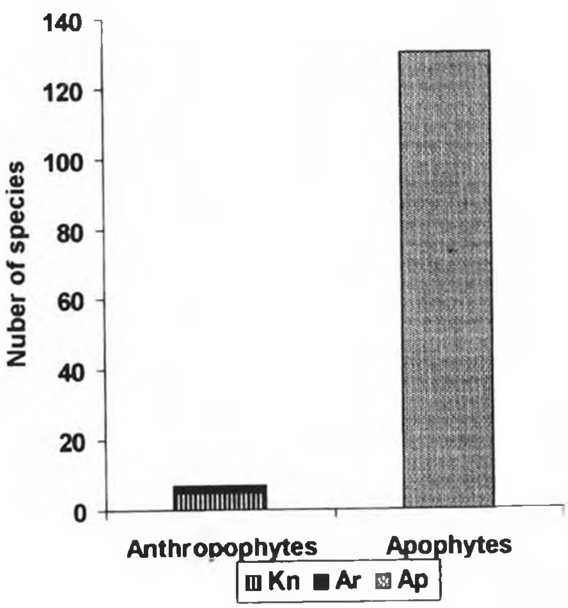

Fig. 4. Geographical-historical groups (after Kornaś 1981) Anthropophytes (alien species): Ar – archaeophyte; Kn – kenophyte; Apophytes (native species) – Ap.

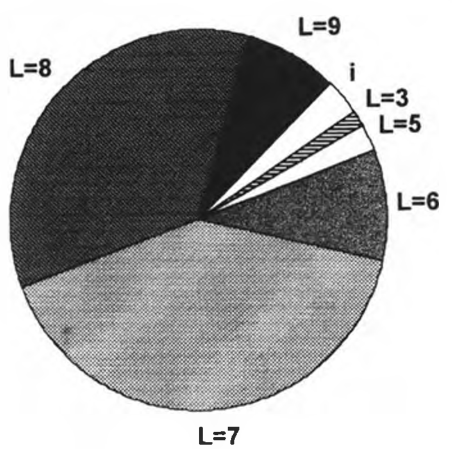

Fig. 5. L – light indicator value (after Ellenberg 1992). i – plants without a light indicator value.

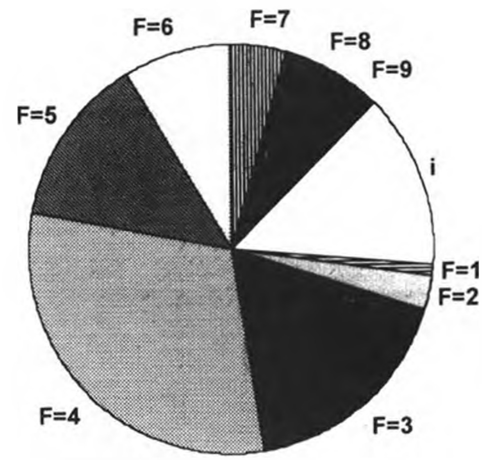

Fig. 6. F – moisture indicator (after Ellenberg 1992). i – plants without a moisture indicator value.

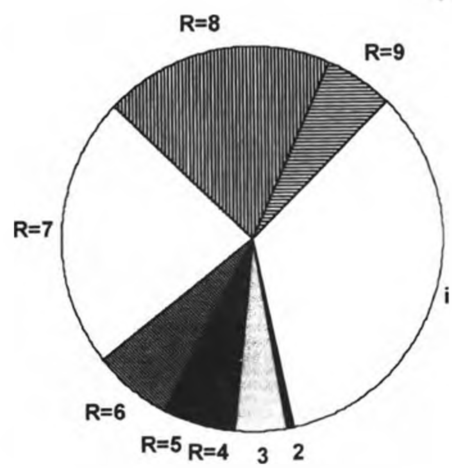

Fig. 7. R – reaction indicator value (after Ellenberg 1992). i – plants without a reaction indicator value.

shows that most (74%) of the species for which values are given are indicators of dry conditions (F = 1-4) moderately moist conditions (F = 5-6), but a substantial minority are indicators of wet (F = 7-9) conditions. The large majority of species for which values are given are base indicators (Fig. 7) and only a small minority are indicators for very acid conditions. A little over half the species with an indicator value are indicators of low nitrogen availability, with the remainder associated in decreasing proportions with moderate to high levels of nitrogen availability (Fig. 8). Fig. 9 indicates that most species tend to occur as scattered individuals (D = 3-4) with only a few species occurring in clumps (D = 6-9).

It is possible to assess the regional significance of the site since a Flora of Jaworzno township has recently been completed (Tokarska-Guzik 1999). *Botrychium lunaria*, *Polygala amarella* and *Orchis militaris* have their only record in the township on the Solvay Process heap. *Teucrium botrys*, and

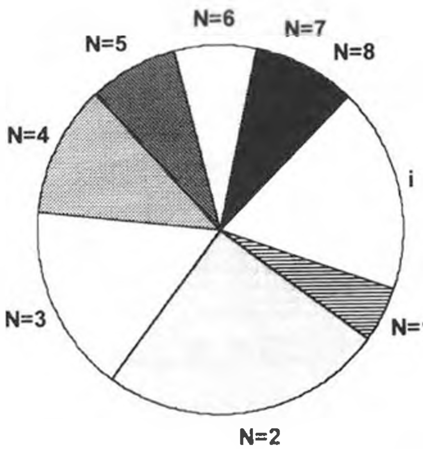

Fig. 8. N – nitrogen indicator value (after Ellenberg 1992). i – plants without a nitrogen indicator value.

