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Plant communities, properties, and age of organic soils in the post-extraction sites of the Trzcińskie Mokrada Peatland (Sudetes Mts., SW Poland)

Abstract: The aim of the study was to show the impact of the peat extraction on the development and properties of organic soils and plant habitat in post-extraction sites. The study was conducted in the complex of the Trzcińskie Mokrada Peatlands (Sudetes Mts., SW Poland). The Trzcińskie Mokrada Peatlands began to form in Preboreal (10960–9330 ±50BP) so that they are one of the oldest peatlands in the Sudetes. We analyzed 8 soil profiles (42 samples). Peat forming process there is still active in the moderate or strong degree (PtII–PtIII). The floristic composition of the studied areas was typical of transition peatlands. Successive dry and moist periods were observed in the developed of organic soils. The time gaps in peat profiles covering hundreds of years prove their extraction in the past.

Key words: peatland, organic soils, wetlands plants, age of soils, human activity, Sudetes Mts.

INTRODUCTION

Drainage of the peatland and their surroundings before and during peat extraction leads to severe changes in the mire environment (Okruszko 1993, Piaścik and Bieniek 1998), including destabilization of water balance (Holden et al. 2004) and the loss of biodiversity (Szube 1903). However, after the cessation of peat extraction and groundwater level increase, the peatlands may undergo regeneration phase as exemplified in the Sudetes Mts. e.g. Jakuszyce Pass, the Jizerska Meadows and the Zieleniec Peatlands (Wojtuń et al. 2001). Since 19th century the extraction of peat took also place in the Trzcińskie Mokrada Peatlands (Zimmerman and Berg 1941). After the World War II the peat extraction was no longer continued and peatlands has partly regenerated (Andrzejczak and Bogacz 2013). The aim of the present paper is to show the age, morphology and selected properties of organic soils and to characterize actual plant communities in the post-extraction sites on the Trzcińskie Mokrada Peatlands.

STUDY AREA

Fieldworks was carried out in the Trzcińskie Mokrada Peatlands (N50°52', E15°54') located in the

Western Sudetes region, in the NE part of the Jelenia Góra Basin. The study area is located in the Rudawy Janowickie Landscape Park (Woźniak 2007). The stands for detailed study were selected during the general field characterization of peatlands area (Andrzejczak 2010, Andrzejczak and Bogacz 2013). The peat extraction in Trzcińskie Mokrada started at the end of 19th century and finished before the World War II. Generally the extraction of peat was looked after by the Stolberg – Werningerode family, the court owner in Janowice village. This family employed one hundred people to work on the extraction at the end of 19th century. In that time the total production of peat in the Trzcińskie Mokrada was 1.85 million cubic meters of peat per one year (Staffa 1998). A thickness of extracted peat layer is unknown, but the portion of non-extracted paths for peat transport allows to approximate that ca. 40 cm was extracted by average. The extraction was limited by ground-water layer (as it can be expected in core No. 6) or worse and worse peat quality due to the higher ash content (as in core No. 3). Nowadays, all the post-extraction sites are completely covered with vegetation and have organic material at soil surface. The investigated stands were located in northern (PN) and southern part of peatland (PS) (Andrzejczak 2010). According to ecological criteria, the peatland belongs mainly to transitional bog type (To-

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bolski 2000) fed by precipitation with a little seasonal supply by the Silnica stream (Jezierski 2002).

METHODS

Eight peat cores were sampled using the auger (diameter 6 cm, 50 cm long). The cores were divided into intervals on the basis of changes in botanical composition and degree of humification. Samples of each core interval were sealed in plastic bags. Samples were double-bagged sealed to prevent water loss. In laboratory duplicated were made. One part of samples were stored at temperature 3–4°C. Second part of samples were dried in oven in temperature 60°C by 16 hours. Oven-dry organic materials were pulverized in agate planetary mill to a particle size <2 mm and homogenize.

The following morphological characteristics were described on the field: soil horizons, thickness of particular layers, transition type, color, structure, degree of peat decomposition on the base of von Post Scale, and degree of peat forming process. The following properties of soil samples were analyzed in the dry samples: ash content – samples burned in muffle furnace at 550°C by 4 hours, total organic carbon (TOC) by CS-MAT 5500 Analyzer, total nitrogen (TN) by Kjeldahl method using Bushi Analyzer, exchangeable acidity (H_{ex}) in 1 mol·dm⁻³ KCl by Sokołow method, base exchangeable cations: Ca⁺², Mg⁺², K⁺, Na by ICP method after extraction in 1 mol·dm⁻³ CH₃COONH₄ at pH=7. Effective cation exchange capacity (CEC_e) = $S + H_{ex}$ was expressed in cmol_c l·kg⁻¹. Properties of soil samples were analyzed in wet condition too: rubbed fiber (B) by half syringe methods (Lynn et al. 1974), soil pH in KCl at 1:2.5 ratio. Statistical analysis in soil material was conducted using Statistica 9.0.

The following geobotanical peat properties in wet samples were examined: botanical composition and percent of non-decomposed plant fragments (Lubliner-Mianowska 1956), as well as kinds, types and species of peat based on botanical peat components according to Polish national standard PN-85/G-00:1985. During the field research the lists of present plant species were completed on sites 1–8 (Fig. 1) and an attempt was done to determine plant communities according to Matuszkiewicz (2001). Description of each site included the related hydrological condition and vegetation (involving the protected species).

