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Chapter VIII

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Changes in habitat conditions and flora of the "Budwity" peat bog caused by water relation disorders and the possibilities of renaturation

INTRODUCTION

Peat bogs are one of the types of wetlands constituting geobiocenosis which is formed under conditions of strong hydration. In these areas, organic deposits are accumulated under anaerobic conditions on hydrophilic flora characterized by a vast contribution of species with a narrow ecological scope (DEMBEK et al. 2000, 2004). According to the taxonomy of Polish soils (1989), peat soils possess an organic layer volume above 30 cm and contain above 20% organic matter. The diverse content of the organic matter and soil formation processes in it influence the physical and chemical properties of hydrogenic soils. These, in turn, together with the habitat conditions determine the flora character of these ecosystems. A peat bog is a habitat with specific hydrophilic or secondary flora growing on it, which was located there after the peat bog drainage. Recently, a new term has been introduced, "*suo*" (from Finnish), which means peat bog or mineral soil areas where the peat formation flora is currently present.

One of peat bog classifications, which characterizes lowland, transition and raised peat bogs, takes into account the habitat trophy and existing water relations resulting from the relief. The peat bog flora is very diverse considering its tolerance for the habitat trophy, its humidity conditions as well as its reaction. The raised peat bogs fed with oligotrophic rain waters are strongly acid, poor in nutritious substances and therefore are floristically poor. The plant communities located there form a small group of specialized stenobionts where peat mosses are dominant. As a result of natural phytocoenosis succession they can be transformed into boggy forests. This process can be accelerated because of natural water condition disorders. The wetlands are endangered ecosystems. It is estimated that in the central and western part of the European continent above 80% (SMITS et al. 2001), and world-wide above 50% (KEDDY 2002) of these wetlands have been dried or transformed to such a degree that they have stopped performing their prime functions in the landscape as the home of specific plant species. The raised peat bogs are among the most endangered ecosystems in Europe. The location of these ecosystems in the Nature 2000 network as natural habitats "important for Europe" with priority significance (Council Directive 92/43 EEC, 1992) is an expression of the concern about their conservation. The majority of large raised peat bogs in Poland have been destroyed or are in a decession stage, and peat bog flora formation is being replaced by secondary communities. At present, the conservation of Polish raised peat bogs requires active protection and the reconstruction of water conditions should be the basic tool.

In the case of every object, the realization of practical actions should be preceded by an analysis of the existing state and processes in a given peat bog. However, there is a lack of complete data to estimate the transformation condition of these ecosystems. There is also a lack of data on the transformation degree of hydrogenic forest habitats, which, along with bush terrains, occupy about 15% of the general area of natural wetlands transformed in Poland (DEMBEK et al. 2004). The "Budwity" peatbog, which is located the "Zielony Mechacz" nature reserve, has been accepted by the European Commission as a special area of habitat protection (PLH 280010) within the Nature 2000 network. This terrain is relatively well studied considering both the state of habitat conditions (PAWLUCZUK, GOTKIEWICZ 2000) and flora (PISAREK, POLAKOWSKI 2001). However, there is no data in the scientific literature on the relationships between habitat conditions and dynamic vegetation changes in this object. Therefore, monitoring studies on the "Budwity" peat bog were undertaken in 2007.

