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RELATIONS BETWEEN VEGETATION AND SOIL IN INITIAL SUCCESSION PHASES IN POST-SAND EXCAVATIONS

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Abstract

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Open-mined sand exploitation always leads to the total liquidation of vegetation and soil cover. The given study presents the relations between vegetation appearing in the excavation and soil development in the initial phases of succession. Investigations were carried out in the Kuznica Warezynska sandpit, located in the Silesian Upland in southern Poland. Results obtained indicate that at uncovered sands, due to exploitation in unreclaimed places, spontaneous regeneration of vegetation-soil cover occurs. In the succession series observed in the excavation, 3 stages were distinguished (primary, secondary and terminal), which were divided into 6 phases. The oldest observed succession stage was made by communities from the *Dicrano-Pinion* connection. The duration of succession of the oldest surfaces is estimated at 25 years. Considering morphology, the forming soil differs at every succession stage. In respect to observed soil formation processes, advancing soils, even the oldest surfaces, have initial character; they are poor in nutrients and characterized by acidic, slightly acidic to alkaline pH-reaction. Physico-chemical properties of soil, forming in the area of the sandpit, are conditioned most of all by the ground water level, its chemical composition and the duration of succession. Investigations proved that the course of succession at habitats fed mainly by waters, originated from the seepage of waters of deep circulation, and this differs from this those in places fed by the precipitation of waters. These differences appear most of all in the first phase of optimum stage. The sandpit is also characterized by a large differentiation of vegetation, resulting from the mosaic character of habitats. Habitat differentiation of the sandpit bottom is connected with its diversified relief and hydrogeological situation.

Key words: vegetation succession, primary succession, species differentiation, soil development, sand excavations

Introduction

The extractive industry is numbered among the most essential anthropogenic factors causing the environment transformation in the world (Jian-Gang et al., 2006; Mannion, 2001). They are often revealed in the total destruction of hitherto functioning ecosystems, consisting in the distribution of vegetation-soil cover and the uncovering of parent rock or covering surface with raw rocky material (Czylok, 2004; Czylok, Rahmonov, 1998). Apart from waste rock dumping sites and collapses, the effects of mine activity are widespread sand excavations (Novak, Prach, 2003; Lukešova, 2001; Rostański, 2006; Szymczyk 1998; Cabała, Rahmonov, 2004).

One of the areas of the largest concentration of sandpits in Europe is the eastern part of the Silesian Upland. Its origination is connected with the use of sand to fill empty places after black coal exploitation. For almost 200 years, this region has been the centre of the largest concentration of black coal mines in Poland. Now the area of overexploited sandy fields here amounts to about 50 km^2 (Czylok, 2004). In the past, the majority of these areas underwent reclamation. Scientific research on the regeneration of ecosystems on post-exploitation terrain was rare. Materials referring to the succession at non-reclaimed sandy parts (Czylok, 1997, 1998; Cieszko, Kucharczyk, 1997; Szymczyk, 1998, 1999; Czylok, Rahmonov, 1996, 2004) indicate that vegetation appearing here has the character of primary succession, and developing ecological systems - considering the occurrence of many rare vegetation species connected with early succession stages - have a unique character (Czylok, Rahmonov, 1996; Czylok, 2004). This fact in these areas creates the possibility to investigate also the initial stages of soil formation in connection with vegetation succession. Among the most important factors determining the course of vegetation-soil succession at this stage are the kind of parent rock, availability and the pH-reaction (Elgersma, 1998; Weigelt, 2001; Fromm et al., 2002; Jentsch, Beyschlag, 2003). Research carried out by Szymczyk (1998, 1999) at sandy excavations proved that the physico-chemical properties of flowing waters there are of essential importance for the course of succession at the humid and water-logged bottoms of sandpits.

The aim of this study was to determine the direction in the course of vegetation succession and soil development at excavations after sand exploitation, in places where vegetation-soil cover was completely disturbed. It refers to these parts of excavations, in which processes of terrestrial ecosystem regeneration were not disturbed by land reclamation exertions and had the character of primary succession.

Study area

Research was carried out in the area of the Kuznica Warezynska sandpit, which is one of the largest in southern Poland. The area of excavation amounts, in total, to 80 ha. Sands of alluvial and fluvioglacial accumulation were exploited here (Gilewska, Klimek, 1967). Sand exploitation, in the oldest areas investigated, ended about 1985.

The essential element of the sandpit geological structure is made by the Quaternary deposits (mainly sands and gravels interbedded by silts). In the majority of the area, these sands are underlain by the Permian deposits, shaped in the form of limestone conglomerates. In a small area at the bottom of the Triassic, Carboniferous and Devonian, deposits (mainly formed as limestone) also occur. In the direct neighbourhood to the north and east of the excavation, the Triassic outcrops occur, including limestone and dolomite. In the excavation bottom, supplying a part of waters of the Quaternary water-bearing horizon, waters connected with the Triassic deposits also take part. The hydrogeological conditions of the sandpit bottom are presented in Fig. 1.

According to data obtained from the nearest meteorological station, located in Katowice, in the area investigated, winds blowing from the south-west and west prevailed. The mean annual air temperature fluctuated between -2.0 ^oC in January to 17.9 ^oC in July. Mean annual temperature amounts to 8.2 ^oC. The largest sum of precipitation falls in July (101 mm), and the smallest one in February (37 mm). Mean annual precipitation amounts to 721 mm. Snow cover occurs here from 75 up to 100 days. Mean annual air humidity amounts to 75%.

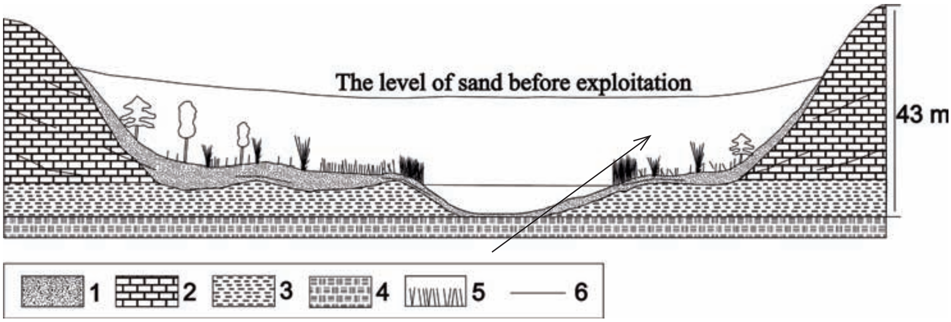

Fig. 1. The scheme of hydro-geological conditions in quarry.

1 – Pleistocene river and glacier sands; 2 – Triassic marl and limestone; 3 – Triassic clay; 4 – carboniferous shale and sandstone; 5 – initial vegetations; 6 – the direction of water migration.

Material and methods

Investigations were carried out at surfaces within the moistened sandpit bottom, where the ground water level was located at a depth of 10 up to 30 cm. The location of the surfaces was conditioned by the type of vegetation and the phases of succession, and connected with them, the changeability of the developing soil cover.