The age of peat samples in two cores (No. 3 and No. 6) was analyzed. The age of 11 peat samples was determined by AMS¹⁴C method at the Poznań Carbon Laboratory using HIDEX 300SL Analyzer.

FIGURE 1. Distribution of research cores on the Trzcińskie Mokradła Peatlands lidar map: 1, 2, 3, 4, 5, 6, 7, 8 – peat soil cores. Source: geoportal.gov.pl

RESULTS AND DISCUSSION

Current structure of selected actual plant communities in the Trzcińskie Mokradła Peatlands

In general, plant habitats in research objects were diverse. The number of species in post-extraction sites in the Trzcińskie Mokradła Peatland was rather low as compared to non-extracted sites. The similar conclusion was presented by Narkiewicz (1999). The phytocenoses were typical for transitional peatlands where the water remains at a high level for a longer part of the year. *Pinus sylvestris* or *Betula pendula* were often found in the plant associations. Noteworthy is the presence of *Drosera rotundifolia* in the site 6 (Table 1). *Drosera sp.* did not form a compact carpet in the Trzcińskie Mokradła Peatland, but occurred only as individual specimens (Table 1). In the central part of the Trzcińskie Mokradła Peatland some rare plants e.g. *Comarum palustre* were found. In the half of examined areas, the *Eriophorum angustifolium* was noted. Other described species were typical of lowland peatlands (Kłosowski and Kłosowski 2006).

TABLE 1. Differentiation of actual plant habitats in Trzcińskie Mokrada Peatlands

<i>Site 1</i>	
horizon a	<i>Betula pendula</i> , <i>Pinus sylvestris</i> , <i>Pinus nigra</i>
horizon b	–
horizon c	<i>Sphagnum angustifolium</i> , <i>Sphagnum fallax</i> , <i>Phragmites australis</i> , <i>Eriophorum angustifolium</i> , <i>Calluna vulgaris</i> , <i>Betula pendula</i> , <i>Quercus robur</i>
Plant community	<i>Sphagno recurvi</i> – <i>Eriophoretum angustifolii</i>
<i>Site 2</i>	
horizon a	<i>Betula pendula</i> , <i>Picea abies</i>
horizon b	<i>Frangula alnus</i> , <i>Quercus robur</i>
horizon c	<i>Sphagnum fallax</i> , <i>Equisetum sylvaticum</i> , <i>Juncus effusus</i> , <i>Carex fusca</i> , <i>Agrostis gigantea</i> , <i>Festuca rubra</i> , <i>Lysimachia vulgaris</i> , <i>Comarum palustre</i> , <i>Galium saxatile</i> , <i>Vaccinium myrtillus</i>
Plant community	Peatland birch degradation phase
<i>Site 3</i>	
horizon a	<i>Betula pendula</i>
horizon b	<i>Sphagnum fallax</i> , <i>Sphagnum flexuosum</i> , <i>Carex fusca</i> , <i>Eriophorum angustifolium</i> , <i>Typha angustifolia</i> , <i>Festuca rubra</i> , <i>Oxycoccus palustris</i> , <i>Lysimachia vulgaris</i> , <i>Comarum palustre</i> , <i>Galium saxatile</i> , <i>Betula pendula</i> , <i>Salix cinerea</i>
Plant community	<i>Sphagno recurvi</i> – <i>Eriophoretum angustifolii</i>
<i>Site 4</i>	
horizon a	–
horizon b	<i>Betula pendula</i> , <i>Salix cinerea</i>
horizon c	<i>Sphagnum angustifolium</i> , <i>Sphagnum centrale</i> , <i>Sphagnum fallax</i> , <i>Sphagnum palustre</i> , <i>Equisetum palustre</i> , <i>Juncus effusus</i> , <i>Carex fusca</i> , <i>Eriophorum angustifolium</i> , <i>Eriophorum vaginatum</i> , <i>Festuca rubra</i> , <i>Comarum palustre</i>
Plant community	<i>Sphagno recurvi</i> – <i>Eriophoretum angustifolii</i> + <i>Betula pendula</i>
<i>Site 5</i>	
horizon a	<i>Betula pendula</i>
horizon b	<i>Betula pendula</i> , <i>Quercus robur</i> , <i>Salix cinerea</i>
horizon c	<i>Sphagnum angustifolium</i> , <i>Equisetum palustre</i> , <i>Carex fusca</i> , <i>Carex rostrata</i> , <i>Agrostis gigantea</i> , <i>Festuca rubra</i> , <i>Betula pendula</i> , <i>Pinus sylvestris</i>
Plant community	Peatland birch degradation phase
<i>Site 6</i>	
horizon a	–
horizon b	<i>Sphagnum fallax</i> , <i>Polytrichum commune</i> , <i>Carex rostrata</i> , <i>Eriophorum angustifolium</i> , <i>Drosera rotundifolia</i> , <i>Oxycoccus palustre</i> , <i>Betula pendula</i> , <i>Pinus sylvestris</i> , <i>Picea abies</i>
Plant community	<i>Sphagno recurvi</i> – <i>Eriophoretum angustifolii</i> and <i>Sphagno recurvi caricetum rostrate</i>
<i>Site 7</i>	
horizon a	<i>Betula pendula</i>
horizon b	–
horizon c	<i>Sphagnum fallax</i> , <i>Sphagnum palustre</i> , <i>Juncus effusus</i> , <i>Carex rostrata</i> , <i>Agrostis gigantea</i> , <i>Lysimachia vulgaris</i>
Plant community	<i>Sphagno recurvi</i> – <i>Eriophoretum angustifolii</i> – in degradation fase
<i>Site 8</i>	
horizon a	–
horizon b	<i>Betula pendula</i> , <i>Pinus sylvestris</i>
horizon c	<i>Sphagnum fallax</i> , <i>Sphagnum palustre</i> , <i>Polytrichum commune</i> , <i>Eriophorum angustifolium</i> , <i>Betula pendula</i>
Plant community	<i>Sphagno recurvi</i> – <i>Eriophoretum angustifolii</i>