THE STUDY AREA

The "Budwity" peat bog is located in the eastern part of the Iława Lake District (KONDRACKI 1998); in the zone of terminal moraines shaped during the Pomeranian phase of the Vistula glaciations. This peat bog belongs to Małdyty community situated within the province of Warmia and Mazury. Taking into account its geobotanic division, the terrain is located in the Iława district, the Pomeranian Lake district and the Baltic Sea watershed (SZAFER 1977). A part of the ombrophilous peatbog is occupied by the "Zielony Mechacz" nature reserve, which was established by the directive of the Minister of Forestry and the Timber Industry, no. 84 of 15 May 1962 (MP No. 51 of 1962, item 252), on the protection of a vanishing glacial relict population − *Rubus chamaemorus.* The south part of the peat bog (about 94.3 ha) is located within the boundaries of the reserve. The northern part of the "Budwity" peat bog, bordering directly with the reserve and covering 271.7 ha, was drained in order to exploit the peat (Fig. 1). For more than 50 years, both the peat bed and the overgrowing flora on the area have been subject to the pressure of a mine. A factor which particularly unfavourably influences the flora on the protected area is the lowering of the underground water level, especially near the boundary of the reserve as a result of dehydration by a system of drainage ditches.

The "Budwity" peat bog was formed on the watershed of the Dzierzgoń and Drwęca rivers and the Elbląg canal system. Surrounded by a peat basin, there are impermeable layers of glacial clay with a thickness of up to about 20 m which separate organic deposits from covering about 35 m below the underground water.

Earlier in that site, a shallow without outflow lake was located (which, due to detritus gittia accumulation has become shallow and allowed the development of rush flora). As a result of lowmoor peat growth layer, the peat bog became independent from the underground water supply and began the ombrogenic stage of the peat bog development. The sequence of the peat in soil profile indicates that such genesis of the peat bog happened in the central part of the “Zielony Mechacz” reserve, as was also been confirmed by earlier studies (PAWLUCZUK, GOTKIEWICZ 2000). A description of this profile shows that a deep bed (13 m) of thick (4.5 m) raised Sphagnum peat makes up the top layer. Assuming the average accumulation speed of raised peat is 0.7 mm per year (ILNICKI 2002), the development of this raised peat bog began in the subboreal period. This was over 3000 years ago, and since that time there has been a permanent peat forming process. The ecosystem of the raised peatbog is characterized by poor, but specific flora, a glacial relict where the cloudberry *Rubus chamaemorus* is the most interesting species. As early as in the first half of the 20^{th} century, the peat bog possessed its natural character and typical flora for raised peatbog dominated in it (POLAKOWSKI 1960). This stable system started to change when a peat mine was opened (1962) and a system of drainage ditches was constructed (Fig.1). The following water and drainage devices have a direct and significant influence on the water relations of the reserve in the terrain of the mine:

- a drainage ditch dehydrating the south peat bed of the mine, running at a length of 600 m along the northern boundary of the reserve at a depth from 0.9 to 1.8 m;
- a network of drainage ditches dehydrating the northern part of the “Budwity” peatbog.

These approximately one meter deep ditches and are dug every 20 meters. The drainage ditches carry waters to the main ditch, 4-5 meters deep and it carries water to the Fiugajka watercourse. The Fiugajka watercourse, which according to official the Polish hydrographic division, is named Iławka, and is the main watercourse of this terrain. On the stretch running 60-150 m from the boundary of the reserve (near the “Zamczysko” forest administration centre), its depth is from 2.0 to 3.0 meters. Culverts and water gates have been built along the path of the flow in order to bank up surface water.

The “Zielony Mechacz” reserve does not possess its own, natural water network. The draining of water from the reserve is carried out only through the drainage ditch which borders on the reserve on its northern side. This drainage ditch is the main cause of hydrological conditions changes in the reserve terrain and these changes of habitat conditions in the “Zielony Mechacz” reserve began, in turn, the successive process of arboreal vegetation. At present only a small fragment (in the central part of the reserve) is covered by peat-forming plant communities. However, in the majority of the reserve area dominate non-peat forming forest populations. The most natural among them is a marsh pine forest (*Vaccinio uliginosi-Pinetum*), whose individual parts differ considerably. The most natural phytocoenosis of this plant association is present in the central part of the reserve, while the most strongly transformed phytocoenosis is on its edges. Generally, there is a concentric distribution in the reserve vegetation resulting from the drainage degree gradient of the water and the thickness of the peat bed (PISAREK, POLAKOWSKI 2001).