Vegetation

To identify plant communities at every typed surface, the phytosociological survey by means of the Braun-Blanquet method and floristic descriptions were made (Fukarek, 1967). Stages and phases of succession were determined on the basis of archival exploitation maps and the real chronosequence of vegetation, together with soil cover. The affiliation of species for particular syntaxonomic groups was determined according to the classification of Matuszkiewicz (2001). Names of vascular plants were accepted according to Mirek et al. (2002), whereas mosses were accepted in accordance with Ochyra et al. (2003).

Soils

Phytosociological relevé was made at surfaces with phases: connected with the development of *Algae* (profile 1), bryophytes, mainly *Bryum pseudotriqetrum* var. *bimum* (profile 2), *Equisetum variegatum* (profile 3), *Carex canescens* (profile 4), *Salix repens* subsp. *rosmarinifolia* (profile 5) and pine-birch-aspen (profile 6). At these surfaces, soil pits were made to characterise habitats and soil that formed. In the case of profiles 2, 3, 5 and 6, the morphological description of them was made (Tables 1–4). From every distinguished genetic horizon, samples were taken for linen sacks or plastic boxes for laboratory analyses.

In samples taken, the following analyses were made according to standards used in Poland: losses in roasting – in a temperature of 550 °C, pH-reaction by means of the potentiometric method with application of glass electrode (in H_2O and 1-molar KCl), organic carbon (Corg) in organic horizons by means of Alten's method, mineral horizons by Tiurin's method, total nitrogen (Nt) by means of Kjeldahl's method, available phosphorous ($P_{avail.}$) by the Egner-Riehm method, hydrolytic acidity (H_h) by means of Kappen's method, exchangeable aluminium (Al^{3+}) and exchangeable hydrogen (H^+) by means of Sokolow's method, total content of P, Mg, Na, K after sample extraction with 1 - molar CH_3COONH_4 of pH = 7; measured by means of apparatus ASA (firm Solaar): Ca and Mg – in absorption version, and Na and K – in the emission version.

T a b l e 1. Soil morphology under the community with *Equisetum variegatum.*

Genetic Horizon	Depth [cm]	Profile description
Ol/A	0–3.5	Organic-humus horizon, composed of litter *Equisetum variegatum, Corynephorus canescens, Salix repens* subsp. *rosmarinifolia*, in its bottom mineral part living roots of the above-mentioned species occur.
A	3.6–6.5	Humus horizon, medium-grained sand with single fractions of gravel, black colour, humid, large amount of living roots.
BC	6.6–13	Initial forming illuvial horizon, varigrained sand with the admixture of silt, dark-yellow colour, single parts of reed rootstock.

Abbreviations: Ol/A – organic-humus horizon; A – humus horizon and BC – illuvial and parent rock horizon.

T a b l e 2. Morphology of soil under bryophytes.

Genetic horizon	Depth [cm]	Profile description
Ol	0–6	Organic horizon formed from turf of bryophytes and single individuals of *Carex canescens and Equisetum variegatum*.
A	6.1–9.8	Humus horizon, fine-grained sand, black colour, significant contribution of dead as well as living roots.
B	10–15	Forming illuvial level, medium-grained sand, with yellow-green spots (traces of gleying), with large amount of fine roots of herbaceous vegetation, below this horizon in sands of features of parent rock rootstock of *Phragmites australis* occur.

Abbreviations: Ol – organic horizon; A – humus horizon and B – illuvial horizon.

T a b l e 3. Morphology of soil under the community with *Salix repens* subsp. *rosmarinifolia*.

Genetic horizon	Depth [cm]	Profile description
Ol	0–0.8	litter subhorizon of organic horizon is mainly composed of pine, birch and aspen litter. Small amount of litter *S.repens* subsp.*rosmarinifolia* is connected with its rapid decomposition.
Of	0.9–1.4	Rotting subhorizon with weakly recognizable remains of the above-mentioned plants.
A	2–13	Humus horizon, medium-grained sand, black colour, humid and mainly overgrown with willow roots.
A/C	14…	Transitional horizon, medium-grained sand, in the bottom part of the horizon ferruginous pockets and smaller contribution of roots occur.

Abbreviations: Ol – litter subhorizon of organic horizon; Of – rotting subhorizon; A – humus horizon and A/C – humus and parent rock transitory horizon.

T a b l e 4. Morphology of soil under the pine-birch-aspen community.

Genetic horizon	Depth [cm]	Profile description
Ol	0–0.5	Organic horizon with litter subhorizon, composed of pine litter (mainly needles and cones – undecomposed), aspen, birch and rosemary-leaved willow.
A	1–6	Humus horizon, varigrained sand, dark-grey colour, humid, small amount of roots.
A/C	7–9	Transitional horizon, medium-grained sand, in the bottom part of the level ferruginous pockets occur.
C	10….	The horizon of parent rock, medium-grained sand, humid, significant contribution of limestone crumbs

Abbreviations: Ol – litter subhorizon of organic horizon; A – humus horizon; A/C – humus and parent rock transitory horizon and C – parent rock horizon.

Description of soil morphology

Profile 3 – phase 0: was made on a community with a predomination of *Equisetum variegatum*, and accompanying them singly, such taxa as: *Betula pendula, Pinus sylvestris, Alnus incana, Salix repens* subsp. *rosmarinifolia, Corynephorus canescens* and *Epipactis palustris*. From bryophytes, *Bryum pseudotriqetrium* var. *bimum* predominates. The profile is situated at the edge of a depression with a slight sloped inlination towards the North. Depressions and micro-depressions are filled with water. The ground water level was at a depth of 10 cm (Table 1). At the terrain surface, in places, deposed precipitates of calcium carbonate were observed.

Profile 2 – moss phase 1: In bryophytes, *Bryum pseudotriqetrum* var. *bimum* predominate here. Among vascular plants, single individuals of *Carex canescens, Equiesetum variegatum, Epipactis palustris* and fine individuals *Salix repens* subsp. *rosmarinifolia* occur. The surface is characterized by a valley-clump structure, where clump height fluctuates between 7 and 15 cm (Table 2).

Profile 5 – phase 3 A: Community with a predomination of *Salix repens* subsp. *rosmarinifolia,* with the following accompanying species: *Pinus sylvestris, Populus tremu*la. From herbaceous vegetation *Carex hirta, Calamagrostis epigejos, Equiesetum variegatum, Holcus mollis* and *Deschampsia flexuosa* were here noted. The surface is flat; the ground water level occurs at a depth of 30 cm (Table 3).

Profile 6 – phase 4: Biogroup pine-birch-aspen (*Pinus sylvestris, Betula pendula, Populus tremula), Salix repens* subsp. *rosmarinifolia, Equiesetum variegatum, Juncus conglomeratus, J. articulatus* and *Lycopodiella innundata* also occur singly.