Explanation: a – the higher floor of trees, b – the lower floor of trees, c – underground, *Frangula alnus* – protected plants.

Properties of organic soil in the post-exploitation sites

The cores represent moderately deep organic soils (80–130 cm), highly or medium palludified (PtIIIc4, PtIIc4) built of medium to strongly decomposed peat. In general soil profiles exhibit horizons sequences Oi–Oa–C, and locally Oi–Oe–Oa–C (Andrzejczak 2010). The decomposition degree of peat mass increases with depth, that is confirmed by the correlation coefficient between rubbed fiber (B) and depth

($r=-0.48^*$, $p\leq 0.05$ (Table 6). The results obtained refer to those reported by D'Amore and Lynn (2002), who noted increasing decomposition of organic matter below the surface layers in Histosols of the Southeast Alaska. Peats were strongly saturated with water due to high groundwater level. Upper horizons, were built of transitional peats and the deeper layers – of low peats (Table 4). Organic soils were underlain by the clays or silt clays, which were derived from the colluvial materials from greenstone-granite weathering (Andrzejczak 2010).

TABLE 2. Selected physical and physicochemical properties of soils

Profile No.	Soil horizons in profiles	Thickness (cm)	Munsell Soil Color (moist)	Ash content (%)	Rubbed fiber % (B)	pH _{KCl}	g·kg ⁻¹		C/N
							TOC	TN	
1	Oi1	0–10	10YR 5/4	11.45	60	3.9	459	14.5	31.6
	Oi2	10–28	10YR 5/6	10.60	55	3.8	465	14.8	31.4
	Oa1	28–50	10YR 3/1	17.46	7	3.6	515	12.3	41.8
	Oa2	50–55	10YR 3/2	33.57	4	3.9	418	13.7	30.5
	Oa3	55–60	10YR 2/1	77.82	0	3.4	124	5.8	21.2
2	Oi1	0–3	10YR 3/3	4.27	–	5.0	515	14.2	36.1
	Oi2	3–10	10YR 4/4	6.60	76	3.3	499	14.8	33.7
	Oe	10–22	10YR 4/6	10.79	30	3.6	516	20.1	25.6
	Oa1	22–31	10YR 5/3	17.35	7	3.9	486	16.0	30.4
	Oa2	31–42	10YR 3/4	22.28	5	3.8	463	18.4	25.1
	Oa3	42–55	10YR 3/3	66.84	5	3.9	213	12.0	17.7
	Oa4	55–80	10YR 3/1	79.46	3	4.2	121	8.4	14.5
3	Oi	0–3	10YR 4/4	23.62	56	4.5	378	14.2	26.5
	Oa1	3–16	10YR 2/1	8.89	9	4.1	436	20.1	21.6
	Oa2	16–32	10YR 3/1	52.25	5	4.2	284	18.2	15.5
	Oa3	32–38	10YR 3/2	70.64	8	4.7	169	13.4	12.6
	Oa4	38–65	10YR 3/4	75.30	12	4.4	154	7.5	20.4
4	Oi	0–20	10YR 4/4	5.34	64	3.6	445	12.6	35.4
	Oe	20–35	10YR 6/6	59.24	23	4.6	241	13.7	17.6
	Oa	35–71	10YR 2/1	66.77	3	4.4	198	11.4	17.3
5	Oi	0–13	10YR 3/4	5.92	69	3.5	499	14.2	35.0
	Oa1	13–32	10YR 3/3	23.15	2	4.4	460	17.0	27.0
	Oa2	32–65	7.5YR 3/2	46.92	4	4.6	171	7.5	22.7
6	Oi1	0–14	10YR 4/6	7.78	63	3.5	469	11.7	39.9
	Oe1	14–30	10YR 3/3	11.76	34	3.7	442	14.5	30.4
	Oi2	30–40	10YR 3/3	9.67	47	3.4	498	14.5	34.2
	Oa1	40–50	10YR 3/4	9.89	14	3.3	550	12.0	45.7
	Oi3	50–60	10YR 5/6	10.25	49	3.8	468	15.9	29.3
	Oa2	60–65	10YR 4/4	9.04	11	3.3	513	12.3	41.7
	Oa3	65–80	10YR 3/4	15.88	9	3.2	478	14.0	34.2
	Oe2	80–90	10YR 3/3	76.06	22	3.6	135	7.0	19.3
7	Oi1	0–9	10YR 6/6	4.75	52	3.7	424	21.5	19.7
	Oi2	9–20	10YR 4/6	8.15	65	3.7	438	16.5	26.5
	Oe1	20–25	10YR 3/3	18.56	19	3.9	436	21.8	20.0
	Oa1	25–33	10YR 4/4	11.73	8	3.9	513	18.2	28.2
	Oe2	33–40	10YR 3/3	14.61	20	3.8	477	19.0	25.1
	Oa2	40–65	10YR 3/4	69.43	6	3.9	166	12.3	13.5
	Oa3	65–90	N 2/0	76.31	5	4.0	144	7.2	19.9
8	Oi1	0–6	10YR 3/4	5.04	52	3.4	409	13.4	30.3
	Oi2	6–34	10YR 4/6	7.26	73	3.6	460	17.0	26.9
	Oi3	34–50	10YR 5/6	7.84	42	3.6	502	16.2	31.0
	Oa	50–70	10YR 3/3	13.71	4	3.6	487	11.4	43.3