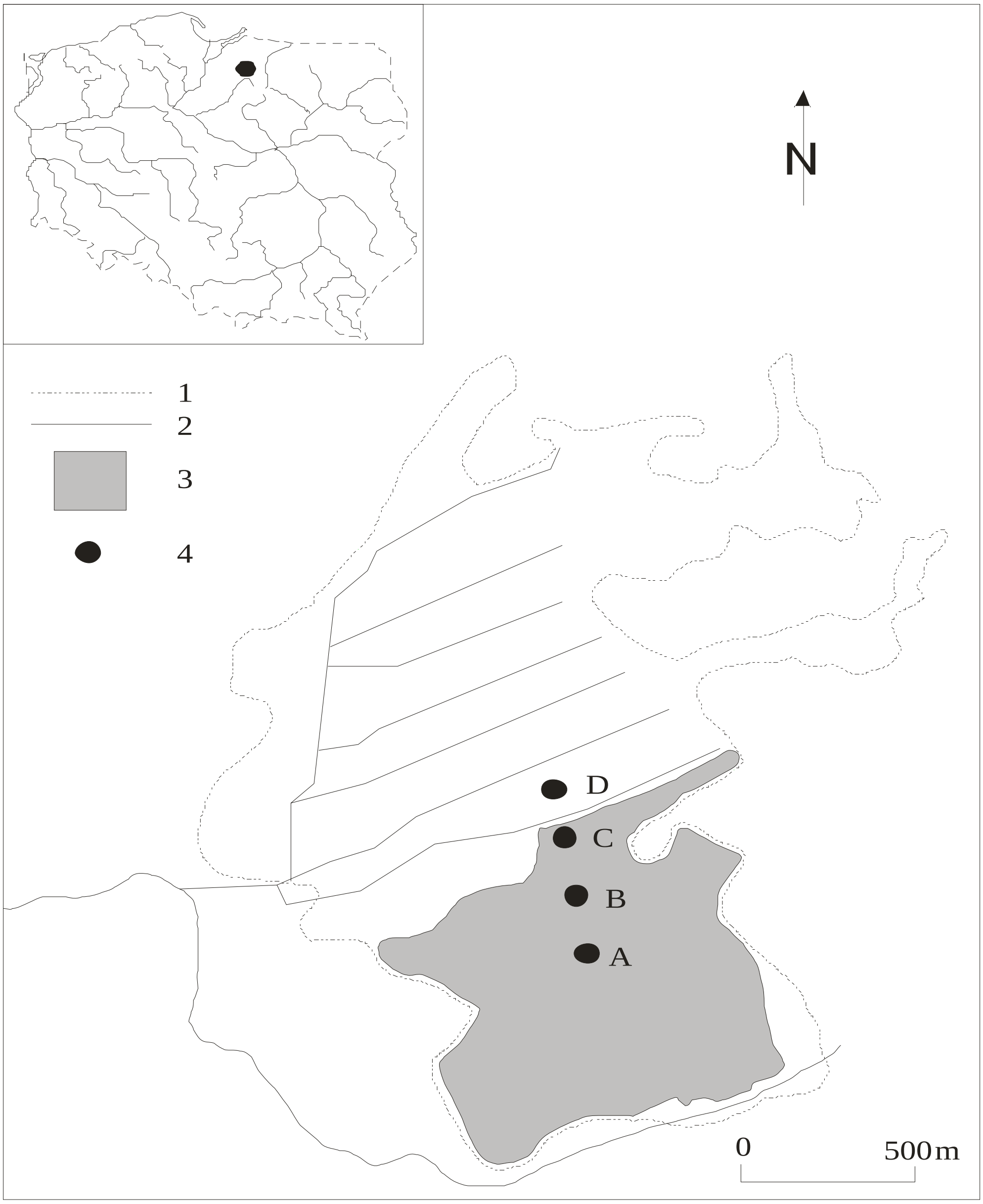

Fig. 1. Location of the study areas on "Budwity" peatland

1 – The boundary of "Budwity" bog, 2 – drainage ditches,
3 – The "Zielony Mechacz" reserve, 4 – study areas