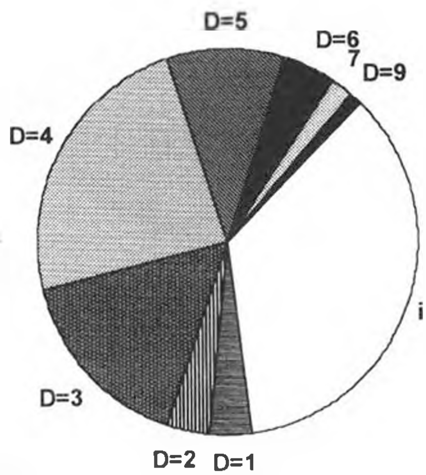

Fig. 9. D – dispersion of population (after Ellenberg 1992). i – plants without a dispersion indicator value.

Antennaria dioica, both quite uncommon in Upper Silesia, have only one other record in Jaworzno township. *Epipactis palustris* occurs in eight other sites but is at its most abundant on the tip.

Fig. 10a represents the presence of protected species in the township on a 1 km grid. The larger the dot the greater the number of protected species. The 1 km square which includes the Solvay Process tip is the second from the top within the township boundary immediately west of line DD (DF4459). The presence of the tip clearly makes this square one of the most significant for protected species in the township.

Fig. 10b shows a similar coincidence map for montane species. These are mostly associated with squares with significant areas of forest. The square containing the Solvay Process tip includes no forest, but clearly the tip acts as a similar refuge for montane species. Similar methodology may be used to demonstrate that the tip is an important refuge for thermophilous species and calcicolous species (Tokarska-Guzik 2000).

The unusualness of this site is evident in the considerable contribution to the vegetation of species such as *Carex panicea*, *Epipactis palustris*, *Parnassia palustris* and *Tofieldia calyculata*.

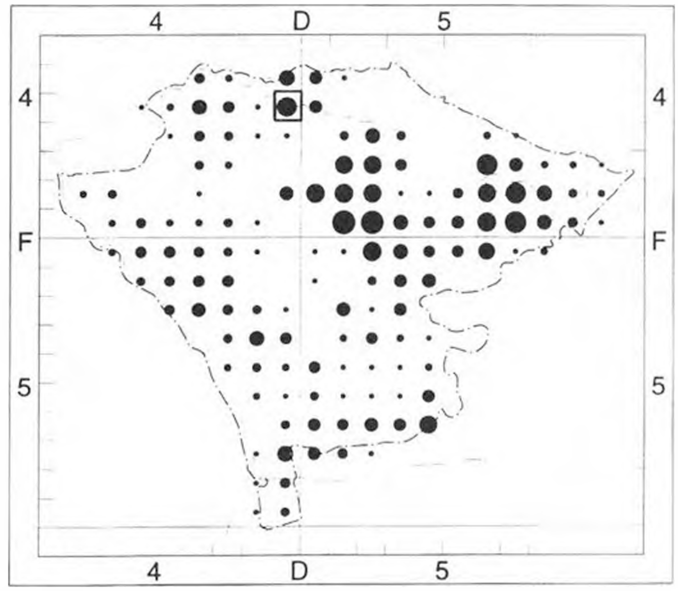

Fig. 10a. Coincidence map for protected species (after Tokarska-Guzik 2000).

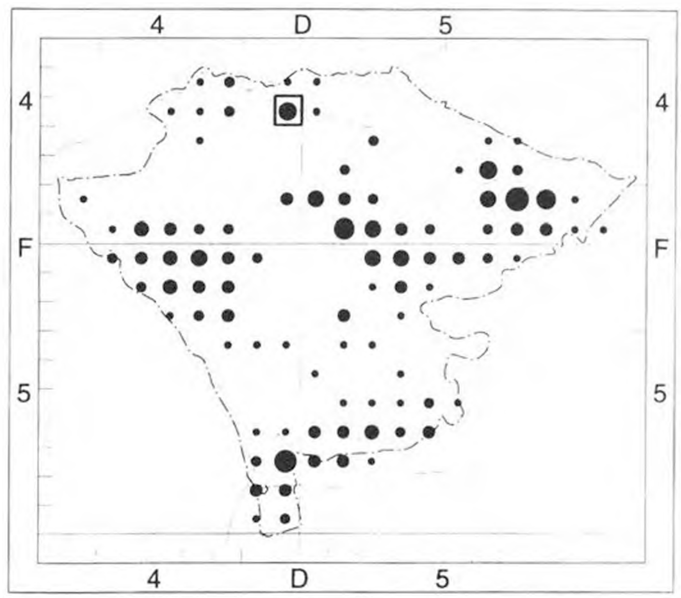

Fig. 10b. Coincidence map for mountain species (after Tokarska-Guzik 2000).

