SUCCESSION OF PLANT COMMUNITIES IN PEAT EXTRACTION PITS BASED ON MACROFOSSILS AND CURRENT PLANT ANALYSIS

Joanna Sender[1]*, Danuta Urban[2], Monika Różańska-Boczula[3], Ewelina Tokarz[2]

[1] Department of Hydrobiology and Protection of Ecosystems, University of Life Sciences in Lublin, Dobrzańskiego 37, 20-262 Lublin, Poland

[2]Instytute of Soil Science and Environmental Engineering and Management, University of Life Sciences in Lublin, Leszczyńskiego 7, 20-069 Lublin, Poland

[3] Department of Applied Mathematics and Computer Science, University of Life Sciences in Lublin, 20-950 Lublin, Poland

Abstract

The small water bodies formed after peat excavation undergo spontaneous succession, and the hydrological factor plays a key role in this process. Plant organic matter deposited in the conditions of high wetness retains the structure of plant tissues; hence, it is possible to identify vegetation that forms subfossil communities and reconstruct the succession series by analysing macroscopic plant remains. The aim of the present study was to identify the sequence of the succession series in the post-excavation peat pits of the Łęczna-Włodawa Lakeland by analysis of plant macrofossils.Depending on trophy conditions and water layer thickness, various communities are responsible for initiation of the peat-forming process in the analysed objects of the Łęczna-Włodawa Lakeland. These include underwater Chara meadows (Ostrówek Podyski object), rush communities from the alliance Magnocaricion (Jelino and Krasne objects), and bryophyte communities forming a floating carpet over an open water surface (Podlaski object). The analysed post-excavation pits are currently undergoing a transitional phase of overgrowing. They have become refugia for many rare and protected plant species, e.g. Rhynchospora alba, Scheuchzeria palustris, or Menyanthes trifoliata.

Keywords: *peat extraction pits, Łęczna-Włodawa Plain, peatland's vegetation, Ellenberg index*

1. INTRODUCTION

Peatlands are the most widespread of all wetland types in the world, representing 50 to 70% of global wetlands. They cover over four million km^2 (3%) of the land and freshwater surface of the planet. Peatlands are one of the most important elements of the structure of the natural environment. On the one hand, they play a role in shaping the landscape and, on the other hand, they take part in the water cycle. They are reservoirs of water and regulate the outflow of water in terms of its volume and distribution. These areas also affect the balance of chemical elements. This is especially true for carbon and nitrogen, but also for calcium, magnesium and phosphorus (Whiting and Chanton 2016, Yu 2012). In these ecosystems are found one third of the world's soil carbon and 10% of global freshwater resources (Joosten and Clarke 2002).

Since the second half of the 20th century, with the ever-increasing demand for energy, land acquisition for agriculture and forestry at the expense of degrading these multi-services ecosystems, there has also been a growing public awareness of conservation actions (Convention on Wetlands 1971, Convention on Biological Diversity 1992, United Nations Framework Convention on Climate Change 1992). Peat bogs are among the priority habitats of conservation interest to the European Union.

In Poland peatlands cover approximately 4% of the country area. They are unevenly distributed in the country; a majority of peatbogs are located in the northern part and along the belt of great glacial valleys. The number of peatlands is estimated at ca. 52 thousand (Ilnicki, 2002) with, as estimated by Borowiec (1990), approximately 2 thousand located in the Lublin region, of which approximately 500 sites showed signs of exploitation. These data are incomplete, since objects with a surface area lower than 1 ha have not been included in the estimation. There are hardly any peatlands in the western part of the Lublin region, while the greatest density is observed in the Łęczna-Włodawa Lake District of Western Polesie. Between the second half of the 19th century and the 60s of the 20th century, hand-peat excavation (mainly for heating purposes) dominated in the Lublin region and resulted in emergence of numerous peat pits and construction of access roads and causeways crossing the peat pits. As indicated by many authors, peat pits and their immediate environment are characterised by great diversity of plant communities as well as the presence of rare and legally protected species (Ilnicki 1996, Iwaniuk 1999, Mosek and Miazga 1999, Podbielkowski 1960, Trąba et al. 2004, Urban et al. 2007, Ożgo et al. 2009).