Quantitative and qualitative changes in the reserve flora are also a consequence of habitat condition transformation. The relict moss – *Dicranum undulatum* has become extinct and the other two glacial relicts − *Sphagnum fuscum* and *Rubus chamaemorus* – have drastically reduced their own occurrence area (PISAREK, POLAKOWSKI 2001). However, a large group of non-peat-bog plants have appeared. Nevertheless, common species with a wide ecological scale of drier and more fertile habits are the majority. Four representative study areas (Fig. 1) in the peat bog terrain have been outlined. Three of them (A, B and C) were established within the boundaries of the reserve. They are arranged along the transect which divides the earlier-mentioned concentric arrangement of present flora, being the effect of water drainage from peat bog causing clear gradient of habitat conditions. Study Area A was situated in the central part of the reserve, where the influence of drainage ditches on the level of underground waters is the smallest. Area C is near the northern boundary of the reserve in direct proximity of peat mine and a deep ditch, which strongly dehydrates the peatbog in the reserve. Area B is situated between two previous areas where habitat conditions, particularly water ones, have an indirect character in the relation to the areas A and C. Moreover, one study has been outlined (area D) which possesses a different character. It is in the terrain of the peat mine, where the majority of the peat bed was exploited several years ago. Thanks to leaving a deeper layer of raised *Sphagnum* peat and a lowered area, the initiation process of secondary peat bog flora succession began in that place.

In 2008, samples of peat in each appointed study area were taken to analyse their physical and chemical properties. Moreover, during the growing season, levels of ground water were measured in installed piezometers. The samples of peat for physical property determinations were taken from layers: 5-10, 15-20, 25-30, 35-40, 55-60, 75-80 and 95-100 cm. However, for chemical property determinations, the samples were taken from layers: 5-10, 25-30 and 35-40 cm. The phytosociological relevé (Table 1) was taken in every study area in August 2008. The density of the arboreal vegetation, which defines light conditions dominating in a herbaceous zone, was calculated from the sum density of trees and bushes (a1, a2, and b). The physical and chemical properties of the samples of peat were determined in a laboratory as follows:

- ash − by combustion of soil samples at 550°C in the muffle furnace. The losses of mass during roasting were accepted for the content of organic matter (SAPEK A., SAPEK B. 1997);
- current moisture − was determined by drying after desiccation of soil samples in cylinders with a capacity of 100 cm^3, at a temperature of 105°C;
- volumetric mass density of dry soil (gc) – with 100 cm^3 capacity cylinders and by drying the samples at 105°C;
- specific mass density of organic soil formations (gw) − was calculated with the regression equation proposed by OKRUSZKO (1971);
- total porosity was calculated with the formula: fc = 1-(gc:gw)× 100 [% vol.];
- redox potential of the soils (Eh) and oxygen diffusion rate (ODR), was measured in field conditions, with an amperometer equipped with 10 platinum electrodes (MALICKI 1999);
- colour of soil – according to Munsell tables (OYAMA, TAKEHARA 1992), in the wet state and in the air dry state;
- pH value in H_2O and in 1 mol of KCl dm^{-3} – with a potentiometer;
- total nitrogen content – with Kjeldahl method;
- mineral nitrogen content ($N\text{-}NO_3$ and $N\text{-}NH_4$) in the soil after incubation at 28°C of soil samples with a preserved structure for 2 weeks. Methodology and border numbers were accepted according to GOTKIEWICZ (1973, 1974). The

samples were taken and determinations were carried out in summer and autumn in 4 replications in layers 5-10, 15-20 and 35-40 cm.