The surface is flat; the ground water level occurs at a depth of 20–22 cm (Table 4).

Water

The ground water level at particular surfaces was determined during soil profile development. Chemical analyses of the water were made for two springs of the largest yield located at excavation and stream flood waters and depressions supplied with precipitation water, in places where clear vegetation differentiation was observed.

The following analyses were made: water pH-reaction, specific electrical conductivity and the content of Ca^{2+}, Na^{+}, K^{+}, HCO_3^-, Cl^-, NO_3^- and SO_4^{2-} ions. The measurement of pH-reaction and specific electrical conductivity was made every time during water sampling in field investigations. The measurement of specific electrical conductivity was made by means of a conductometer of the CC-315 type from the Elmetron firm, and the measurement of pH-reaction by means of a pH-meter of the CP-315 type from the Elmetron firm. Chemical analyses were made and checked according to methods described by Krawczyk (1999).

Results

Succession course

In the observed succession series at excavation after sand exploitation, 3 stages were distinguished (initial, optimal and terminal), which were divided into 6 phases. The duration of succession at the oldest surfaces was evaluated at 25 years. The succession at water-logged, sandy surfaces of the excavation bottom was initiated by algae and blue-green algae (phase 0). The appearance of this stage at humid sands does not depend on physico-chemical properties of water, but on the features of material building the substratum, such as the contribution of fine-grained fraction. But the physico-chemical properties of water can find their influence in the species composition of algae, which occupy sand. Patches of algae initiate the development of soil through the binding of sand grains and their attachment.

Phase 1 marks the period of algae cover colonization mainly by hydrophilous and hygrophilous bryophytes. Among them it is possible to mention: *Bryum pseudotriquetrum* var. *bimum, Polytrychum commune, Sphagnum flexuosum, Aulacomnium palustre, Caliergonella cuspidate* and *Campylium stellatum* (Fig. 2). Species composition-forming, bryophyte communities are determined by the physico-chemical properties of supplying waters. At surfaces fed by waters with pH-reactions similar to neutral and with significant contents of Ca^{2+} ions, bryophytes, such as *Bryum pseudotriquetrum* var. *bimum*, mainly appear. In places of the influence of waters with acidic pH-reactions and low concentrations of Ca^{2+} ions, the bryophyte stage most often is built of peatmosses *Sphagnum* sp., *Polytrychum commune*, and sometimes of *Aulacomnium palustre*.

Phase 2 is characterised by the gradual development of low-sedge bog-springs, which can appear early enough at surfaces not occupied yet by bryophytes (Fig. 3). Also in this phase, physico-chemical properties of supplied water influence the emerging vegetation. In places fed by waters of high concentrations of Ca^{2+} ions (Table 5), communities with a predomination of variegated horsetail *Equisetum variegatum*, and eutrophic low-sedge bog-springs from the connection *Caricion davallianae*, develop. At surfaces fed by acidic waters with a low concentration of Ca^{2+} ions, this phase was represented by oligotrophic communities of low-sedge bog-springs from the connection *Caricion nigrae* (Fig. 2).

Phase 3 is characterised by the development of bushy communities, such as the association, *Betulo-Salicetum repentis*, with the characteristic contribution of *Salix repens* subsp. *rosmarinifolia* and species passing from class *Thalspietea rotundifolii* and *Scheuchzerio-Caricetea nigrae*. The appearance of this vegetation as well as the following phases of succession observed in the sandpit are independent of local changeability of the physico-chemical properties of waters supplying the analysed surfaces.

The introduction of arborescent species begins as early as phase 2 and takes part through the formation of biogroups (phase 4). The species initiating the formation of clumps are most often bushes of *Salix repens* subsp. *rosmarinifolia*. The clumps are composed of *Pinus sylvestris, Populus tremula* and *Betula pendula*. In such clumps, with time, the predomination is obtained by *Pinus sylvestris,* coniferous forest species also appear (phase 5), passing into the terminal stage (Fig. 3). At such a stage of succession, species typical of coniferous forest communities are *Pyrola rotundifolia, P. minor* or *Vacccinum vitis-idaea* and other. The oldest phase of the terminal stage observed in the area investigated was created by plantings of a different type – *Pinus sylvestris* (Fig. 3) – which, in the future, will be transformed into a pine coniferous forest.

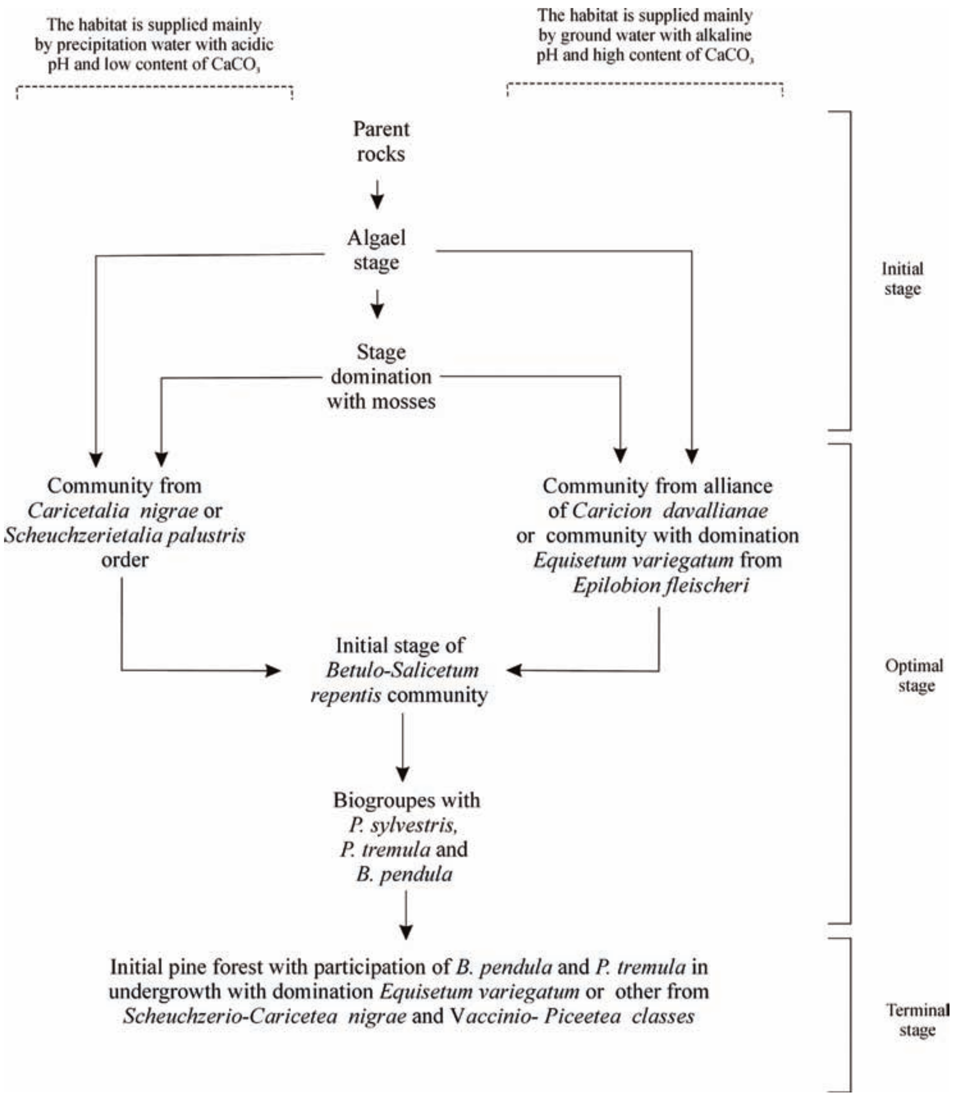

Fig. 2. The course of succession in the area of Kuznica Warezynska.