All types of post-excavation peat pits undergo a renaturalization process. Many depleted peatlands have undergone spontaneous re-naturalization (Jasnowska and Markowski 1995, Sugier 2014, Urban 2007a, b). Natural and slow succession of peat pits occurs in a few stages, hence the following phases have been distinguished: initial (aquatic communities from the classes *Lemnetea* and *Potametea*), transitional (communities from the classes *Phragmitetea* or *Scheuchzerio-Caricetea nigrae*), and final (*Betula pubescens* and *Salix cinerea* shrubs) (Podbielkowski 1960). Depending on their age, size, and depth, the peat pits exhibit different stages of ecological succession. Succession of peat pits does not always follow the aforementioned scheme.

The uniqueness of this type of ecosystems and relatively few studies gave rise to a study to determine the impact of anthropogenic transformation of peatlands on the direction of post-peatland vegetation succession in the Łęczna-Włodawa Plain. Do these ecosystems, subjected to anthropogenic transformation, undergo ecosystem restoration processes in the light of historical changes? The identification of the stages of vegetation development in the regenerating post-peat-bogs is crucial for any work aimed at the restoration of the bogs. The research included, on the one hand, an analysis of the subphyllous plant communities and, on the other, of the contemporary phytocoenoses found in these post-peat bogs. Habitat changes were also assessed on the basis of Ellenberg index numbers.

2. MATERIALS AND METHODS

2.1. Study area

The investigations were conducted in 2015 and 2017, during the vegetation season, in the peat extraction pits (5), located in 4 peatbogs: Krasne, Jelino, Ostrówek Podyski (I, II) and Podlaski. According to the physico-geographical division, the objects are located in the Łęczna-Włodawa Plain, which is a mesoregion of Western Polesie (Kondracki 2001).

All studied peatlands covered different form of protected areas. They are also varied in size (Tab. 1).

Table 1. Characteristic of studied objects

Peatland	geographical coordinates	surface (ha)	a.s.l. (m)	form of protection
Krasne	N 51º24’34,0” E 22º57’28,9”	3,5	166	Łęczna-Włodawa Lake District, Łęczna Lakeland Landscape Park, Parczew Forestry Division
Ostrówek Podyski I, II	N 51º21’13,7” E 23º09’01,4”.	44,0	172-173	Łęczna-Włodawa Lake District, Natura 2000 area “Jeziora Uściwierskie”.
Jelino	N 51º25’08,8,7” E 23º01’50,7”	8,9	168	Łęczna-Włodawa Lake District, Natura 2000 region
Podlaski	N 51º26’05,7” E 23º28’20,9”.	1,3	168	Łęczna-Włodawa Lake District, Sobibór Forestry Division, within the Poleski Protected Landscape Area

2.2. Methods

2.2.1. Field investigation

The research was carried out in 2012-2014. Detailed lithological reconnaissance of the sediments of each investigated peatland was based on a grid of geological drilling, along orthogonally oriented transects (N-S; W-E) at 50 m intervals. For further studies, 3, representative for each site, were selected, where in 3 seasons of the year (spring, summer, autumn) boreholes to the mineral bottom were made with INSTORF type probe. Complete cores, with intact structure, were taken for laboratory analyses. This material was also used for macroscopic description of the sediments. Sediment classification was adopted according to Tobolsky (2000). In addition, the water table level was also measured in permanently installed piezometers.

Mapping of the vegetation communities present was carried out at each study site. The method used was to delineate the extent of plant patches (Faliński 1990) using a GPS location system. In the delineated homogeneous patches, phytosociological photographs were taken according to the commonly used Braun-Blanquet method (1964). The area of each phytosociological photo was 25 m2. The phytosociological classification and nomenclature of plant communities was based on the work of Matuszkiewicz (2012). The nomenclature of vascular plants was adopted after Mirek et al. (2002), and of bryophytes after Ochyra et al. (2003).