- organic carbon in soil was determined with the colorimetric method, using an oxidising mixture, 0.2 M solution of potassium dichromate in sulphuric acid and absorbance measurement with a spectrophotometer.

Table. 1

Vegetation of the study areas

	Study areas			
	A	B	C	D
1	2	3	4	5
Cover of higher trees (a1) [%]	0	40	40	0
Cover of lower trees (a2) [%]	40	10	0	0
Cover of shrubs (b) [%]	2	80	50	0
Cover of herbaceous plants (c) [%]	70	50	90	80
Cover of bryophytes (d) [%]	100	30	20	0
Number of species in the record	14	26	17	8
Sample area [m^2]	150	200	150	40
Ch. Oxyxocco-Sphagnetea				
Eriophorum vaginatum	3	·	·	1
Rubus chamaemorus	1	·	+	·
Sphagnum magellanicum	2	·	·	·
Oxycoccus palustris	1	·	·	·
Polytrichum strictum	+	·	·	·
Aulacomnium palustre	+	·	·	·
Andromeda polifolia	+	·	·	·
Ch. Scheuczerio-Carcecetea nigrae				
Eriophorum angustifolium	·	·	·	4
Carex canescens	·	·	·	+
Ch. Vaccinio-Piceetea				
Vaccinium myrtillus	1	3	4	·
Pleurozium schreberi	+	2	2	·
Betula pubescens a2	+	2	·	·
Betula pubescens b	.	3	3	·
Betula pubescens c	1	·	1	+
Pinus sylvestris a1	·	3	3	
Pinus sylvestris a2	3	·	·	·
Pinus sylvestris b	+	·	·	·
Pinus sylvestris c	+	·	·	+
Ledum palustre	2	·	1	·
Picea abies b	·	1	+	·
Picea abies c	·	1	+	·
Vaccinium vitis-idaea	·	.	2	·
Hylocomium splendens	·	1	·	·
Trientalis europaea	·	+		·

Table. 1 continued

1	2	3	4	5
Accompanying species				
Frangula alnus b	·	3	·	·
Frangula alnus c	+	1		+
Dicranum polysetum	·	+	2	·
Dicranum scoparium	·	1	+	
Orthodicranum flagellare	·	1	+	
Molinia caerulea	·	+	·	1
Calluna vulgaris	+	·	+	·
Sphagnum fallax	5	·	·	·
Sorbus aucuparia b	·	2	·	·
Sorbus aucuparia c	·	+	·	·
Lepidozia reptans	·	1	·	.
Brachythecium rutabulum	·	1	·	.
Sciuro-hypnum oedipodium	·	1	·	·
Millium effusum	·	+	·	·
Dryopteris carthusiana	·	+	·	·
Maianthemum bifolium	·	+	·	·
Oxalis acetosella	·	+	·	·
Plagiothecium curvifolium	·	+	·	·
Pohlia nutans	·	+	·	·
Polytrichastrum formosum	·	+	·	·
Rubus idaeus	·	+	·	·
Rubus pedemontanus	·	+	·	·
Tetraphis pellucida	·	1		·
Dicranodontium denudatum	·		+	·
Empetrum nigrum	·	·	+	·
Melampyrum pratense	·	·	+	·
Polytrichum juniperinum	·	·	+	·
Quercus robur c	·	·	+	·

In piezometers installed on study areas, the ground water level was measured. The nomenclature of vascular plants was accepted according to MIREK et al. (2002), and mosses for OCHYRA et al. (2003). Phytosociological nomenclature and affiliation of plant species to individual syntaxononomic units were based on MATUSZKIEWICZ'S elaboration (2001).