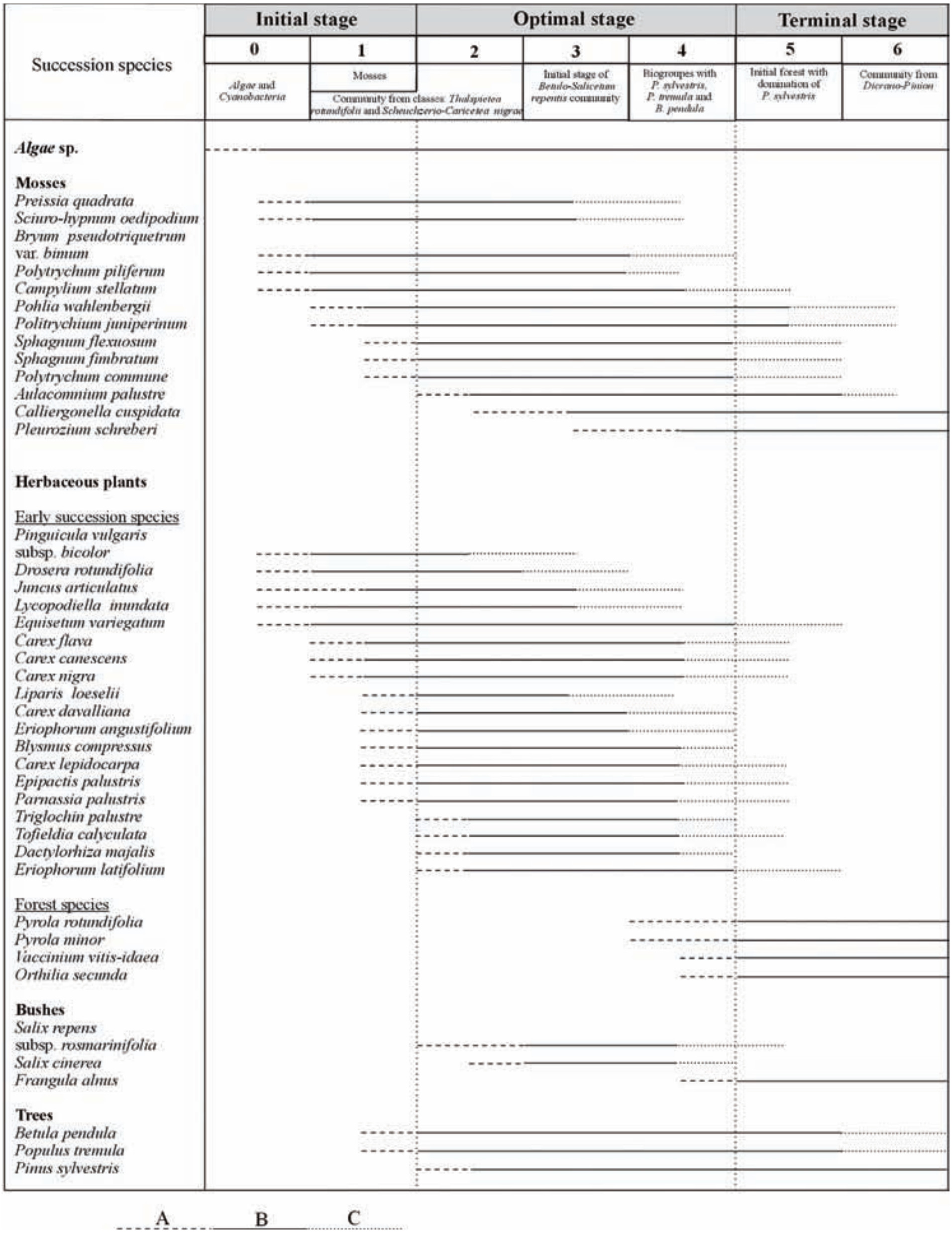

Fig. 3. Species changes of plants and communities sequence during succession in Kuznica Warezynska:
A – the species encroachment in the initial stage of succession;
B – optimum occurrences of species during the succession;
C – the species withdrawal in terminal stage of succession.

T a b l e 5. Some physical and chemical outflow water properties in the area of Kuznica Warezynska quarry.

Number of points	pH	C [µS/cm]	M [mg/l]	TH [mg/l]	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	NO_3^-	Cl^-	Type of water
					[mg/l]								
1.	6.49	795	492.9	259.3	64.5	32.6	27.5	2.9	195.0	110.0	0.0	54.9	HCO_3-SO_4-Ca-Mg
2.	7.3	729	452.0	312.8	78.0	28.7	16.6	1.7	214.2	92.8	12.4	46.2	HCO_3-Ca-Mg

Abbreviations: the points of 1, 2 – water from outflow.

Among the elements of flora taking part in the formation of initial communities at excavations after sand exploitation, special attention was paid to numerous contributions of protected, rare species and even Polish flora species threatened by extinction. They are as follows *Pinguicula vulgaris, Liparis loeseli, Epipactis palustris*, *Tofieldia caliculata*, *Drosera rotundifolia, Lycopodiella inundata* and others (Fig. 3).

A large differentiation of habitats at the excavation bottom was mainly conditioned by the origin of supplyed water. Among the water physico-chemical parameters investigated, the content of calcium ions and pH-reaction is of the most essential importance for the course of early succession stages. Their pH-reaction is similar to neutral or alkaline (Table 5). Higher values of pH-reaction and contents of Ca^{2+} ions were noted in the water of drying, flooded areas fed by outflows. Completely different parameters were typical for waters in depressions, which were mainly fed by relatively acidic and weakly mineralised precipitation water. They were characterized by low pH-reaction and small content of calcium ions, and their chemical composition was varied (Table 6).

T a b l e 6. Some physical and chemical properties of flood water (points: 1,2,3) and water in hollow without flow (points: 4,5) in the area of Kuznica Warezynska quarry.