2.2.2. Macro-cuttings study

The material taken from the drilling ('cores') was used for the macroscopic description of the sediments. Sediment classification was adopted according to Tobolsky (2000). Material for the determination of plant macrofossils (50 cm3 samples) was taken: from peats every 10 cm, from gyttja every 50 cm. A sample of known volume was washed through a sieve with a mesh diameter of 125μm, then soaked with water and 10% KOH for a few minutes to dissolve humic acids and washed successively on the same sieve. Separation of plant debris was carried out according to the methodology developed by Tobolski (2000). For the determination of quantitative ratios, four microscopic preparations were made for each sample, using a stereoscopic microscope and 10x magnification. The results of the determinations were given as percentages. For the determination of plant remains, available keys and atlases were used (Dombrowska et al. 1969;. Grosse-Brauckmann 1972, 1974, Görres, Bludau 1992, Grosse-Brauckmann, Streitz 1992; Tobolski, 2000) and comparative preparations made from modern vegetation.

Additionally, the samples collected at the 10-cm intervals were assayed for pH in H_2O and KCl in 1M KCl – electrometrically with the use of an Elmetron meter and a combination silver chloride electrode. To determine the ash content, the samples were dried at 105ºC until constant weight and next burnt at a temperature of 550ºC. After cooling, the samples were weighed; the results are presented as a percentage of dry mass.

2.2.3. Data analysis

The Shannon-Wiener biodiversity index (H^') was calculated (for historical and current data) according to::

$$H' = -\sum_{i=1}^{S} p_i \cdot \log_2 p_i \quad (1)$$

where S - number of species (species richness)

n_i – number of individuals of i-th species

N – number of all individuals from all species.

The mean value of Ellenberg indices (E̅) (Ellenberg et al. 1992) was calculated (for historical and current data) according to:

$$\bar{E} = \frac{\sum_{i=1}^{S} n_i \cdot Ell}{a} \quad (1)$$

Ell – Ellberg number (T, F, N) determined for a given species

a - $\sum_{i=1}^{S} n_i$ when the Ellenberg number (T, F, N) determined for the species is different from 0.

The ranges of moisture conditions were assessed on the basis of studies by Kloss (2004, 2007), and the division of trophic habitats according to Roo-Zielińska (2014),(after Lindacher 1995) (Table 2).

Table 2. Types of wetland habitats (after Kloss, 2004 and Roo-Zielińska 2014)

Degrees and variations of habitat moisture		Phytocoenotic Wetness Indices (F)	Phytocoenotic Trophy Indices (N)	Degrees and variations of habitat trophy
Moist	temperate moist	6.0-6.4	extremely poor	1
	strongly moist	6.5-6.9	poor	2-3
Wet	temperate wet	7.0-7.4	moderately rich	4-5
	strongly wet	7.5-7.9	rich	6-7
Marshy	flooded	8.0-8.4	very rich	8-9
	strongly Flooded	8.5-8.9		
	swampy	>9.0		

To determine whether there were significant changes over time a Student's t-test was performed for the dependent data. Normality and homogeneity of variance were verified by the Shapiro-Wilk and Levene's test, respectively.

Pearson's correlation coefficient was used to determine the linear relationship between depth, ash content, pH in H_2O and pH in KCl for the peat profiles. The analysis of the study results was performed using STATISTICA 13.3 and Excel, assuming a significance level of $\alpha = 0.05$.

3. RESULTS

The analysis of the ash content showed that the roof of the objects was formed of non-silted peats. With depth, an increase in the proportion of the mineral content was observed. The tendency persisted in the lower part of the core, and the increase in the mineral content on the bottom and the presence of clayey gyttja were accompanied by an increase in the ash content even up to 90%. The reaction of the analysed formations was in the acidic ranges, not exceeding the value of pH=6 in any of the objects. In layers where sphagnum peat accumulated, the pH values were the lowest (Tab. 3).

Table 3. Selected chemical properties of sediments deposited and values of particular phytotenotic indexes in the analysed post-excavation peat pits