Explanation: TOC – total organic carbon, TN – total nitrogen.

The pH of the soils varied and was strongly correlated with degree of peat mass decomposition ($r=0.48^*$, $p\leq 0.05$) (Table 6). Uronic acids predominate in fibric *Sphagnum* peat, whereas humic and fulvic acids predominate in sapric peat (Naucke et al. 1993). Peat reaction ranged from strongly acid ($\text{pH}_{\text{KCl}} 2.8$) in the surface of fibric horizon to acid ($\text{pH}_{\text{KCl}} 6.0$) in slightly decomposed peat layers (Table 2).

The content of TOC in organic horizons ranged from $121 \text{ g}\cdot\text{kg}^{-1}$ in the highly muddy horizon to $550 \text{ g}\cdot\text{kg}^{-1}$ in the low ashes sapric peat. Peat horizons were

developed under different conditions in habitats which were characterized by a diverse TN contents (Jongerius and Pons 1962, Anderson 2002, Moore et al. 2011). The content of TN in organic horizons varied between 5.8 and $21.8 \text{ g}\cdot\text{kg}^{-1}$ (Table 2). The contents of nitrogen were significantly negatively correlated with depth ($r=-0.80^*$, $p\leq 0.05$) (Table 6). Value of C/N ratio, which is considered to be an indicator of biological changes occurring in the peat (Lucas 1982, Cleveland and Liptzin 2007) ranged from 12.6:1 to 45.7:1 (Table 2). The sapric horizons with low C/N values (less than 20:1)

TABLE 3. Sorption properties of the soils studied

Profile No.	Soil horizons in profiles	Depth of horizon	Ca ⁺² cmol _c ·kg ⁻¹	Mg ⁺²	K ⁺	Na ⁺	S	H _{ex}	CEC _e	BS %
1	Oil	0–10	35.92	7.40	0.34	0.55	43.49	11.5	54.99	79.1
	Oi2	10–28	37.92	7.89	0.25	0.50	46.56	9.2	55.76	83.4
	Oa1	28–50	19.96	5.18	0.05	0.25	25.44	14.0	39.44	64.4
	Oa2	50–55	6.18	1.74	0.12	0.17	8.21	18.0	26.21	31.3
	Oa3	55–65	9.38	3.32	0.13	0.14	12.97	7.2	20.17	64.3
2	Oil	0–3	46.90	15.27	2.24	0.41	64.82	4.0	68.82	94.2
	Oi2	3–10	20.95	7.66	2.11	0.51	31.23	13.6	44.83	69.7
	Oe	10–22	26.94	5.01	0.88	0.63	33.46	15.2	48.66	68.7
	Oa1	22–31	25.15	6.50	0.25	0.39	32.29	8.4	40.69	79.3
	Oa2	31–42	15.56	2.40	0.18	0.27	18.46	8.4	26.86	68.7
	Oa3	42–55	13.97	3.08	0.14	0.27	17.49	5.6	23.09	75.7
	Oa4	55–100	11.97	3.09	0.15	0.31	15.53	3.2	18.73	82.9
3	Oi	0–3	31.93	10.45	2.73	1.07	46.21	6.8	54.01	85.5
	Oa1	3–16	30.73	7.40	1.89	0.80	40.84	8.4	49.25	82.9
	Oa2	16–32	25.54	4.08	0.32	0.37	30.33	4.0	34.33	88.3
	Oa3	32–38	19.96	3.78	0.20	0.28	24.25	2.4	26.65	91.0
	Oa4	38–65	16.36	3.45	0.16	0.27	20.26	2.0	22.26	91.0
	Oa5	65–90	12.97	2.95	0.16	0.24	16.34	2.4	19.74	82.8
4	Oi	0–20	23.95	8.07	1.07	0.74	33.83	4.3	38.13	88.7
	Oe	20–35	20.35	4.80	0.30	0.32	26.38	1.2	27.58	95.6
	Oa	35–71	35.71	5.72	0.17	0.28	27.75	0.7	28.45	97.5
5	Oi	0–13	10.37	5.41	1.88	0.45	18.11	7.6	25.71	70.4
	Oa1	13–32	29.94	3.29	1.12	0.45	34.80	1.6	36.40	95.6
	Oa2	32–65	18.36	2.13	0.23	0.28	21.00	1.8	22.80	92.1
6	Oil	0–14	16.76	5.76	0.38	0.50	23.40	12.8	36.20	64.4
	Oe1	14–30	18.96	4.52	0.20	0.46	24.14	10.4	34.54	69.9
	Oi2	30–40	16.36	3.86	0.12	0.40	20.74	12.0	32.74	63.3
	Oa1	40–50	11.97	3.05	0.07	0.32	15.51	14.0	29.51	52.5
	Oi3	50–60	15.76	3.98	0.12	0.43	20.20	10.8	31.00	65.2
	Oa2	60–65	13.97	3.49	0.07	0.32	17.85	14.4	32.25	55.3
	Oa3	65–80	11.97	2.66	0.05	0.26	14.94	14.8	29.74	50.2
	Oe2	80–90	4.99	0.79	0.10	0.12	6.00	13.6	19.60	30.6
7	Oil	0–9	19.56	4.94	1.40	0.46	26.36	11.2	37.56	70.2
	Oi2	9–20	25.15	5.15	0.48	0.53	31.31	8.8	40.11	78.1
	Oe1	20–25	18.96	3.07	0.25	0.32	22.60	8.8	31.40	72.0
	Oa1	25–33	23.95	3.74	0.17	0.34	28.20	7.2	35.40	79.7
	Oe2	33–40	26.34	4.24	0.17	0.43	31.18	6.8	37.90	82.3
	Oa2	40–65	11.97	2.10	0.12	0.22	14.41	6.4	20.81	69.2
	Oa3	65–90	8.98	2.03	0.12	0.17	11.30	6.0	17.30	65.3
8	Oil	0–6	11.97	2.39	0.77	0.72	15.85	16.0	31.85	50.2
	Oi2	6–34	16.96	6.23	0.74	0.22	24.15	15.2	39.35	61.4
	Oi3	34–50	14.97	4.87	0.63	0.12	20.59	12.8	33.39	61.7
	Oa	50–70	14.37	3.90	0.48	0.05	34.65	14.8	49.45	70.1