Number of points	pH	C [µS/cm]	M [mg/l]	TH [mg/l]	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	NO_3^-	Cl^-
					[mg/l]							
1	7.44	765	474.3	380.0	125.0	16.5	12.5	3.9	314.3	102.3	16.0	23.0
2	7.35	621	385.0	270.3	82.2	15.8	13.0	5.7	181.8	111.1	13.0	28.7
3	7.37	688	426.6	310.3	76.2	29.2	15.4	4.3	265.4	75.0	2.0	31.9
4	5.44	154	95.4	56.1	17.8	2.8	2.0	4.3	19.5	39.5	3.8	2.8
5	6.62	185	114.7	75.1	24.0	3.6	3.0	4.7	33.6	37.4	2.7	11.7

Abbreviations: the points of 1, 2, 3 – flood water and 4,5 – hollow.

Soil morphology and chemical properties

Soil forming at the excavation bottom in the particular phases of succession reveals the variety in respect to morphology into the organic horizon (O) and humus horizon (A). The organic horizon (O) is only differentiated into subhorizons Ol and Of in the cases of soil forming under *Salix repens* subsp. *rosmarinifolia* (Tables 3, 7). Initial soils formed under this species are characterized by a profile composition of the Ol-Of-A-A/C-C type. In the remaining soils, only the forms O/A (in the case of *Algae*) Ol, and Ol/A, in profiles 2, 3 and 6, were observed. The most thick humus horizons also occur under *Salix repens* subsp. *rosmarinifolia,* contrary to the remaining soil profiles (soil Table 1).

Horizon Ol in every case produces undecomposed litter (branches, leaves and other). Chemical parameters characterizing this subhorizon are presented in Table 7. The content of Corg fluctuates between 14 and 50%, of nitrogen Nt from 0.375 to 0.980%, and the relation C/N amounts to 26.

Soils forming under the investigated plant communities are characterised by pH-reactions from acidic to alkaline, fluctuating in mineral horizons within the range of 5.4–7.5 in water and 5.1–7.1 in KCl. Hydrolytic and exchangeable acidities (H^+, Al^{3+}) are similar and show very low values (Table 7).

The content of organic carbon and nitrogen on dependence on vegetation type is varied. The largest concentration of these elements was stated in horizon A in the bryophyte phase (Table 7). The relation C/N fluctuates within wide limits in every community investigated, which results in the weak process of mineralization and biological activity of soil. The contents of forms P, Mg, K, Na available for plants in humus horizons are low, and among them the lowest content is typical for phosphorus. The highest contents of elements investigated were stated in organic horizons or subhorizons (Table 8).

According to the nomenclature of the Systematics of soils in Poland (1989), the soils investigated should be determined as lithogenic, mineral initial and weakly shaped, initial soils, and after FAO (1988): *Haplic Arenosols,* after WRB (1998): *Protic Arenosols*.

Discussion

Excavations after sand exploitation of large sizes are an example of such drastic environment deformations that ecosystems (together with soil) should form here again. It resembles a situation that happened here after glacier recession in the Pleistocene (Czylok, 1997, 2004). Excavation bottoms, as well as scarps create barren washed sands and gravel; insertions with a significant contribution of silts are also encountered. In places where – during exploitation – the water-bearing horizons were cut, water flows or percolates. Regarding the fact that the above-mentioned sands often directly contact with the Mesozoic deposits (Triassic, Jurassic), seepage waters in places are rich in calcium carbonate, magnesium, and hydrogen carbonates (Czylok, Rahmonov, 1996).

T a b l e 7. Some chemical properties of soils forming under various type of vegetation in the area of Kuznica Warezynska.

Nr. of profiles	Tickness of horizons	Loss ignition	Corg	Nt	C/N	pH		Hy-drolitic acidity	Acidic cations	
									H^+	$Al3^+$
	[cm]	[%]				H2O	KCl	cmol(+).kg-1		
Profile 1	Soil under *Equisetum variegatum*									
Ol/A	0–3.5	71	35	0.834	42	-	-	-	0.36	0.21
A	3.6–6.5	14	6.5	0.298	22	7.0	6.9	-	0.09	0.03
BC	6.6–13	1	0.271	0.008	34	7.0	6.8	0.23	0.18	0.57
C	14…	1.51	0.53	0.007	75	7.3	6.7	0.23	0.09	0.0
Profile 2	Soil under *Bryum pseudotrigetrum* var. *bimum*									
Ol	0–6	79	38	0.650	58	-	-	0.31	0.0	0.0
A	6.1–9.8	25	9	0.412	22	-	-	0.23	0.0	0.0
B	10–15	2.4	0.59	0.014	42	7.1	7.0	0.19	0.09	0.0
Profile 3	Soil under pine-birch-aspen biogroups									
Ol	0–0.5	71	45	0.597	75	4.3	4.2	1.25	2.61	0.78
A	1–6	3	1.34	0.038	35	5.4	5.1	1.08	0.57	0.18
A/C	7–9	-	-	-	-	-	-	-	-	-
C	10….	0.41	0.10	0.004	25	7.3	6.7	0.45	0.09	0.15
Profile 4	Soil under *Salix repens* subsp. *rosmarinifolia*									
Ol	0–0.8	90	50	0.980	51	-	-	-	2.44	0.86
Of	0.9–1.4	67	42	0.926	45	5.7	5.5	-	0.66	0.45
A	2–13	4.1	2.3	0.078	29	6.5	6.1	0.86	0.05	0.05
A/C	14…	-	-	-	-	-	-	-	-	-
Profile 5	Soil under *Carex canescens*									
Ol	0–3	52	14	0.375	37	7.4	7.2	-	0.0	0.0
A	3–6	6	2.1	0.104	20	7.5	7.4	0.19	0.0	0.0
C	> 7	1.4	0.33	0.029	11	7.5	7.1	0.0	0.0	0.0
Profile 6	Soil under *Algae*									
A	0–3	3.27	1.52	0.041	37	4.9	4.4	2.29	1.2	0.45

Abbreviations: Ol – litter subhorizon of organic horizon; Of – rooting horizon; Ol/A – organic-humus horizon; A – humus horizon; A/C – humus and parent rock transitory horizon; BC – illuvial and parent rock horizon ; B – illuvial horizon; and C – parent rock horizon.

Vegetation succession is a very slow process, which in many cases enables the direct observation of vegetation transformations, happening during it in short time. Therefore, to determine vegetation succession and soil development occurring at excavations, the chronosequence of real vegetation communities and soil formation was applied, on the assumption that older surfaces passed the same development stages as younger ones. This

T a b l e 8. Contents of chosen nutrient elements in soils of Kuznica Warezynska.