Non-computer analysis of the vegetation

The results of this analysis are shown in Table 4. There are twelve species of high (>80%) frequency in the vegetation. *Lotus corniculatus*, *Rhinanthus minor*, *Ranunculus acris*, *Festuca rubra*, *Trifolium pratense* and *Achillea millefolium* grow in meadows, *Carex flacca*, *Plantago media* and *Briza media* are grassland species. Most of these species are characteristic of neutral to calcareous soils where management or environmental stress suppress the vigour of more competitive species. The frequent occurrence of *Epipactis palustris* and *Parnassia palustris* is of particular interest since these plants grow in rare eutrophic peat bogs. Only *Calamagrostis epigejos* is a common plant. A further 9 species occurred with a frequency of over 50%. The Table 4 also includes a considerable group of meadow and grassland species.

Many species occurred at only low frequency in the data, 29 with only 2 occurrences, but in combinations which produced distinctive facies, such as *Ononis spinosa* and *Galium mollugo* in the taller vegetation, and *Thymus serpyllum, Hieracium pilosella* and *Erigeron acris* in the shorter vegetation. Plant cover varied from 75% up to 100% but is mostly 95-100%. The number of vascular plant species is quite high in all samples, ranging from 16-34 with a mean and standard error of 24.65 +/- 1.06. Six moss species were recorded, *Brachythecium salebrosum, B. rutabulum, B. velutinum, Bryum cespiticium, Amblystegium serpens* and *Plagiomnium rostratum*. Mosses were recorded in only 5 samples where their cover was 1-2% except in sample 7 where they reached 25% cover.

Table 4 shows the relative homogeneity of the vegetation, but distinguishes 2 major sub-units. The first contains 11, possibly 13, samples and is defined by the presence of species such as *Avenula pubescens, Carlina vulgaris* and *Polygala vulgaris* which grow in dry, basic habitats. These are the more species-rich samples. The second sub-unit is defined by *Molinia caerulea* and *Valeriana officinalis* which grow in wet meadows and calcareous mires. It contains 7, possibly 9, samples. The vegetation of this sub-unit is taller and coarser than that of the first one. Samples 7 and 8 appear transitional, having some of the species of both sub-units, but being more species-rich than either and having a higher proportion of bare ground and mosses.

The table shows a distinctive unit with *Tofieldia calyculata, Arabis hirsuta, Potentilla arenaria* and *Sanguisorba minor* represented by the two transitional samples and three others. Three other facies are shown in the table characterised respectively by *Gymnadenia conopsea, Anthyllis vulneraria* and *Botrychium lunaria*.

Table 4 also shows two groups of species, one associated with meadow, the other with grassland. However, the overall character of the soda heap vegetation is quite distinctive and is not consistent with these two vegetation types.

Computer analysis of the vegetation

Multivariate vegetation analysis of the sample data using the computer program TWINSPAN confirmed the overall homogeneity of the vegetation with low eigenvalues at each division. Even at the first division of the samples the eigenvalue was only 0.204, suggesting that only 20% of the variability in the data was explained at that division and that there was relatively little coordinated variation in species distribution between samples. The program has identified a number of vegetation types shown in Table 5. This table is analogous to the results shown in Table 4. The numbers in the body of this table are abundance levels on a scale of 1-4, the sample classification is shown horizontally at the top and bottom of the table, and a simplified species classification is shown vertically at the right hand side. Binary notation is used for both sample and species classifications.

The overall character of the vegetation is defined by the large number of constant species which appear as a large block two-thirds of the way down Table 5, species Group 01. The species above this block characterise the main vegetation type present in the study area (species Group 001), and a single variant (species Group 000). Species Group 001 is clearly the larger group identified in Table 4 using non-computer methods. The species below the main block, species Group 1, characterise a second vegetation type and also a further variant of the main vegetation type.

The first main division of the samples identified a distinctive vegetation type represented by samples 16, 18 and 19 (sample Group 1) and differentiated by *Valeriana officinalis* at high levels of abundance, *Ononis spinosa, Medicago sativa, Galium mollugo* and *Molinia caerulea*. These species are