Explanation: CEC_e – effective cation exchange capacity, BS – base saturation, S – sum of base cations, H_{ex} – exchange acidity, Oi, Oe, Oa, – soil horizons.

TABLE 4. Kind and composition of plant remains in the organic horizons

Profile No.	Soil horizons in profiles SGP 2011	Depth of horizon (cm)	Wood and bark (%)	Leaves	<i>Sphagnum</i>	<i>Bryales</i>	<i>Carex</i>	<i>Eriophorum</i>	<i>Juncus</i>	Other	Not recognized	Type of peat	Kind of peat
PN-85/G-02500:1985													
1	Oi1	0–10			65	10	10	10			5	P	Minero-Sphagnioni
	Oi2	10–28			65	10	10	10			5	P	Minero-Sphagnioni
	Oa1	28–50			60	5	15	15			5	P	Minero-Sphagnioni
	Oa2	50–55			20	15	30	30			5	N	n.d.
	Oa3	55–65	completely decomposed peat										
2	Oi1	0–3	10		45		35				10	P	Minero-Sphagnioni
	Oi2	3–10	15		75		+				10	P	Minero-Sphagnioni
	Oe	10–22	+		40		40				20	P	Minero-Sphagnioni
	Oa1	22–31			60	15	15				10	P	Minero-Sphagnioni
	Oa2	31–42	completely decomposed peat										
	Oa3	42–55	completely decomposed peat										
	Oa4	55–100	completely decomposed peat										
3	Oi	0–3	15		60	10	10				5	P	Minero-Sphagnioni
	Oa1	3–16	+		45	+	50				5	P	Minero-Sphagnioni
	Oa2	16–32	completely decomposed peat										
	Oa3	32–38	completely decomposed peat										
	Oa4	38–65	completely decomposed peat										
4	Oi	0–20			65		15			15	5	P	Minero-Sphagnioni
	Oe	20–35	15		5		65			5	10	N	Magnocarisoni
	Oa	35–71	5		+		75			+	10	N	Magnocarisoni
5	Oi	0–13		5	30		45				20	P	Minero-Sphagnioni
	Oa1	13–32			5		90				5	N	Magnocarisoni
	Oa2	32–65	completely decomposed peat										
6	Oi	0–14			45	5	45				5	P	Minero-Sphagnioni
	Oe1	14–30			30	35	25				10	N	Bryalo-Parvocancioni
	Oe2	30–40			25	5	65				5	N	Bryalo-Parvocancioni
	Oa1	40–50					90				10	N	Magnocarisoni
	Oi	50–60			5		85				10	N	Magnocarisoni
	Oa3	60–65			+		90				10	N	Magnocarisoni
	Oa4	65–80			+		95				5	N	Magnocarisoni
	Oe3	80–90			+		95				5	N	Magnocarisoni
	Oa3	80–90	strongly mudded peat										
7	Oi1	0–9			20		+		65		15	P	n.d.
	Oi2	9–20	+	5	55		15		15		10	P	Minero-Sphagnioni
	Oe1	20–25	25	5	20		25		15		10	P	Betulioni
	Oa1	25–33			5	+	70				25	N	Magnocarisoni
	Oe2	33–40			25	+	60				15	P	Minero-Sphagnioni
	Oa2	40–65	strongly mudded peat										
	Oa3	65–90	strongly mudded peat										
8	Oi1	0–6			70	+	30					P	Minero-Sphagnioni
	Oi2	6–34			65		35					P	Minero-Sphagnioni
	Oi3	34–50			60		40					P	Minero-Sphagnioni
	Oa	50–70	completely decomposed peat										