Deposit	Depth (cm)	Ash content %	pH in H2O	pH in KCl	Phytocoenotic Wetness Indices **(F)**	Phytocoenotic Trophy Indices (N)	Phytocoenotic	subfossil communities
Ostrówek Podyski I								
Cotton grass-Sphagnum peat	0-30	5.36	5.01	3.51	7.89 / strongly wet	1.10/ extremely poor	4.47	*Eriophoro-Sphagnetum recurvi*
low sedge and reed peat	30-100	5.90	4.37	3.16	8.69 / strongly flooded	4.22/ moderately rich	5.67	*Phragmitetea*
Water with gyttja	100-130	-	-	-	-	-	-	
low sedge peat	130-180	26.56	4.75	3.82	8.61 / strongly flooded	3.91/poor	5.65	*Magnocaricion*
Loamy gyttja	180-200	89.60	5.80	4.49	-	-	-	
Ostrówek Podyski II								
Cotton grass-Sphagnum peat	0-50	5.1	4.99	3.37	8.37/ flooded	1.34/extremely poor	5.93	*Scheuchzerio-Caricetea nigrae*
detritus gyttja	50-170	14.34	4.63	3.60	-	-	-	
low moss peat	170-190	14.75	4.9	3.93	8.91/ strongly flooded	1.43/ extremely poor	4.82	*Ass Bryales*
low sedge peat	190-200	66.8	5.6	4.39	8.33/ flooded	3.64/ moderately rich	5.73	*Magnocaricion*
Podlaski								
Cotton grass-Sphagnum peat	0-100	4.21	4.349	3.34	8.43 / strongly flooded	1.49/ extremely poor	5.89	*Scheuchzerio-Caricetea nigrae*
Water with gyttja	100-130	6.03	4.61	3.78	-	-	-	
low moss peat	130-170	7.55	4.66	3.75	8.80 / strongly flooded	1.49/ extremely poor	4.64	*Ass. Drepanocladus*
Loamy gyttja	170-230	92.0	4.30	3.48	-	-	-	
Krasne								
Cotton grass-Sphagnum peat	0-50	6.44	4.18	3.10	8.28 / flooded	1.35/ extremely poor	5.93	*Scheuchzerio-Caricetea nigrae*
water	50-100	-	-	-	-	-	-	
low sedge peat	100-135	10.00	5.09	3.81	8.66 / strongly flooded	3.84/ moderately rich	5.67	*Magnocaricion*
Loamy gyttja	135-150	90.70	5.25	4.20	-	-	-	
Jelino								
Cotton grass-Sphagnum peat	0-100	5.06	4.70	3.53	8.36 / flooded	1.54/ extremely poor	5.90	*Scheuchzerio-Caricetea nigrae*
Water with gyttja	100-200	-	-	-	-	-	-	
Detritus gyttja	200-225	33.8	4.40	3.69	-	-	-	
low sedge peat	225-250	39.0	4.30	4.12	8.65 / strongly flooded	3.79/ moderately rich	5.61	*Magnocaricion*
Loamy gyttja	250-260	91.9	4.29	4.10	-	-	-	

The analysis of the phytocoenotic wetness indices (F) indicates that water relations (strongly flooded and waterlogged environment) suitable for the development of peat-forming communities, i.e. rushes as well as transitional and raised-bog communities, were promptly established in the analysed post-excavation pits. In the peat pits analysed, biogenic sediments such as gyttja lie directly on peat layers that remained after the extraction process. This relationship is confirmed by the values of the phytocenotic indicator N (Tab. 3). In Krasne, Jelino, and Ostrówek Podyski, this 25-50 cm-thick layer of fen sedge peat is formed by representatives of the class *Phragmitetea*, e.g. *Carex sp., Carex rostrata, Phragmites australis*, and *Equisetum fluviatile.* The species composition in the bottom layer suggests that the peat-forming process was initiated by the strong moistening of the bottom. The species occurring in this layer exhibit high tolerance to pH (from 3,53 to 5,25 in the analysed objects) and suggest a mesotrophic habitat. In the Ostrówek Podyski I peatbog, *Characeae* oospores were found, which indicated functioning of the water reservoir. Concurrently, this layer demonstrated development of *Schoenoplectus lacustris* rushes, and the spread of diverse nympheid communities, including those with *Nymphaea alba*, suggests progressive shallowing of the reservoir. Vascular plants were accompanied by inconsiderable numbers of mosses. Only in the Podlaski peatbog, the 40-cm thick layer of fen moss peat formed primarily by *Drepanocladus fluitans, Bryales*, as well as *Carex sp.* and *Menyathes trifoliata* is deposited on clayey gyttja in the bottom layer. In all objects, there is a water layer (from 30 to 100 cm deep) with organic gyttja over the peat layer. Detritus gyttja underlies the water layer in the Jelino peat pits. Above this layer, up to the roof, there is transitional sphagnum-sedge peat with a thickness between 50 cm in Krasne peatbog and 100 cm in Podlaski and Jelino. As the thickness of the deposited peat increased, the hydrological conditions stabilised, which resulted in retreat of aquatic and rush species. The conditions were characteristic for transitional mires with *Sphagnum cuspidatum, Sphagnum sp., Oxycoccus palustris, Eriophorum angustifolium, Carex rostrata,* and *Carex sp.* dominating in the post-excavation peat pits. Additionally, in the Jelino peatbog, dominance of *Calla palustris* and *Menyanthes trifoliata* was noted at a depth of 80-90 cm, which indicated variable water levels ranging between highly wet and swampy. In Ostrówek Podyski I, 70-cm thick fen sedge-rush peat was formed over the water table comprising *Carex sp., Phragmites australis,* and *Sphagnum sp.* Simultaneously, the presence of *Pinus sylvestris* and *Betula sp.* wood suggests occurrence of single specimens of these species in the analysed post-excavation peat pit; in turn, the 30-cm thick roof layer is formed by raised-bog sphagnum-cotton grass peat comprising *Eriophorum vaginatum, Sphagnum fallax, Oxycoccus palustris, Eriophorum angustifolium*, and substantial amounts of *Pinus sylvestris* bark (up to 20%).