The "Budwity" peat bog characteristic

The deposit of raised peat throughout the "Budwity" peat bog does not show any larger differentiation. According to current systematics of Polish soils (1989) it is peat swamp soil of raised peat bog, strongly swampy, formed from raised *Sphagnum* peat, decomposed very faintly (H = 10%). The raised *Sphagnum* peat with light brown colour (colour of wet peat 10YR5/6, the colour of dry peat 10 YR5/8), with small contribution of sedges and reed remains at a depth of 450 cm and covers lowmoor sedge peat which is moderately decomposed (H = 40%), with black brown colour (colour of wet peat 10YR4/2, colour of dry peat 10YR4/3). At a depth below 550-700 cm, it covers very faintly decomposed (H = 10%) lowmoor sedge peat. At a depth below 700 cm until a depth of 1300 cm the detritus gyttia is present, with the colour of olive and semi-liquid gelatinous consistency. The maximum thickness of detritus gyttia layers reaches 6.6 metres, while the average thickness of the detritus gyttia layers is 1.5 – 2.0 metres, however, on the terrain of the reserve it is from 0.3 to 6.6 metres. The "Budwity" peat bog is exclusively fed with poor rain waters. Such habitat feeding water is an ombrogenic type of hydrological water feeding (OKRUSZKO 1988, 1992).

THE PHYSICAL AND CHEMICAL PROPERTIES OF PEAT

The physical properties of peat in layers to 100 cm on all four analysed study areas do not show any larger differentiation and are typical for raised peat (Table 2). Oligotrophic peat of the "Budwity" site are characterized by low ash content. In the 5-60 cm layers, the ash content differs in the range 3.2 – 6.7%, however, in layers below 60 cm, it does not exceed 2%. The low ash content in peat in the "Budwity" object is connected with the peat being very faintly decomposed (H = 10%) and located in a lake basin, where no watercourse flows into the lake basin, resulting in a lack of external mineral particles. The whole lake basin, which is felt up with peat, is surrounded by glacial till which covers 62.5% of the area. The volumetric mass density of studied raised peat is very low, because it does not exceed 0.105 g cm^{-3}, which shows the exceptionally low condensation of these organic soils. The specific mass density of the studied raised peat in ceiling layers was about 1.5 g cm^{-3}. The specific mass density in deeper layers of peat soils was slightly lower and in layers 75-100 cm it was about 1.48 g cm^{-3} (Table 2).

Table 2

Physical properties of the Budwity raised bog

Layer [cm]	Soil horizon	Ash content [%]	Bulk density [g cm^{-3}]	Specific density [g cm^{-3}]	Total porosity [% vol.]
5-10	Otwy*	4.2	0.081	1.508	94.8
15-20	Otwy	5.7	0.080	1.527	95.0
25-30	Otwy	6.7	0.105	1.538	93.1
35-40	Otwy	3.3	0.079	1.498	95.0
55-60	Otwy	3.2	0.079	1.497	94.8
75-80	Otwy	2.0	0.081	1.482	94.5
95-100	Otwy	1.5	0.079	1.478	94.6

*Otwy – raised peat bog

The total porosity of the studied peat was very high and in layers to 100 cm it averaged 94.5%, which was the highest value in the peat. Such large porosity shows the very large water capacity of the peat and the large possibilities of water accumulation. The levels of underground water in the terrain of the peatbog are shown in Table 3. The direct influence of the mine on the level of underground water was measured by a piezometer installed in peat located directly the boundary of the reserve (area C). In summer, the ground water level was at a depth of 110 cm, while in autumn the level of ground water rose to a depth of 81 cm. In Study Area A, furthest located from the boundary (with a mine), the level of ground water was high and during the summer was at a depth of 5 cm, and in autumn it was 2 cm. In a piezometer installed in Study Area B, the level of ground water was at a depth of 30 cm in summer, while in autumn it was at a depth of 20 cm. In a piezometer located in the studied area, in the terrain of the mine (area D), the ground water was at a depth of 15 cm in the summer, while in the autumn the level of underground water increased and was at a depth of 5 cm (Table 3).