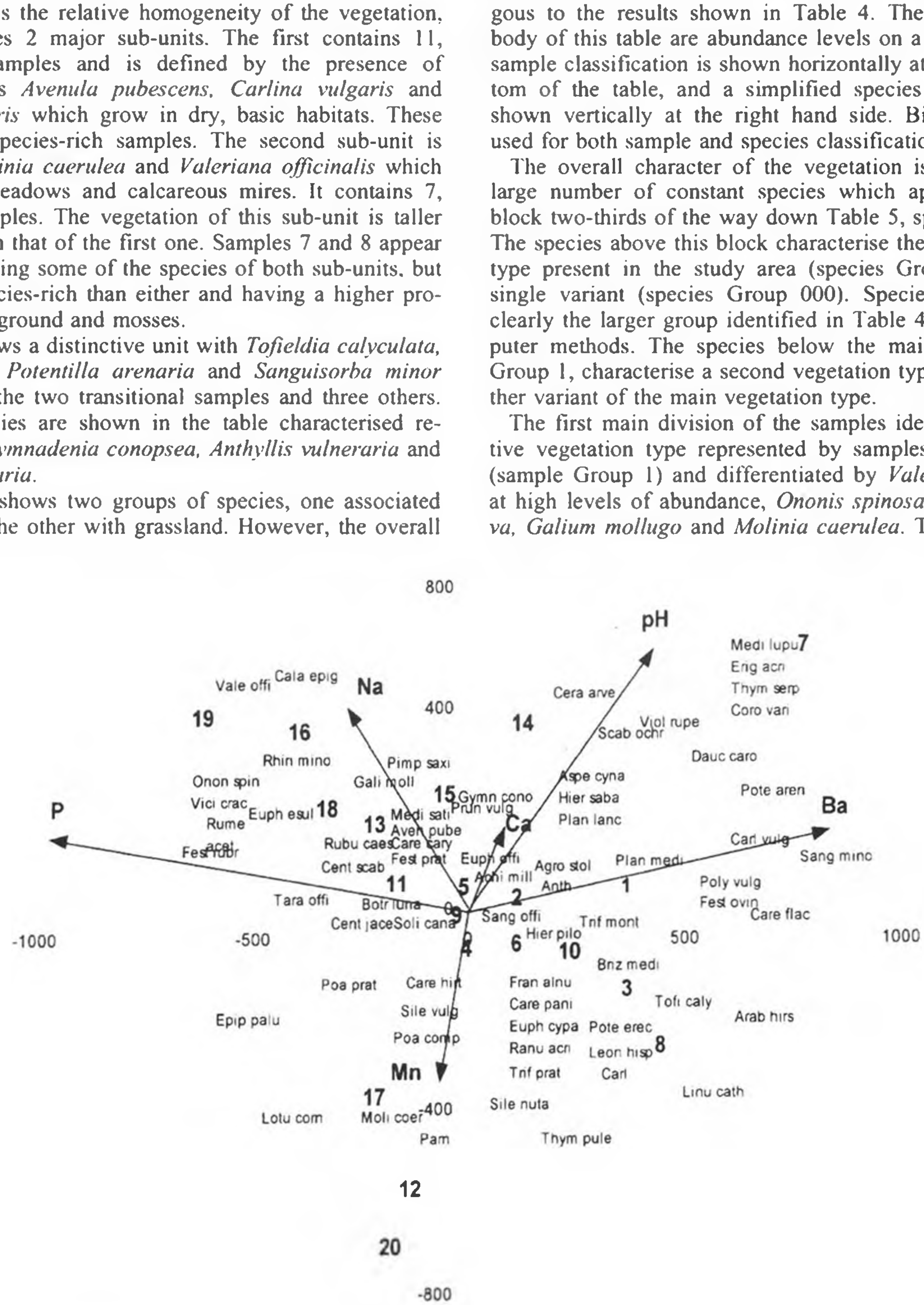

Fig. 11. RDA ordination diagram of releves, species and environmental variables.

TABLE 5. TWINSPAN classification of releves and species.
Binary notation is used for releve and species groups to show relationships.
Numbers in the body of the table represent abundance levels on a scale of 1-4.