were generally placed in bottom parts of the profiles studied. This phenomenon may indicate the existence of more dry periods in the development of these horizons (Wang et al. 2014). The rapidly changed C/N value can be also associated with periods when peat was extracted. Differences between C/N value in natural and harvested peatlands in the eastern Quebec were reported by Glatzel et al. (2003).

The effective cations exchange capacity (CEC_e) ranged from 17.49 to 73.26 $cmol_c \cdot kg^{-1}$. Higher values of (CEC_e) are typical for the surface horizons and are strongly negatively correlated with depth ($r = -0.79$, $p \leq 0.05$) (Table 6). Garcia et al. (2011) reported similar trends in Histosols of the Western Guayana, Venezuela. This phenomenon depends on kind of peat and trophic status of mineral basement. Base saturation (BS)

exceeded 50% (Table 3), therefore the soils were classified as Epifibric Endosapric Eurtic or Epifibric Endosapric Dystric Histosols (IUSS Working Group WRB 2015). Calcium and magnesium predominated among exchangeable base cations. Contents of Ca^{2+} and Mg^{+2} varied between the different soil horizons, often reaching values above $40 \text{ cmol}_c \cdot \text{kg}^{-1}$ in the case of calcium, and $10 \text{ cmol}_c \cdot \text{kg}^{-1}$ soil in the case of magnesium (Table 3).

Geobotanical properties of peat

The organic soil in the Trzcińskie Mokradła consist mostly of the reed (transitional) and sphagnum-carex (transitional) peats. These genus are characterized by species typical of mesotrophic, sometimes oligotrophic sites (PN/85G-02500:1985). Detailed examination allowed to classify peat as a sphagnum-carex species with a large participation of *Radicelles* and *Sphagnum recurvum* (Tobolski 2000) (Table 4). In some peat layers the recognition of peat species was impossible due to decomposition of plant remains. The low peat type was also encountered in the samples from the bottom peat layers. The surface peat layers are considered to be a result of the peat-forming process in peatland and consists of transitional peat, whereas layers of low peat were found only in the bottom part of each core. This may indicate the changing conditions of the water supply, and in particular the growing role of rainwater and peat acidification and oligotrophication in the regeneration phase (Herbichowa et al. 2009). The Trzcińskie Mokradła Peatlands horizons represented by transitional and low peat, were generally characterized by high proportion of *Sphagnum* and *Carex* fragments with little participation of *Bryales* and *Eriophorum*. The emergence of non-decomposed plant remains of *Eriophorum* instead of *Sphagnum*, showed the decrease of moisture (Tomaszewska 2000). Some layers contained also negligible amounts of wood bark and leaves (Table 4).

Age of soils studied

The accumulation of organic matter in the core No. 3 began about 10960 ± 50 BP, during the Preboreal period. The age in the bottom of the core No. 6 was 9330 ± 50 BP (Table 5). In this period, birch and birch – pine formation predominated in Poland (Jachowicz and Dębowicz-Jachowicz 2003). The age of the peat deposits is similar to the oldest radiocarbon dates of organic sediments in the Jizera and the Karkonosze Mountains (Dumanowski et al. 1962). The age of peat decreased in the overlying horizons. However, the age in both cores rapidly changes at the depth of 32–40 cm. In the core No. 3 the age dropped abruptly from 8960 ± 50 BP to 2290 ± 35 BP (and then to modern age), and in the core No. 6 – from 4350 ± 35 BP to modern age (Table 5). That was most likely caused by peat extraction (Fiałkiewicz-Kozieł et al. 2014). In the Lower Silesian peatlands we can find many places where peat was mined (Staffa 1998). The lack of fire indicators in macrofossils analyses precludes the fire on peatland. If excavation was stopped after water of the surface peatlands set sedimentation of peat could start again (Tomaszewska et al. 2014). The effects of peat extraction in described area are presented on a lidar map (Fig. 1). We can observe borders between extracted or not extracted areas and the causeways to transport peat (geoportal.gov.pl).

CONCLUSION

1. Rapid changes in the age of overlying peat layers testified that the part of peat formed during the last 4–8 millennia was probably extracted.
2. The composition of the vegetation communities in the post-extraction sites in the Trzcińskie Mokradła Peatland is typical for transitional peatlands. The plant species, soil morphology, and kind of soil organic matter indicated that peat-forming process is moderately (PtII) or highly (PtIII) intensive at present.