Table 3

Average moisture and groundwater level of the raised bog

Parameter	Layer [cm]	Soil profiles							
		A		B		C		D	
		Summer	Autumn	Summer	Autumn	Summer	Autumn	Summer	Autumn
Soil moisture [% vol.]	5-10	94.76	94.10	68.15	83.30	63.20	68.50	89.80	87.20
	25-30	94.80	96.60	82.45	85.40	66.35	66.20	84.80	85.70
	35-40	94.90	96.30	80.90	87.10	71.80	77.65	80.25	86.50
Ground water level [cm]		5	2	30	20	110	81	15	5

Determinations of current moisture in layers up to 40 cm in the growing season show that in the “Budwity” peat bog, high moisture was maintained in Study Areas A and D. The moisture of peat in the top layers in Area A was in summer at 94.8% vol., and in autumn it was 94.1% vol. In deeper layers of peat in this area, the moisture increased and in summer it was 94.9% vol. and 96.3% vol. in autumn. In Study Area D in summer the moisture of the top layers was 89.8% vol., and in autumn it was 87.2% vol., and it slightly decreased in deeper layers. In Study Areas C and B, the top layers of peat were too dry. In Area C located in the proximity of the mine, the ceiling layers of peat had 63.2% vol moisture in summer, and in autumn it was 68.5% vol. In Study Area B, the low moisture of peat in layers 5-10 cm was only in the summer (68.1% vol.), while in autumn the moisture of these peat layers increased to 83.3% vol. The layers of peat at a depth of 35-40 cm, in Area B, had a 80.9% vol. moisture level in summer and 87.1% vol. in autumn (Table 3).

The chemical properties of peat soils of the “Budwity” site are given in Table 4. The reaction of a studied soil, according to the accepted criteria for organic soils (OKRUSZKO 1991), was very acid. In the top layers, the pH value of peat in 1 M KCl ranged from 2.96 (pH value of peat on the study area B), to 3.35 (pH value of peat on the study area D), while the pH value determined in H_2O was in the 3.45 – 3.76 range. In peat located at a depth of 25-40 cm, the pH value in 1M KCl was in the

2.87 – 3.37 range, while the pH value of peat determined in H_2O was in the 3.54 – 3.96 range.

The content of organic carbon in peat in the "Budwity" site in Study Areas A, B and D was in the 49.6 – 55.5% range of dry matter. In comparison with the carbon content in different kinds of peat, there is a low affluence of peat in that constituent. The low content of carbon in the samples of peat of the "Budwity" site, is connected with the occurrence of very faintly decomposed (H = 10%) *Sphagnum* peat in the top layers. The organic matter forming peat is subject to continuous changes which are conditioned, among others, by the occurring level of underground water and moisture. The low level of ground water in Study Area C (and the resulting dry top layers of peat) initiated the mineralisation process of organic matter. The carbon content in peat in these layers was very low and in top layers it was 31.72% (Table 4) as an effect of these processes. In layers 25-40 cm the content of organic carbon in peat of the area C was considerably higher and was on average 57.27%.

The total nitrogen content in peat in the studied areas of the "Budwity" site was slightly diverse and in layers to 40 cm it was in the 0.92 – 0.99% range. In comparison with the content of nitrogen in lowmoor peat, it can be considered as a low level, however, there is a high content of nitrogen in *Sphagnum* peat (LUCAS 1982). The most important coefficient of the nitrogen accessibility released in the mineralisation process of organic matter for plants is the relation C:N. In Study Areas A, B and D, the C:N ratio in layers of peat to 40 cm, is in the 53 to 58 range (Table 4). Such a wide C:N ratio shows that in these studied areas existing habitat conditions do not favour the mineralisation process of organic nitrogen compounds. The current study has shown that in Study Areas A, B and D, the content of mineral nitrogen in peat to 40 cm, in the growing season was in the 3.22 – 9.65 mg dm^{-3} range, which is very low. No larger content fluctuations of nitrogen in peat in these areas were found in summer or in autumn (Table 5).