Nr profiles	Tickness of horizons	P_{tot}	$P_{avail.}$	Mg	Na	K
	[cm]	mg/kg		mg/kg		
Profile 1 – soil under *Equisetum variegatum*						
Ol/A	0–3.5	790	147	117	312	226
A	3.6–6.5	238	18	31	70	163
BC	6.6–13	57	8	0,8	34	33
C	14...	110	11	-	-	-
Profile 2 – soil under *Bryum pseudotrigetrum* var. *bimum*						
Ol	0–6	578	98	102	846	1874
A	6.1–9.8	460	12	31	124	372
B	10–15	161	81	7.6	36	57
Profile 3 – soil under pine-birch-aspen biogroups						
Ol	0–0.5	494	72	92	114	926
A	1–6	74	5	0.96	36	52
A/C	7–9	-	-	-	-	-
C	10….	51	1,1	2	25	18
Profile 4 – soil under *Salix repens* subsp.*rosmarinifolia*						
Ol	0–0.8	784	111	239	120	1906
Of	0.9–1.4	746	92	117	210	736
A	2–13	93	1.4	9	53	39
A/C	14…	-	-	-	-	-
Profile 5 – soil under *Carex canescens*						
Ol	0–3	330	88	-	198	1366
A	3–6	116	10	-	44	50
C	> 7	54	6	-	26	21
Profile 6 – soil under *Algae*						
A	0–3	81	2.4	0.96	27	43

Abbreviations: Ol – litter subhorizon of organic horizon; Of – rooting horizon; Ol/A – organic-humus horizon; A – humus horizon; A/C – humus and parent rock transitory horizon; BC– illuvial and parent rock horizon ; B – illuvial horizon; and C – parent rock horizon.

way, used many times by research workers to describe vegetation succession and soil development in different ecosystems (Pickett, 1989; Fastil, 1995; Rahmonov, 2007), allowed the observation of transformations at temporally differentiated surfaces characterised by similar habitat conditions. The duration of succession was also evaluated on the basis of archival exploitation maps, containing the dates of particular finishing levels.

After exploitation-finishing in the areas where gravitational draining occurs and the surface is not disturbed, the colonization of the excavation bottom follows with associations of so-called overground soil algae (Shtina, Hollerbach, 1976; Rahmonov, Piątek, 2007). The initial phases of succession connected with the appearance of algae and observed in the excavation are similar to those observed in the sandy substratum, as well as in depressions between dunes (Elgersma, 1998; Picińska-Fałtynowicz, 1997; Cabała, Rahmonov, 2004; Czylok, Rahmonov, 2004).

At habitats, where the water level is permanently high, the factor inhibiting tree introduction can be morass built of species from genus *Sphagnum* sp. and *Polytrychum commune* or *Aulacomnium palustre,* shaped in earlier succession stages. Regarding the problem of the inhibition of late succession species introduction by early succession species, Walker, Chapin (1987) as well as Armesto, Pickett (1986) lent their attention. This inhibition can happen in a different ways. Dense cushions of these mosses can physically hinder the supply of seeds of arborescent trees to the seed bank, isolating them from the substratum. A similar influence of dense mossy turf in sandy areas of deep levels of water tables was stated by other researchers (Osbornová et al., 1990; Symonides, 1986). The phenomenon of the pergelation of mossy turf due to the lack of snow cover, which was also observed in sandpits, can cause the freezing out of one-year, weakly rooted seedlings. Other factors inhibiting arborescent species introduction at surfaces of permanent water seepage is the periodical occurrence in sandpits of aufeis (ice on top) connected with outflows of underground waters (Rzętała, 2008, 2009), which can cause the freezing out of seedlings and less resistant species. The largest and thickest covers of aufeis were formed in places overgrown by mossy communities or more rarely by vegetation from the class *Scheuchzerio-Caricetea fusce*. In these communities only stunted pines and birches appeared.

In every case, the succession is initiated by variegated horsetail *Equisetum variegatum*. From the phytogeographical point of view, this species is the Artcic-Alpine element (Zając, 1996). In Alaska, as well as in the region of western Spitsbergen, this horsetail, together with other species, also takes part in the formation of the initial stages of vegetation succession (Crocker, Major, 1955; Święs, 1988). In the phytosociological literature (Matuszkiewicz, 2001), it is considered to be characteristic of the *Epilobietalia fleischeri* order. These order are groups of open pioneer communities, initiating vegetation succession at gravel-banks and in the valleys of unregulated mountainous rivers. Among pioneer species in the Kuznica Warezynska excavation -which in the Carpathians take part in the settling of gravel heaps and gravel-banks – *Myricaria germanica* was noted (Czylok, 2004). At further stages of succession, in water-logged parts of excavation bottom, variegated horsetail participated in the formation of low-sedge bog-springs from the connection, *Caricion davallianae* (Czylok, 1997). In areas where succession has lasted for more than 60 years, more advanced stages with birch-willow brushwood of *Betulo-Salicetum repentis* are observed.

Soil

Soil pH-reaction in horizon A, as the succession progresses, admittedly does not indicate the differentiation (Table 7) under predominating species at every stage and phase of succession, apart from algocenoses and *Pinus sylvestris*. The contemporary acidity, especially under *Pinus sylvestris* in organic and humus horizons (O and A), can be caused by organic acids produced by decomposing plant litter, especially pine litter. It is connected with the chemical composition of this species litter, which influences the process of forming soil properties (Rahmonov, 2007). In communities tending towards coniferous forest formation, a clear drop in pH-reaction is observed (Czyżewska, 1992; Jankowski, Bednarek, 2000, 2002; Nierop et al., 2001; Jentsch et al., 2005), whereas in the soils investigated, this trend is not observed. Because the parent rock of profiles investigated in every case is characterised by varied pH-reactions (Table 7), the soils investigated should be determined as acidic, slightly acidic and alkaline. It is connected with the presence of carbonates (in the form of limestone crumbs of different size, carbonate precipitations and calcium dissolved in water) within analysed layers of fluvioglacial sands or proluvial-alluvial sands, originating from the period of the Middle Polish and Vistulian glaciations (Szczypek, Wach, 1989; Gilewska, Klimek, 1967; Pełka-Gościniak, 2007), and water from the water-bearing Triassic horizons. This water is of essential influence on the physico-chemical soil properties at this stage of its development. This is also confirmed by investigations carried out by Szymczyk (1999) in other excavations. Dissolved organic and mineral substances in these waters supply plants with nutrients; in the case of other ecosystems, these components originate most often from processes of litter mineralization (Dziadowiec, 1990), soil processes and mineral weathering (Bednarek et al., 2004). The results obtained are very similar to results from habitats with plant communities located at similar succession stages of succession series in other areas (Czylok, Rahmonov, 2005).