TABLE 5. Age of peat and organic-mineral material in profiles No. 3 and No. 6

Profile No.	Depth (cm)	TOC ($\text{g} \cdot \text{kg}^{-1}$)	Age ^{14C}	Number of data	Profile No.	Depth (cm)	TOC ($\text{g} \cdot \text{kg}^{-1}$)	Age ^{14C}	Number of data
3	0–3	378	$106.49 \pm 0.37^*$	Poz-30198	6	0–14	469	$112.68 \pm 0.41^*$	Poz-30210
	3–16	436	$106.94 \pm 0.36^*$	Poz-30199		14–30	442	$111.86 \pm 0.39^*$	Poz-30211
	16–32	284	$2290 \pm 35\text{BP}$	Poz-30200		30–40	499	$165 \pm 30\text{BP}$	Poz-30208
	32–38	170	$8960 \pm 50\text{BP}$	Poz-30201		40–50	550	$4350 \pm 035\text{BP}$	Poz-30209
	38–65	154	$9650 \pm 50\text{BP}$	Poz-30202		50–80	486	n.d.	–
	65–90	96.3**	$10960 \pm 50\text{BP}$	Poz-30204		80–90	135	$9330 \pm 50\text{BP}$	Poz-30213

Explanation: * pMC – percent modern carbon, n.d. – not detected, ** organic-mineral material, BP – before present.

TABLE 6. Correlation coefficients between some properties of soils

Value	pH	B	TOC	TN	Ca ⁺²	Mg ⁺²	K ⁺	Na ⁺	CEC _e
Depth	0.29	-0.48*	-0.80*	-0.83*	-0.67*	-0.58*	-0.46*	-0.72*	-0.79*
pH		-0.26	-0.48*	-0.33	0.16	0.14	0.18	-0.14	-0.13
B			0.50*	0.43*	0.33	0.25	0.19	0.52*	0.43*
TOC				0.84*	0.54*	0.47*	0.26	0.59*	0.75*
TON					0.59*	0.36	0.60*	0.60*	0.68*
Ca ⁺²						0.81*	0.56*	0.69*	0.89*
Mg ⁺²							0.77*	0.67*	0.85*
K ⁺								0.58*	0.84*
Na ⁺									0.76*

Explanation: * significant at ≤ 0.05 .

3. Botanical composition of peat material and low C/N ratio in particular peat layers indicated a water regime differentiation during the evolution of the studied peatland. Peat extraction most likely influenced these changes.
4. Currently the transitional peats has been developing which indicate the dominant role of rainwater in the regeneration phase of peatlands development.

REFERENCES

- Anderson D.E., 2002. Carbon accumulation and C/N ratios of peat bogs in North West Scotland. *Scottish Geography Journal* 118(4): 323–341.
- Andrzejczak M., 2010. Properties and the stage of evolution in peat and post-peat soils in object Trzcińskie Mokradła. PhD Thesis, Wrocław University of Life Sciences: 1–186 (in Polish).
- Andrzejczak M., Bogacz A., 2013. Composition of humic fraction in organic soil in different parts of peatland split by railway line. *Zeszyty Naukowe the Wrocław University of Life Sciences* 595: 7–19 (in Polish).
- Cleveland C.C., Liptzin D., 2007. C:N:P stoichiometry in soil in there a Redfield ratio. How the microbial biomass? *Biochemistry* 85: 235–252.
- D'Amore D.V., Lynn W.C., 2002. Classification of forested Histosols in Southeast Alaska. *Soil Science Society America Journal* 66: 554–562.
- Dumanowski B., Jahn A., Szczepankiewicz S., 1962. The Holocene of Lower Silesia in the light of results of first radiocarbon dating. *Bull. de l'Academie Polonaise des Sciences, Seria Des Science. Geologia et Geografia* 10(1): 47–52.
- Fiałkiewicz-Kozieł B., Kołaczek P., Micheżyński A., Piotrowska N., 2014. Net construction of a reliable absolute chronology for the last two millennia in an anthropogenically disturbed peat bog: Limitations and advantages of using a radioisotopic proxy and age depth modeling. *Quaternary. Geochronology* 25: 83–95.
- Garcia P., Schargel R., Zink J.A., 2011. Properties and Classification of the Tepui Peats (Zink J.A., Huber O., Editors). [In:] *Peatlands of the Western Guyana Highlands, Venezuela, Ecological Studies* 217: 141–189.
- Glatzel S., Kalbitz K., Dalva M., Moore T.R., 2003. Dissolved organic matter properties and their relationship to carbon dioxide efflux from restored peat bogs. *Geoderma* (113): 397–411.
- Herbichowa M., Ćwiklińska P., Sadowska A., 2009. Restoration of bog in former peat excavation areas: assumptions, previous experience and results. *Przegląd Przyrodniczy* XX, 3/4: 43–53 (in Polish).
- Holden J., Chapmasn P.J., Labadz J.C., 2004. Artificial drainage of peatlands, hydrological and hydro chemical process and wetland restoration. *Progress in Physical Geography* 28(1): 95–123.
- IUSS Working Group WRB, 2015. World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. *World Soil Resources Report No. 106*. FAO, Rome: 1–232.
- Jachowicz A., Dębowski-Jachowicz S., 2003. *Paleobotanic. Silesia University Press Katowice*: 1–210 (in Polish).
- Jeziński P., 2002. The chemistry of groundwater and there dynamics in the area of Rudawy Janowickie. PhD Thesis, Geology Institute, University of Wrocław (in Polish).
- Jongierius A., Pons L.J., 1962. Soil genesis in organic soils. *Boor en Spade* 12: 292–307.
- Kłosowski S., Kłosowski G., 2006. *Water and Wetlands Plants. Institute of Botany, PAN, Warszawa, Multico Press*: 1–51 (in Polish).
- Lubliner-Mianowska K., 1956. *Direction the study of peat, PTW, Katowice*: 1–83 (in Polish).
- Lucas R.E., 1982. Organic soils (Histosols), formation, distribution, physical and chemical properties and management for crop production. *Michigan State University. Research Report, No. 435 (Farm Science)*.
- Lynn W.C., Mckinzie W.E., Grossman R.B., 1974. Field laboratory tests for characterization of Histosols. [In:] *Histosols: their characteristics, classification and use*. (Stelly M., Editor) SSSA Special Publication 6, Medison, WI: 11–20.
- Matuszkiewicz W., 2001. *Guide for the detection of Polish plant communities. PWN, Warszawa*: 1–537 (in Polish).
- Moore T.R., Trofynov J.A., Prescott C.E., Titus B.D., 2011. Nature and material in the dynamics of C, N, P during litter decomposition in Canada forest. *Plant and Soil* 339: 163–175.
- Narkiewicz C., 1999. On Trzcińskie Mokradła Peatland in Jełoniogórska Basin. *Przyroda Sudetów Zachodnich* 2: 3–6 (in Polish).