Releve number	7	8	2	3	5	6	1	9	10	4	11	13	14	15	12	17	20	16	18	19	Species
Species																					Group
Coronilla varia	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	000
Erigeron acris	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	000
Festuca ovina	3	3	1	.	.	.	.	.	2	.	.	.	.	.	2	.	.	.	.	.	000
Medicago lupulina	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	000
Potentilla arenaria	2	2	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	000
Thymus serpyllum	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	000
Daucus carota	2	2	.	.	1	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	000
Hieracium pilosella	.	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	000
Frangula alnus	.	1	.	.	.	.	.	.	1	.	.	1	.	.	.	2	.	.	.	.	000
Linum catharticum	1	2	.	2	.	1	.	.	.	1	.	.	.	.	1	1	1	.	.	.	000
Asperula cynanchica	2	.	2	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	000
Carlina vulgaris	3	3	2	2	.	1	3	2	2	1	1	.	2	.	.	.	.	.	.	.	000
Sanguisorba minor	3	2	.	2	1	2	2	.	2	1	.	.	.	1	.	.	.	.	.	.	000
Tofieldia calyculata	1	2	.	3	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	000
Trifolium montanum	.	2	2	.	.	1	2	.	.	.	.	.	1	.	.	2	.	.	.	.	000
Arabis hirsuta	1	1	.	2	.	1	.	.	1	.	.	.	.	.	.	1	.	.	.	.	000
Hieracium sabaudum	1	.	.	2	1	.	3	.	.	.	.	2	2	.	.	.	.	.	.	.	001
Leontodon hispidus	1	2	2	3	3	3	2	2	3	2	2	2	2	2	2	.	1	.	.	.	001
Plantago lanceolata	1	.	.	1	2	3	2	2	2	.	.	1	2	2	.	.	.	.	.	.	001
Polygala vulgaris	2	.	2	2	.	1	1	1	2	2	1	1	2	1	.	1	.	.	.	.	001
Agrostis stolonifera	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	001
Anthyllis vulneraria	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	001
Botrychium lunaria	.	.	2	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	001
Carex hirta	.	.	.	.	.	1	1	.	1	.	1	.	.	.	.	.	.	.	.	.	001
Carex panicea	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	001
Centaurea scabiosa	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	001
Festuca pratensis	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	001
Galium verum	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	001
Gymnadenia conopsea	.	1	.	.	.	.	.	.	.	.	.	.	3	3	.	.	.	.	.	.	001
Avenula pubescens	.	.	.	.	.	3	.	3	2	3	3	3	3	3	.	.	.	.	.	.	001
Leontodon autumnalis	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	001
Prunella vulgaris	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	001
Rubus caesius	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	001
Sanguisorba officinalis	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	001
Trifolium repens	.	.	1	.	2	1	.	.	.	2	.	.	.	.	.	.	.	.	.	.	001
Carlina acaulis	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	001
Solidago canadensis	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	001
Dianthus carthusianorum	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	001
Poa compressa	.	.	.	.	1	1	.	.	.	.	1	.	.	.	2	1	.	.	.	.	001
Poa pratensis	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	1	.	.	.	001
Silene nutans	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	1	.	.	.	.	001
Silene vulgaris	.	.	.	.	.	.	1	3	.	.	.	.	.	.	.	.	2	.	.	.	001
Centaurea jacea	.	.	.	.	.	.	.	1	.	.	.	2	.	.	.	.	1	.	.	.	001
Trifolium pratense	2	2	3	2	3	3	1	2	1	3	3	2	1	2	2	2	3	.	2	.	01
Euphrasia officinalis	.	2	1	.	1	1	1	1	.	.	.	.	.	.	.	.	.	1	.	.	01
Scabiosa ochroleuca	2	2	2	1	2	.	.	.	.	.	1	.	1	1	.	1	.	.	2	.	01
Briza media	3	3	4	4	3	3	4	3	4	3	3	3	3	3	.	.	3	2	2	.	01
Carex flacca	3	3	3	3	2	3	3	2	3	3	1	1	3	3	3	2	2	3	2	2	01
Lotus corniculatus	2	3	4	3	4	4	3	4	4	4	4	4	2	4	4	4	4	4	3	3	01
Parnassia palustris	.	2	1	2	1	2	.	.	1	2	2	2	2	2	2	2	2	1	1	.	01
Plantago media	3	3	2	2	2	3	3	3	3	.	3	2	3	2	2	2	2	.	2	2	01
Potentilla erecta	.	2	.	3	1	.	2	2	1	2	.	1	.	1	.	2	.	.	2	.	01
Ranunculus acris	1	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	.	01
Viola rupestris	2	1	.	.	.	.	1	.	1	.	.	2	2	2	1	.	.	.	2	.	01
Thymus pulegioides	.	2	2	3	.	1	1	2	1	.	.	.	.	.	1	.	1	1	1	.	01
Calamagrostis epigejos	2	2	3	3	3	3	2	3	2	3	3	3	3	3	1	3	.	4	4	3	01
Epipactis palustris	.	2	2	2	3	2	2	2	3	3	3	2	2	2	2	2	2	2	3	2	01
Festuca rubra	.	2	2	2	3	2	3	2	.	2	2	3	2	3	3	3	2	3	3	3	01
Rhinanthus minor	2	2	2	2	2	2	1	2	2	3	3	2	3	3	2	1	2	3	2	3	01
Euphorbia cyparissias	.	.	.	.	.	.	.	.	2	1	.	.	.	.	.	.	.	1	1	.	01
Taraxacum officinale	.	.	.	.	.	1	1	3	3	2	.	3	1	2	.	2	2	3	2	2	1
Achillea millefolium	2	2	2	2	2	2	2	.	2	.	2	2	.	1	2	.	1	3	1	2	1
Carex caryophyllea	3	3	.	.	1	.	.	.	2	2	3	3	3	3	3	2	2	2	3	2	1
Molinia caerulea	1	3	.	.	.	.	.	.	.	.	.	.	.	.	4	4	4	.	3	3	1
Euphorbia esula	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	1
Galium mollugo	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	.	1
Ononis spinosa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	4	1
Pimpinella saxifraga	.	.	.	.	.	2	2	.	.	.	.	.	.	.	.	.	.	2	2	.	1
Valeriana officinalis	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	2	2	3	1
Vicia cracca	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1
Medicago falcata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	1
Cerastium arvense	2	.	.	.	.	.	.	.	.	.	.	1	.	2	.	.	.	.	2	.	1
Rumex acetosa	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1	1
Releve Group	**00**								**010**							**011**			**111**		

not all exclusive to this vegetation type, but they are strongly preferential.

The next two divisions of the samples differentiated the main group (sample Group 010). The first of these divisions separated off the two samples 7 and 8 which proved "anomalous" in the non-computer analysis (sample Group 00). The second division separated off three samples, 12, 17 and 20, (sample Group 011) with abundant *Molinia caerulea*. These were placed alongside the other *Molinia* samples 16, 18 and 19 (Group 1) as in Table 4. However, these six *Molinia* samples are divided here on the basis of the strongly preferential species of sample Group 1 and the greater affinity of the companion species in sample Group 011 to sample Group 010.