The current vegetation cover in the analysed post-excavation peat pits is characterised by high diversity of plant communities. Plant associations and communities from classes *Potametea*, *Utricularietea intermedio-minoris*, *Phragmitetea*, *Scheuchzerio-Caricetea fuscae*, *Oxycocco-Sphagnetea*, *Alnetea glutinosae*, and *Vaccinio-Piceetea* were found (Tab. 4)

Table 4. Associations and communities inhabiting the analysed peatbogs: + - very rare, frequency: 1 – rare, 2 – frequent, 3 – very frequent OP – Ostrówek Podyski, K- Krasne, Po – Podlaski, J- Jelino

Indentified phytosociological syntaxa	Objects				
	OP I	K	Poi	J	OP II
Potametea R.Tx. et Prsg, *Potametalia* Koch 1962, *Nymphaeion* Oberd. 1953					
com. *Utricularia vulgaris*	.	+	.	.	.
Nupharo-Nymphaeetum albae Tomasz. 1977	1	.	.	1	.
Utricularietea intermedio-minoris Den Hartog et Segal 1964 em. Pietrch 1965,					
Utricularietalia intermedio minoris Pietsch 1965, *Sphagno-Utricularion* Müll. et Görs 1960					
Sphagno cuspidato-obesi R.Tx. et Hüb.1958	2	.	.	3	3
Warnstorfietum exannulatae Szańkowski 1988 n.n.	.	.	.	1	.
Sphagno-Utricularietum ochroleucae (Schum. 1937) Oberd. 1957	.	.	.	2	.
Scheuchzerio-Caricetea nigrae (Nordh. 1937) R.Tx. 1937, *Scheuchzerietalia palustris* Nordh. 1937					
Rhynchosporion albae Koch 1926					
Caricetum limosae Br.-Bl. 1921	1	.	.	.	.
Caricion lasiocarpae Vanden Bergh. ap. Lebrunt et all. 1949					
Sphagno-Caricetum rostratae Rübel 1912	3	3	.	3	3
Caricetum lasiocarpae Koch 1926	2	2	3	1	.
Caricetum diandrae Jon. 1932 em. Oberd. 1157	1	.	.	1	.
com. *Comarum palustre*	2	2	1	1	.
com. *Menyanthes trifoliata*	2	1	.	2	.
com. *Calla palustris*	3	2	2	3	.