The content of organic carbon and its differentiation at particular succession phases is mostly conditioned by the kind of vegetation and ground water level. Such large contents of Corg in mineral and organic horizons are strictly connected with organic colloids originating from contemporary vegetation litter. At every stage of succession relations C/N (Table 7), there are disadvantages and processes of mineralization occur very slowly. This is especially connected with high ground water level in this terrain (occurring already at a depth of 10 cm). The contents of elements investigated, such as P_{tot}, $P_{available,}$ Mg, Na and K at this succession stage, are not conditioned by rock weathering, at which soil is formed, but with the mineralization of organic matter *in situ*, as well as *ex situ*, and, as was mentioned earlier, with waters of deep circulation. The sands, which make the parent rock for soil development, contain significant amounts of dusty and silty fraction. This causes such surfaces to be colonised by early succession blue-green algae and algae. Yearly die-back of their thallus, supplies the soil with organic matter (Rahmonov, 2007; Rahmonov, Piątek, 2007). Therefore, the substratum, at which succession is initiated, is not completely devoid of organic matter and nutrients, especially of free atmospheric nitrogen (Shtina, Hollerbakh, 1976). The initial information of the pioneer role of the algae stage in the initiation of soil-formation processes at excavations after sand exploitation is also reported by Czylok, Rahmonov (2004). The stage in which formation apart from algae: fungi, lichens, liverworts, bryophytes take part, is called the biological soil crust (Belnap et al., 2003).

The following source of enrichment in nutrients of excavations after exploitation is the supply of allochthonous material from neighbouring forest and meadow complexes. It is conditioned by a relatively small size and form of excavations, favouring the deposition of allochthonous organic matter, blown in the form of soil particles and plants remains. This matter is mostly deposed in terrain depressions, at elevation foothills and in humid places. This interception additionally causes the local enrichment of substratum, and it is one of reasons for the quick succession rate and floristic richness, in comparison to neighbouring areas (Rahmonov, Kin, 2007).

Conclusion

Initial results of research on processes of spontaneous vegetation introduction into areas of excavation after sand exploitation indicate their high value as polygons for research on the regeneration of ecosystems, as well as the course of vegetation-soil succession in deformed areas, especially at their not-reclaimed parts. At the oldest surfaces investigated in the Kuznica Warezynska sandpit, the vegetation succession occurred for about 25 years. Analysing the species composition of plants spontaneously settling in water-logged bottoms of excavations, it appears that the initial succession stages are mainly represented by built of species of anemochoric type of diaspors dispersal, mainly including bryophytes, horsetails, orchidaceous, and from trees – common birch, aspen and common pine.

In the succession series observed in the excavation, 3 stages (initial, optimal and terminal) were distinguished, which were divided into 6 phases. The oldest observed stage of succession was made by communities from the *Dicrano-Pinion* union. Considering morphology, the forming soil differs in every succession stage. In every stage there are initial soils that are poor in nutrients and characterized by slightly acidic to alkaline pH-reactions. Physico-chemical soil properties in this area are mostly conditioned by the ground water level, the content of Ca^{2+} in water and sometimes the duration of succession.

Investigations proved that the course of succession at habitats, which are mainly fed by waters originating from seepages, is different than in places that mainly use precipitation water. These differences are primarily revealed in the 1 phase of the optimal stage. The degree of sand humidification and physico-chemical properties of seepage waters determines the species composition of plant communities forming at the bottom of excavations.

From the point of view of the nature protection unusually important is the fact that initial stages of succession formation at excavations create conditions for many unique plant species to keep relatively numerous populations. They can be convenient places for the survival and development of many valuable, rare plant species and species threatened by extinction in Poland. Despite the legal duty of land reclamation in post-exploitation areas, the interesting objects should be left to their fate. The fact, that in post-exploitation terrain, substituted habitats for species threatened by extinction are formed, should be regarded in species saving programs.

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References

Armesto, J. J., Pickett, S.T.A., 1986: Removal experiments to test mechanisms of plant succession in old fields. Vegetatio, 66: 85–93.

Bednarek, R., Dziadowiec, H., Pokojska, U., Prusinkiewicz, Z., 2004: Ecological and soil investigation (in Polish). PWN, Warszawa, 343 pp.

Belnap, J., Büdel, B., Lange, O.L, 2003: Biological soil crust: Characteristics and distribution. In Belnap, J., Lange, O.L. (eds), Biological soil crusts: Structure, function, and management. Ecol. Stud., 150: 3–30.

Cabała, J., Rahmonov, O., 2004: Cyanophyta and algae as an important component of biological crust from Pustynia Błędowska Desert (Poland). Polish Bot. J., 49, 1: 93–100.

Cieszko, J., Kucharczyk, M., 1997: Closed sandpits as secondary biotop of mars clubmoss *Lycopodiella innundata* (L.) Holub. (in Polish). In Wika, S. (ed.), Vegetation of sandy areas. WBiOŚ UŚ i Zrząd ZJPK Woj. Katowickiego, Katowice-Tychy, p. 50–60.

Crocker, R.L., Major, J., 1955: Soil development in relation to vegetation and surface age at Glacier Bay, Alaska. J. Ecol., 43: 427–428. doi:10.2307/2257005

Czylok, A., Rahmonov, O., 1996: Unique phytocenosis of excavations in easthern part of Katowice province (in Polish). Kształtowanie Środowiska Geograficznego i Ochrony Przyrody na Obszarach Uprzemysłowionych i Zurbanizowanych, 23: 27–31.

Czylok, A., 1997: Pioneering plant communities with variegated horsetail *Equisetum variegatum* in the areas of sand-pits (in Polish). In Wika, S. (ed.), Vegetation of sandy areas. WBiOŚ UŚ i Zarząd ZJPK Woj. Katowickiego, Katowice-Tychy, p. 61–66.

Czylok, A., 1998: Some interesting aspects of biodiversity in anthropogenic areas (in Polish). Problemy środowiska i jego ochrony. Centrum Studiów nad Człowiekiem i Środowiskiem. Uniwersytet Śląski, Katowice, p. 97–107.

Czylok, A., Rahmonov, O., 1998: The initial stages of succession with variegated horsetail *Equisetum variegatum* Schleich on wet sands of surface excavations. In Szabo, J., Wach, J. (eds), Anthropogenic aspects of geographical environment transformations. Debrecen–Sosnowiec, p. 81–86.

Czylok, A., 2004: The vegetation of sand excavations in the Silesian Upland (in Polish). In Partyka, J. (ed.), Zróżnicowanie i przemiany środowiska przyrodniczo-kulturowego Wyżyny Krakowsko-Częstochowskiej. Przyroda, Ojców, 1: 205–212.

Czylok, A., Rahmonov, O., 2004: The encroachment of Scots pine *Pinus sylvestri* L. on the area of former sand exploitation in the Eastern Silesian Upland. Coniferous forest vegetation – differentiation, dynamics and transformations. Seria Biologia, Wydaw. Nauk. UAM, Poznań, 69: 251–256.

Czylok, A., Rahmonov, O., 2005: The conception of active protection natura values of Błędów Desert (in Polish). In Szczypek, T. (red.), Środowisko Przyrodnicze Wobec Zagrożeń Antropogenicznych. Uniwersytet Sląski, Katowice, p. 34-39.

Czyżewska, K., 1992: Syntaxonomy of inland pioneers sandy grasses (in Polish). Monogr. Bot., 74: 1–174.

Dziadowiec, H., 1990: Decomposition of litters in selected forest ecosystems (mineralization, nutrient release, humification (in Polish). Toruń, 137 pp.