Comparison of analyses

Both analyses have identified a *typical* vegetation type consisting of almost the same samples: 1-4, 6 and 9-15. Only sample 5 was classified differently in the two analyses. Both analyses have distinguished samples 7 and 8. In the non-computer analysis they were shown to span 2 vegetation types and a variant of one of them. In TWINPAN they were separated out at one end of the sample ordination as a distinct variant of the *typical* vegetation. A tall vegetation type characterised by *Molinia caerulea* was clearly identified by both methods, but whereas in Table 4 it appears as a homogeneous vegetation type, TWINSPAN has recognised two distinct variants. No further variants or distinctive facies were apparent in the TWINSPAN analysis, while the non-computer analysis has recognised a *Tofieldia calyculata – Arabis hirsuta* variant on the *typical* community and a further three facies each characterised by a single species.

Substrate characteristics

The substrates, at least in the upper horizons sampled, were all fine textured with a perceptible crumb structure, a significant penetration by roots, and were dark stained with organic matter. Table 6 shows that the pH across the site does not vary greatly. Elemental concentrations varied across the site with manganese, zinc, lead, aluminium, iron, barium and magnesium tending to be higher in samples 1-4 and 20, while calcium and sodium were higher in other parts of the site.

Redundancy analysis of substrate-plant relationships

A preliminary assessment was made of the entire sample and substrate data using both Canonical Correspondence Analysis and Redundancy Analysis. This indicated that Redundancy Analysis was the more appropriate method, and that few of the substrate variables had a distinct, or coordinated, influence on the vegetation. Despite the relatively low variability in total phosphorus shown in Table 6, phosphorus and barium and to a lesser extent pH, sodium and manganese were shown to have the strongest influence, though none were statistically significant. These five plus calcium in view of its relative abundance in the substrate, were the only 6 variables selected for the main Redundancy Analysis, the results of which are shown in Fig. 11.

Ordination of samples along axes 1 and 2 in Fig. 11 show similar groupings to those identified by the TWINSPAN and the non-computer analyses. Axis one shows the clear separation of the taller and coarser vegetation in TWINSPAN sample Groups 1 and 011 and the influence of phosphorus on this vegetation. The *typical* vegetation lies in the centre of the ordination with the 'anomalous' samples 7 and 8 at the other extreme. Axis 2 separates both the variants of the coarse vegetation and samples 7 and 8 from each other.

TABLE 6. Releve soil characteristics. The figures are expressed as elemental states as percentage of sieved, dry soil.

Releve	pH	Al	Ba	Ca	Cl	Cu	Fe	K	Mg	Mn	Na	P	Pb	S	Si	Ti	Zn
1	7.9	8.85	0.078	24.19	0.17	0.005	5.71	0.95	2.05	0.075	0.25	0.21	0.036	0.38	29.32	0.39	0.20
2	7.6	6.61	0.055	31.13	0.12	0.004	4.15	0.78	0.96	0.056	0.30	0.21	0.028	0.30	24.40	0.29	0.15
3	7.6	6.26	0.061	34.09	0.20	0.004	3.84	0.56	2.02	0.055	0.26	0.18	0.024	0.37	23.19	0.26	0.14
4	7.6	7.27	0.081	27.31	0.13	0.005	4.80	0.78	2.45	0.072	0.23	0.22	0.033	0.40	26.98	0.32	0.19
5	7.6	4.73	0.035	38.47	0.27	0.003	2.32	0.50	0.61	0.039	0.29	0.19	0.021	0.25	22.08	0.16	0.10
6	7.7	4.59	0.034	45.62	0.13	0.003	2.20	0.46	0.59	0.034	0.33	0.18	0.021	0.23	17.49	0.15	0.10
7	7.7	5.20	0.091	42.05	0.20	0.007	2.65	0.61	0.72	0.042	0.32	0.18	0.022	0.25	19.98	0.18	0.10
8	7.7	4.66	0.035	43.36	0.12	0.003	2.61	0.41	0.61	0.036	0.33	0.16	0.021	0.20	17.41	0.16	0.10
9	7.7	4.74	0.036	43.16	0.22	0.003	2.35	0.51	1.58	0.039	0.31	0.18	0.021	0.24	19.52	0.15	0.12
10	7.5	5.78	0.048	36.49	0.12	0.003	3.06	0.59	1.75	0.052	0.26	0.18	0.028	0.27	22.84	0.21	0.15
11	7.6	6.01	0.047	34.68	0.23	0.004	3.53	0.75	0.72	0.051	0.34	0.21	0.025	0.25	22.37	0.24	0.12
12	7.6	5.63	0.044	35.86	0.15	0.003	3.08	0.56	2.09	0.058	0.28	0.19	0.025	0.28	22.97	0.21	0.14
13	7.7	5.89	0.044	36.61	0.12	0.004	3.30	0.73	0.88	0.049	0.34	0.20	0.028	0.26	22.45	0.23	0.15
14	7.9	5.53	0.042	38.29	0.22	0.004	3.00	0.68	0.81	0.042	0.36	0.19	0.026	0.23	22.06	0.20	0.13
15	7.8	6.00	0.046	37.63	0.26	0.004	3.48	0.70	0.96	0.047	0.37	0.18	0.028	0.26	22.17	0.23	0.15
16	7.7	5.38	0.039	39.37	0.18	0.006	2.86	0.61	0.65	0.044	0.33	0.20	0.024	0.24	21.29	0.20	0.12
17	7.7	5.51	0.043	39.47	0.17	0.003	2.84	0.60	0.67	0.043	0.31	0.18	0.025	0.24	20.72	0.20	0.12
18	7.7	6.20	0.047	35.53	0.12	0.004	3.41	0.69	0.69	0.05	0.31	0.21	0.031	0.28	21.48	0.23	0.15
19	7.5	5.67	0.042	35.99	0.24	0.005	3.16	0.75	0.73	0.051	0.30	0.24	0.027	0.31	23.27	0.22	0.14