com. *Eriophorum angustifolium*	1	2	2	.	3
Oxycocco-Sphagnetea Br.-Bl. et R.Tx. 1943, *Sphagnetalia magellanici* (Pawł. 1928) Moore (1964),					
Sphagnion magellanici Kastner et Flossner 1933 em. Dierss. 1975					
com. *Eriophorum vaginatum-Sphagnum fallax* Hueck 1928 (*Eriophoro vaginati-Sphagnetum recurvi*)	3	3	2	.	.
Ledo-Sphagnetum magellanici Sukopp 1959 em. Neuhausl. 1969	1	1	.	.	.
Alnetea glutinosae Br.-Bl. et. R.Tx. 1943, *Alnetalia glutinosae* R.Tx. 1937					
Alnion glutinosae (Malc. 1929) Meijer Dress 1936					
Salicetum pentandro-cinereae (Almq. 1929) Pass. 1961	1	2	1	.	.
Ribeso nigri-Alnetum Sol.-Górn. (1975) 1987	1	1	1	.	.
Sphagno squarrosi-Alnetum Sol.-Górn. (1975) 1987	.	.	.	1	.
Vaccino-Piceetea Br.-Bl. 1939, Cladonio –Vaccinietalia Kiell.-Lund 1967, Dicrano-Pinion Libb. 1933					
Vaccinio uliginosi-Pinetum Libbert 1933	.	.	1	1	.

The analysis of the current vegetation cover showed that the post-excavation peat pits were dominated by raised-bog communities from the class *Oxycocco-Sphagnetea.* The group of non-forest raised-bog vegetation was represented by two associations, i.e. *Eriophoro-Sphagnetum* and *Sphagnetum magellanici.* The association *Eriophoro-Sphagnetum* dominated by *Eriophorum vaginatum* and *Sphagnum fallax* occurred as small size patches in terrestrialised post-excavation pits. Small patches of raised-bog moss *Sphagnetum magellanici* have developed on the shores of some of the peat pits. Elevated areas (along the causeways) were colonised by communities representing forest raised-bog phytocoenoses, e.g. *Ledo-Sphagnetum magellanici*. Some patches of this phytocoenosis were strongly related to bog forests *Vaccinio uliginosi-Pinetum* from the class *Vaccinio-Piceetea.*

The Shannon Wiener index of floristic diversity for individual peatlands reached high values and ranged from 1.82 Podlaski through 2.23 Jelino, 2.44 Ostrówek Podyski I to 2.50 and 2.57 in Ostrówek Podyski II and Krasne respectively.

Our research allowed us to establish the course of plant succession, which followed different directions in the investigated peat pits. Immediately after peat exploitation ended, the peat pits filled with water. The course of succession of the plant communities in these peat bogs is shown in Fig. 1 (the last stage is the contemporary community).