Elgersma, A.M., 1998: Primary forest succession on poor sandy soils as related to site factors. Biodivers. Conserv., 7: 193–206. doi:10.1023/A:1008884418570

Fastil, C.L., 1995: Causes and ecosystem consequences of multiple pathways on primary succession at Glacier Bay, Alaska. Ecology, 76: 1899–1916. doi:10.2307/1940722

Fromm, A., Jakob, S., Tischew, S., 2002: Sandy grassland in former mining areas. Naturschutz und Landschaftsplanung, 34: 45–51.

Fukarek, F., 1967: Phytosociology (in Polish). PWRiL, Warszawa, 219 pp.

Gilewska, S., Klimek, K., 1967: Querternary of Silesian Upland (in Polish). In Czwartorzęd Polski. PWN, Warszawa.

Isermann, M., 2005: Soil pH and species diversity in coastal dunes. Plant Ecol., 178: 111–120. doi:10.1007/s11258-004-2558-8

Jankowski, M., Bednarek, R., 2000: Quantitative and qualitative changes of properties as basis for distinguishing development stages of soils formed from dunes sand. Pol. J. Soil Sci., 33: 61–69.

Jankowski, M., Bednarek, R., 2002: Secondary development stages of soils formed on inland dunes under pine woodlands. Transactions CD-ROM, Symp. 39, No 797, 17th WCSS, 14-21 August, Bangkok, Thailand, p. 12.
Jentsch, A., Beyschlag, W., 2003: Vegetation ecology of dry acidic grasslands in the lowland area of central Europe. Flora, 198: 3–25.
Jian-Gang, Y., Wei, F., Ling, F., Yan, C., Dong-Qing, W., Zhong-Yi, Y., 2006: Soil formation and vegetation establishment on the cliff face of abandoned quarries in the early stages of natural colonization. Restor. Ecol., 14, 3: 349–356. doi:10.1111/j.1526-100X.2006.00143.x
Krawczyk, E.W., 1999: Hydrochemystry (in Polish). Wyd. Uniw. Śląskiego, Katowice, 92 pp.
Lukešová, A., 2001: Soil algae in brown coal and lignite post-mining areas in Central Europe (Czech Republic and Germany). Restor. Ecol., 9: 341–350. doi:10.1046/j.1526-100X.2001.94002.x
Mannion, A.M., 2001: Global environment change. A natural and cultural environmental history. Addison Wesley Longan, 450 pp.
Matuszkiewicz, W., 2001: Guidebook for identification of plants community in Poland (in Polish). PWN, Warszawa, 537 pp.
Mirek, Z., Piękoś-Mirkowa, H., Zając, A., Zając, M., 2002: Flowering plants and pteridophytes of Poland. A checklist. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków, 442 pp.
Nierop, K.G.J., van Lagen, B., Buurman, P., 2001: Composition of plant tissues and soil organic matter in the first stages of a vegetation succession. Geoderma, 100: 1–24. doi:10.1016/S0016-7061(00)00078-1
Novak, J., Prach, K., 2003: Vegetation succession in basalt quarries: pattern on a landscape scale. Appl. Veg. Sci., 6: 111–116.
Ochyra, Żarnowiec, J., Bednarek-Ochyra, H., 2003: Census catalogue of Polish mosses (in Polish). Institute of Botany, Polish Academy of Sciences, Kraków, 372 pp.
Osbornová, J., Kovárová, M., Lepś, J., Prach, K., 1990: Succession in abandone fields. Studies in Central Bohemia, Czechoslovakia, Geobotany 15. Kluver Academic Publishers.
Pełka-Gościniak, J., 2007: Aeolian processes in old and new industrialised areas in the Silesian Upland. Acta Geographia Silesiana, 1: 41–44.
Picińska-Fałtynowicz, J., 1997: Algae (in Polish). In Piotrowska, H. (ed.), Przyroda Słowińskiego Parku Narodowego. Bogucki Wydawnictwo Naukowe, Poznań-Gdańsk, p. 143–156.
Pickett, S.T.A., 1989: Space-for-time substitution as an alternative to long-term studies. In Likens, G.E. (ed.), Long-term studies in ecology: approaches and alternatives. Springer Verlag, New York, p. 110–135.
Rahmonov, O., 2007: Relations between vegetation and soil in initial phase of succession in sandy areas. Wydawnictwo Uniwersytetu Śląskiego, Katowice, 198 pp.
Rahmonov, O., Kin, N.O., 2007: Role of allochthonous substance in initial stage of succession. Acta Geographia Silesiana, 1: 53–60.
Rahmonov, O., Piątek, J., 2007: Sand colonization and initiation of soil development by cyanobacteria and algae. Ekológia (Bratislava), 26, 1: 52–63.
Rostański, A., 2006: Spontaneous plant cover on colliery spoil heaps in Upper Silesia (Southern Poland) (in Polish). Wydawnictwo Uniwersytetu Śląskiego, Katowice, 230 pp.
Rzętała, M., 2008: Functioning of water resevoirs and the course of limnic processes under conditions of varied anthropopression a case study of Upper Silesian Region (in Polish). Wydawnictwo Uniwersytetu Śląskiego, Katowice, 171 pp.
Rzętała, M., 2009: Purification of surface water flowing in transfer reservoirs. Series of Monographs, Polish Journal of Environmental Studies, 3: 43-50.
Shtina, E.A., Hollerbakh, M.M., 1976: Ecology of soil algae (in Russian). Nauka, Moscow, 127 p.
Symonides, E., 1986: Seed bank in old-field successional ecosystems. Ekol. Pol., 34, 1: 3–29.
Szczypek, T., Wach, J., 1989: Accumulation phases of the Quaternary deposits in the Błędów Desert based on lithological studies. Quaest. Geogr. Special Issue, Wyd. UAM, Poznań, p. 137–145.
Szymczyk, A., 1998: Regeneration of biocenosis in excavation in example of Siemonia (in Polish). In Geografia w kształtowaniu i ochronie środowiska oraz transformacji gospodarczej regionu górnośląskiego. Sosnowiec, p. 58–59.
Szymczyk, A., 1999: Significance of karst water outflows to spontaneous regeneration of biocenosis on the basis in Siemonia sandpit, Poland. Acta Universitatis Szegediensis, Acta Geographica, 36: 78–84.

Święs, F., 1988: Geobotanical differentation of tundra in southern coast of Bellsund (western Spitsbergen) (in Polish). Wyprawy Geograficzne na Spitsbergen. Wyd. UMCS, Lublin, p. 21–228.
Walker, L. R., Chapin, F. S., 1987: Interactions among processes controlling successional change. Oikos, 50: 131–135. doi:10.2307/3565409
Weigelt, A., 2001: Plant competition on inland dunes: Influence of water availability, nitrogen supply and the role of belowground processes. PhD Thesis, Universität Bielefeld.
Zając, M., 1996: Mountain vascular plants in the Polish Lowlands. Pol. Bot. Stud., 11: 1–92.