The remaining percentage for each releve represents non-measurable elements, such as C and N, and the occurrence of elements in soils as oxides.

Variations in the vegetation in relation to bases can be seen on both axes. The differences between the apparent relationships of barium and sodium probably relates to their different mobilities in the soil, with sodium being more readily leached than barium; calcium was intermediate and less significant. The association of manganese with the *Molinia caerulea* and *Parnassia palustris* vegetation at the lower end of axis 2 is suggestive of periodic waterlogging. Fig. 11 shows two main trends in the vegetation, both starting from the upper right hand quadrant. Moving left to the upper left hand quadrant, there is a successional transition from short, dry, open, base rich, nutrient poor vegetation to taller, coarser, more nutrient demanding vegetation.

Moving clockwise from the upper right hand quadrant there is a gradual transition to less base rich more mesic vegetation and then to damp coarser vegetation in the lower left hand quadrant, although the influence of bases is still apparent. The samples clustered in the centre of this diagram show the current status of the vegetation in relation to these trends.

DISCUSSION

The analyses have shown that the vegetation of the soda heap is not strongly differentiated, although there is some clear variation in both the species composition and in the vigour of the vegetation, some of which can be related to successional trends and water regime. The *typical* vegetation, which contains the majority of samples, is species rich and contains a number of rare species which are usually only found in uncommon and highly valued vegetation types. These include a number of calcicolous and xerothermal species whose presence is related to the particular characteristics of the substrate on the soda heap. The general appearance of the vegetation is of species rich calcicolous grassland and has some of the species of the classical vegetation types *Molinio-Arrhenatheretea* meadow, *Festuco-Brometea* grassland and *Caricetalia davalianae* mire. This unique combination of species has arisen in response to the very specific habitat conditions associated with the soda heap. Nevertheless, the vegetation is coherent and not simply a random assemblage of species, as indicated by the overall similarity of the floristic structure of the vegetation in most of the samples, and the identification of successional trends and localised environmental influences in others. In the absence of a comprehensive classification of synanthropic vegetation, a possible name for this community could be *Rhinantho-Caricetum flaccae*.

Both the computer and non-computer analyses have been valuable in characterising the vegetation of the old soda heap. The small differences in the definition of variation in the vegetation between the two methods are related to the different ways in which Tables 4 and 5 are constructed. Patterns and trends in the data and known groupings of species are systematically identified by eye and experience in the construction of the non-computer table. TWINSPAN on the other hand, takes no account of typical groupings of species, only groupings within the data set. It simultaneously takes account of all species, their abundance and occurrence in all samples so that sample groupings are only defined by the co-ordinated responses of individual species, or groups of species, drawn from the entire data. Thus although the two samples with *Gymnadenia conopsea*, for example, are placed together in the sample ordination, in the TWINSPAN analysis their overall species composition is not sufficiently different for them to be separated from adjacent samples, even at lower levels of division.

In the analysis of unusual vegetation such as that in the present study which has not previously been described, both methods have merits. The non-computer method (similar to Braun-Blanquet methodology) facilitates the comparison with naturally occurring associations and recognises subtle variations related to particular species, while TWINSPAN allows the objective definition of vegetation types and variants.

The development of spontaneous communities on post-industrial sites is influenced by aspects of soil chemistry such as alkalinity or acidity, nutrient level and toxicity, and by physical factors such as soil structure and particle size (Bradshaw and Chadwick 1980). Although there were some clear trends in the influence of soil chemistry on the Jaworzno soda heap vegetation, the absence of any statistically significant effects suggests that there are also factors other than these influencing the composition of the vegetation. Lee and Greenwood (1976) found that even in wastes younger than those of Jaworzno, the plant associations observed generally could not be related to soil chemistry and that physical features such as compaction and its effect on hydrology were more important. They observed that the water content of wastes up to 32 years old was always high within the rooting zone, although compaction resulted in the formation of a hard dry crust impenetrable to roots with localised standing surface water in places. These observations are consistent with the nature of the vegetation at Jaworzno, where the better drained edges of the plateau supported a more open, stress-tolerant, calcicolous vegetation, while there were some areas in the centre of the plateau where the CANOCO analysis indicated periodic waterlogging.