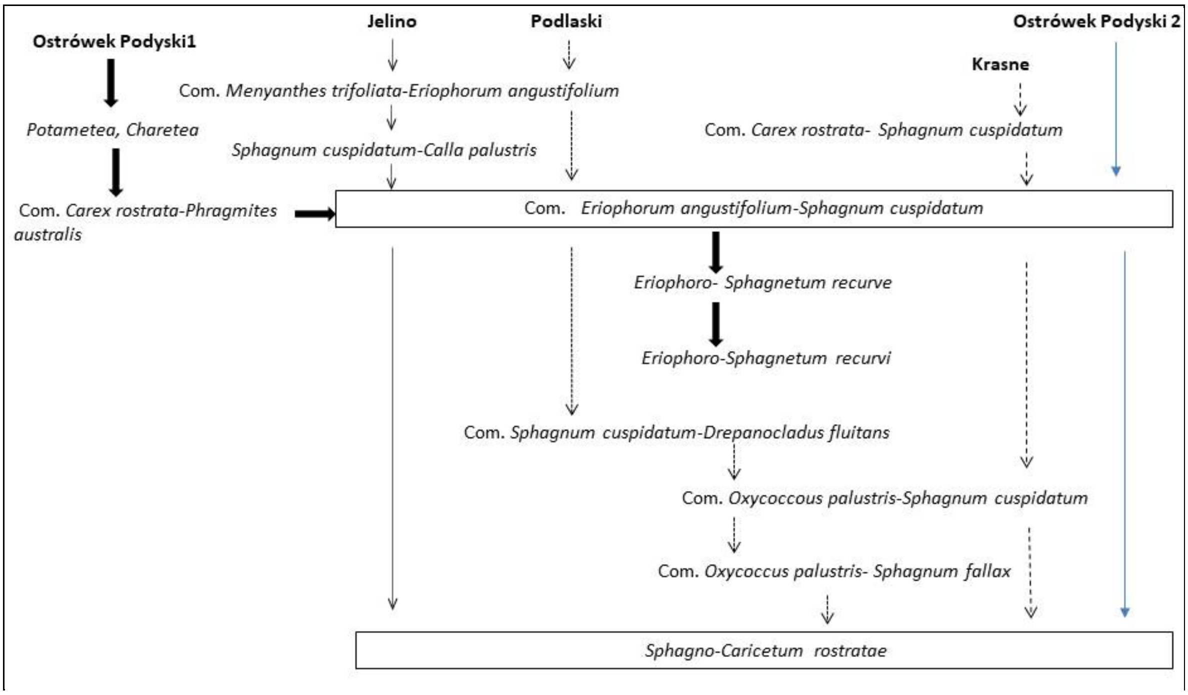

Fig. 1. Vegetation succession of the studied post-peat pits

Based on analyses of habitat indices (moisture, trophy and thermal), it can be concluded that habitat fertility (N) increased in all post-morph pits, and in the case of Krasne, Ostrówek Podyski II and Podlaski, from extremely poor to moderately rich habitats. There is also a clear increase in the thermal index (T), which confirms global climate change. These indices showed statistically significant differences (Table 6). The moisture index (F) values also showed a decreasing trend from swampy to floody.

Table 5. Mean values of habitat indicators (moisture F, trophic N and thermal T) in historical and contemporary data

average value of the index	Jelino		Krasne		Ostrówek Podyski I		Ostrówek Podyski II		Podlaski	
	Present	Past	Present	Past	Present	Past	Present	Past	Present	Past
T	4.4	5.88	4.58	5.89	4.86	5.34	4.37	5.58	3.44	5.53
F	8.19	9.07	9.3	9.12	9.1	9.25	8.72	9.05	8.37	9.01
N	2.17	1.74	4.48	1.76	3.36	3.23	3.36	1.7	2.97	1.49

Table 6. Student's t-test for dependent samples for individual indicators in historical and contemporary data

Index	t Stat	p-value
T	-5.04	0.0073*
F	-1.97	0.1199
N	2.92	0.0431*

*p-value < 0.05

4. DISCUSSION

Researchers distinguish three methods for effective renaturalisation of post-excavation peat pits: (1) reintroduction of peatbog vegetation, (2) application of mulch as a protective cover, (3) raising the water level by blocking drainage channels (Rochefort et al. 2003, Rochefort and Lode 2006). Yet, there is another way of renaturalisation of post-excavation peat pits, i.e. spontaneous vegetation succession, which requires specific conditions. These include the mode of peat extraction (industrial, small-scale); a relatively small size of the excavated site, otherwise the spontaneous renaturalisation process will proceed too slowly; and presence of natural vegetation serving a function of a seed bank in the surroundings of post-excavation peat pits. Additionally, the hydrological conditions should not be altered drastically and, most importantly, the process requires a long time. Therefore, spontaneous renaturalisation of post-excavation peat pits occurs relatively rarely, e.g. only 4% of Canadian post-excavation peat pits undergo spontaneous natural succession (Quinty and Rochefort 2003). Large post-excavation peat pits may be devoid of the vegetation cover for up to 20-30 years, although the remnants of extracted peat contain sporomorphs and plant seeds, since initiation of natural renaturalisation and development of plants, including the peat-forming *Sphagnum* species, requires specific and stable conditions (water availability, substrate temperature, pH) (Clymo and Duckett 1986, Campbel et al. 2003).

As presented by Podbielkowski (1960, 1968), water is one of the key factors determining the type of the vegetation in post-excavation peat pits. In the analysed localities (with acidic pH waters), species from the class *Phragmitetea* e.g. *Phragmites australis, Carex rostrate*, or *Equisetum fluviatile* and from the classes *Potametea* and *Charetea* appear in the initial phase. According to Mosek and Miazga (1999), aquatic communities from the classes *Lemnetea* and *Potametea* are predominant in the initial phase. All the analysed post-excavation peat pits represented a transitional phase dominated by phytocoenoses from the classes *Scheuchzerio-Caricetea nigrae* and *Oxycocco-Sphagnetea.* Investigations conducted by Mosek and Miazga (1999) indicate that the initial phases are dominated by phytocoenoses from the classes *Phragmitetea* or *Scheuchzerio-Caricetea nigrae*, whereas dominance of *Salix cinerea* and *Betula pubescens* shrubs is characteristic of the final phase.