- Naucke W., Heathwaite L., Egglesmann R., Schuch M., 1993. Mire chemistry. [In:] Heathwaite L., Göttlich K. (Eds) Mires: process, exploitation and conservation. John Wiley & Sons., Chichester: 263–310.
- Okrusko H., 1993. Transformation of fen-peat soil under the impact of draining. *Zeszyty Problemowe Postępów Nauk Rolniczych* 406: 3–73 (in Polish).
- Piaścik H., Bieniek B., 1998. Changes in the properties of used agricultural peat soils of the Mazury Lake District expression of their degradation. *Zeszyty Problemowe Postępów Nauk Rolniczych* 460: 209–218 (in Polish).
- PN-85/G-02500:1985. Peat. Genetic division of the raw material. Polish Norm (in Polish).
- Schube T., 1903. Die Verbreitung der Gafabplahen in Schilesien. Breslau, preussischen und osterreichischen Anteils, Druck von R.. Nischkarsky: 1–361 (in German).
- Staffa M., 1998. Dictionary the tourist geography of the Sudeten. Jeleniogórska Basin. I-BIS Press: 4–518 (in Polish).
- Tobolski K., 2000. Guide for the determination of peat and lake sediments. PWN, Warszawa: 1–508 (in Polish).
- Tomaszewska K., 2000. Communities of selected sub-fossil peat bogs of the Jizera Mountains. *Opera Concorctica* 37: 390–395 (in Polish).
- Tomaszewska K., Malkiewicz M., Podlaska M., 2014. History of the development of a small bog within Uroczyska Wetlands Lower Silesian Forests. *Peckiana* 9: 83–92.
- Wang M., Moore T.R., Talbot J., Richard P.J.H., 2014. The cascade of C:N:P soil chemistry in an ombrotrophic peatlands: from plants to peat. *Environment Research Letters* 9: 1–7.
- website 1. (www.geoportal.gov.pl/web/quest/DOCHK). Główny Urząd Geodezji i Kartografii. 2016.
- Wojtuń B., Matuła J., Tomaszewska K., Żołnierz L., 2001. Peatlands protection in Jizerskie Mountains. *Opera Concorctica*, 37: 596–601 (in Polish).
- Woźniak M., 2007. Trzcińskie Wetlands. *Sudeten* 2: 32–33 (in Polish).
- Zimmerman E., Berg G., 1941. Erlaterungen zu Blatt Kaufung Geol. Karta Deutsch. Reiches 1:25 000. Preussichen Geologischen Landesanstalt, Berlin.

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Szata roślinna, właściwości i wiek gleb organicznych na powierzchniach po eksploatacji torfu Trzcińskich Mokradel (Sudety Zachodnie)

Streszczenie: Celem badań było ukazanie wpływu wydobycia torfu na tworzenie się i właściwości gleb organicznych oraz zbiorowisk roślinnych na powierzchniach po historycznej eksploatacji. Badania były prowadzone na kompleksie torfowisk Trzcińskie Mokradła (Sudety Zachodnie). Torfowiska Trzcińskie Mokradła powstały w Preboreale (10960–9330±50BP). Należą zatem do starszych w Sudetach. Analizowano 8 profili glebowych (42 próbki). Proces torfotwórczy jest tu ciągle aktywny w stopniu średnim i silnym (PtII-PtIII). Skład florystyczny dla badanych obiektów jest typowy dla torfowisk przejściowych. Występujące okresy suche i wilgotne były obserwowane w rozwoju gleb organicznych. Luki stratygraficzne w profilach torfowych obejmują tysiące lat i są najprawdopodobniej wywołane wydobyciem torfu w przeszłości.

Słowa kluczowe: torfowisko, gleby organiczne, roślinność bagienna, wiek gleb, działalność człowieka, Sudety