Lee and Greenwood (1976) describe soil development on lime wastes over a period of 32 years as simply the accumulation of organic material on the surface of unalterd parent material. The dieback of shrubs such as *Frangula alnus* and the rarity of other woody species except *Betula*, suggests that the situation is similar at the Jaworzno soda heap even after 87 years. Birch is a very successful pioneer species on industrial wastes being tolerant of a wide range of toxic compounds (Atkinson 1992; Białobok 1979). Its success on the Jaworzno soda heap may have implications for the future of the vegetation on the site. The establishment and growth to a considerable size of substantial numbers of birch trees may already have contributed to nutrient enrichment on the site. Fig. 11 shows a trend for coarser less species rich vegetation to be associated with nutrient enrichment which if continued, could further threaten the diversity of the *typical* vegetation.

The expansion of industrial, agricultural and urban activities has resulted in massive losses of natural habitats and the native species they support. In built-up areas, therefore, special attention should be paid to the spontaneous vegetation appearing in synanthropic habitats since many vulnerable and rare species of vascular plants have been recorded in them (Adamowski 1998; Shaw and Halton 1998; Tokarska-Guzik 1991a, 1996). With its calcicolous and xerothermal species, the soda heap in Jaworzno is an example of the way in which synanthropic habitats can be the mainstay of locally uncommon and even rare plant species in an area, providing a refuge or replacement habitat. It is also important as a reservoir of diversity for the surrounding industrial landscape.

As with the most valued semi-natural plant communities, the vegetation at Jaworzno is important not only as a refuge for locally and nationally uncommon and rare species, but also for its intrinsic beauty and for its unusual vegetation which shares many of the characteristics of the vegetation of other soda heaps (Lee and Greenwood 1976; Wilkoń-Michalska and Sokół 1968). Whether semi-natural or anthropogenic, plant communities develop in response to particular combinations of environmental conditions and at Jaworzno the conditions, and the vegetation they have given rise to, are very unusual. Unusual biological communities such as this, can be so intimately linked with the particular industrial process which created them that they can be considered to be unique and non-recreatable (Box 1993). As such, they have a value even beyond their undoubted ecological value in their contribution to the cultural, industrial and economic heritage of the region to which they belong.

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FLORA I ROŚLINNOŚĆ STAREJ HAŁDY POSODOWEJ W JAWORZNIE (GÓRNY ŚLĄSK, POLSKA)

STRESZCZENIE

Praca przedstawia analizę flory i zbiorowisk roślinnych, w powiązaniu z wynikami badań fizykochemicznych materiału zwałowego starej hałdy posodowej położonej w Jaworznie na terenie Górnego Śląska (Polska). Na powierzchni 15 000 m^2 stwierdzono występowanie 136 gatunków roślin naczyniowych. Analizowaną florę wyróżnia dominacja wieloletnich bylin łąkowych i murawowych, w tym znaczny jest udział gatunków z rodziny Asteraceae. Pomimo antropogenicznego pochodzenia obiektu, 95% flory stanowią gatunki rodzime. Większość gatunków charakteryzują wskaźniki Ellenberga właściwe dla siedlisk dość suchych, umiarkowanie ubogich w związki azotowe. Badany obiekt jawi się jako ważna ostoja gatunków chronionych, górskich oraz innych elementów nieczęstych w lokalnej florze.

Analiza wyników (wykonana metodami tabelaryczno-opisową oraz komputerową analizą wieloczynnikową wg programu TWINSPAN) wykazała względną jednorodność roślinności ze zróżnicowaniem na warianty, które grupowały płaty miejsc wilgotniejszych. Zestawienie wyników analiz podłoża dla poszczególnych powierzchni badanych wykazało małą zmienność pH i brak większych koncentracji metali ciężkich. Analiza korelacji podłoże–roślinność sugeruje, że zróżnicowanie to w największym stopniu zależy od gradientu stężenia fosforanów, a w dalszej kolejności od gradientu pH oraz prawdopodobnie wilgotności podłoża. Najbogatsza gatunkowo roślinność związana była z niską zawartością fosforanów i wysokim pH.

Uzyskane wyniki sugerują, że zarówno proces rozwoju gleby, jak i sukcesja roślinności przebiegają wolno, lecz w sposób zauważalny, w kierunku prawdopodobnego zmniejszania się różnorodności. Roślinność stanowi względnie jednolite ugrupowanie z niewielkimi nawiązaniami do zbiorowisk łąkowych z klasy *Molinio-Arrhenatheretea*, murawowych z klasy *Festuco-Brometea* i torfowisk eutroficznych z rzędu *Caricetalia davallianeae*. Ważnym wynikiem prowadzonych badań jest wykazanie znacznych walorów florystycznych tego obiektu. Powinien on być objęty ochroną oraz dalszymi badaniami naukowymi.

SŁOWA KLUCZOWE: hałdy sodowe, analiza flory i roślinności, gatunki rzadkie, chronione i górskie, waloryzacja zasobów przyrodniczych.