In a majority of the analysed object, progressive regeneration of peat-forming communities was noted, beginning on the peripheries of the post-excavation peat pits but rarely involving their entire surface at the same time. The succession process was mainly initiated by rush communities from the class *Phragmitetea* in the Krasne and Jelino post-excavation peat pits, and by moss communities in the Podlaski peatbog, where the substantial share of *Menyanthes trifoliata* suggests that the peatbog may have been formed by floating carpets colonising the water table. The appearance and development of sphagnum species implies poor trophic conditions, which are suitable for the development of a floating *Sphagnum*-lawn preventing the flow of ground waters rich in dissolved nutrients (Ingram 1992). Beside sphagnum species, this layer was inhabited by sedges (*Carex rostrata, C. lasiocarpa*), which evidenced the presence of a water layer on the surface (Magyari et al. 2001). Similar cases of regeneration of the peatbogs in the Łęczna-Włodawa Lakeland were reported by Iwaniuk (1999), Mosek and Miazga (1999), Sugier (2014), and Urban co-authors (2007). In turn, a novel element in Ostrówek Podyski was the presence of *Chara* meadows evidenced by the occurrence of *Chara* oospores, which tolerate a wide pH range (from 5,8 to 8,3) (Haas 1994). Their occurrence is limited by high concentrations of phosphorus; therefore, the presence of *Chara* oospores reflects a low concentration of the element and indicates poor trophic condition of waters retained in post-excavation peat pits (Langangen 1974). Therefore, it can be assumed that the *Phragmites australis* and *Carex sp.* remains present in this layer do not originate from a phosphorus-poor substrate, as higher plants exhibit a considerably greater demand for this biogen. Sedges and rushes entered this layer via penetration with their 40 cm-1.8 m long root-rhizome systems (Ravit et. 2003). Based on the analysis of the plant remains, an approximately 80-cm penetration zone can be suggested. The roof of all the analysed post-excavation peat pits is formed by transitional and raised-bog communities, indicating a transitional phase of succession in the post-excavation peat pits. The phytocoenotic wetness indices imply prevalence of a high degree of wetness in the past, which is reflected in the species composition in this layer. The decrease in the wetness degree led to mineralization of nitrogen and a decline in the pH value (e.g. in Ostrówek Podyski, the average pH of the entire layer is 3.04); additionally, phosphorus becomes more soluble in the acidic environment (Hughes 2000).

A higher concentration of biogens and reduced wetness promotes development of *Eriophorum vaginatum* and *Eriophorum angustifolium.* In the Podlaski, Krasne, and Jelino, transitional peatbog communities from the class *Scheuchzerio-Caricetea nigrae* developed above the gyttja-containing water layer. However, in the bottom part of this layer (80-100 cm) in the Jelino peatbog, dominance of *Comarum palustre* has been reported, i.e. a species that does not tolerate of calcium carbonate and is characteristic for shores of acidic water reservoirs (Kłosowski and Kłosowski 2006). Peat extraction in the analysed objects did not inhibit peat-formation, which continues thanks to the presence of water, i.e. a factor that initiates the process.

5. CONCLUSIONS

Similar to other objects of this type, the analysed post-excavation peat pits are characterised by great phytocoenotic and floristic diversity (high values of S-W index), which is related to the age, depth, and size of these peat pits as well as the type of the peat deposit. Therefore, peat pits serve as refugia for many phytocoenoses, which retreat due to changes in the water-trophy conditions and are replaced by other communities.

The current course of succession promotes development of peat-forming plant communities. The peat extraction process has created suitable conditions for development of peat-forming communities from the classes *Scheuchzerio-Caricetea nigra* and *Oxycocco-Sphagnetea.*

Maintaining habitat conditions that are constant for peatlands will preserve the valuable qualities of wetland ecosystems and slow down succession processes that are accelerated as habitat fertility increases and wetness decreases.

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