In the mineralisation process of organic nitrogen compounds in the peat in Study Areas A, B and D, the $N\text{-}NH_4$ form dominated, whose content in the summer was in the 2.75 – 5.27 mg dm^{-3} range, and in autumn was 1.53 – 5.74 mg dm^{-3}. The $N\text{-}NO_3$ content in peat of Study Areas A, B and D throughout the growing season did not exceed 1.52 mg dm^{-3}, which is very low according to current norms. Most of the mineral nitrogen was released in the mineralisation process of organic nitrogen compounds located at the boundary of the reserve with the mine (area C). The high level of mineral nitrogen in the soil in area layers took place particularly in summer (35.93 mg dm^{-3}). In the mineralisation process of organic nitrogen compounds in Study Area C, the $N\text{-}NO_3$, form was predominant with content in peat in summer in the 29.06 – 34.63 mg dm^{-3} range, and in autumn in the 7.61 – 19.87 mg dm^{-3} range. According to current standards [GOTKIEWICZ J., GOTKIEWICZ M. 1991], the affluence of peat in this form of nitrogen was considerable in summer, and average in autumn. The $N\text{-}NH_4$ content in peat in that studied area was low and in summer was on average 1.08 mg dm^{-3}, and in autumn 0.88 of mg dm^{-3}. The calculated $N\text{-}NO_3$ to $N\text{-}NH_4$ ratio, which is the coefficient used to evaluate the mineralisation conditions of organic nitrogen compounds, indicates that good conditions for the nitrification process appeared only in Study Area C.

Table 4

Chemical properties of the soils studied

Parameter	Soil profiles			
	A	B	C	D
Layer 5-10 cm				
pH in H_2O	3.51	3.45	3.51	3.76
pH in KCl	3.11	2.96	3.01	3.35
N-total [%]	0.978	0.932	0.928	0.956
organic-C [%]	55.54	49.60	31.72	53.21
organic matter	95.75	85.51	54.69	91.73
C:N	56.79	53.22	34.18	55.66
Layer 25-30 cm				
pH in H_2O	3.74	3.64	3.54	3.96
pH in KCl	3.08	3.06	2.99	3.34
N- total [%]	0.988	0.987	0.954	0.933
organic-C [%]	54.83	53.11	53.61	53.45
organic matter	94.53	91.56	92.42	92.15
C:N	54.94	53.81	56.19	57.29
Layer 35-40 cm				
pH in H_2O	3.54	3.36	3.56	3.57
pH in KCl	3.24	2.87	3.02	3.37
N- total [%]	0.949	0.938	0.904	0.922
organic-C [%]	54.45	54.91	52.94	52.83
organic matter	93.87	94.66	91.27	91.08
C:N	57.38	58.54	58.56	57.30

The N-NO_3 -to- N-NH_4 ratio, in that area in summer was on average 29.9, and in autumn it was 18.2. In peat in Study Areas A, B and D in the mineralisation process of nitrogen compounds, the N-NO_3 -to- N-NH_4 ratio throughout the growing season was below average, which shows that in these areas the conditions were similar to natural wetland conditions, where the mineralisation process of organic nitrogen compounds proceeds with a low intensity.

Table 5

Mineral nitrogen content and the properties of the soils studied

Parameter	Soil profiles							
	A		B		C		D	
	Summer	Autumn	Summer	Autumn	Summer	Autumn	Summer	Autumn
Layer 5-10 cm								
$N\text{-}NO_3$ [$mg \cdot dm^{-3}$]	0.80	1.00	1.52	0.95	34.63	19.87	1.01	1.20
$N\text{-} NH_4$ [$mg\,dm^{-3}$]	3.59	2.49	8.13	4.14	1.30	1.41	5.27	5.74
N-mineral [$mg\,dm^{-3}$]	4.39	3.49	9.65	5.09	35.93	21.28	6.28	6.94
$N\text{-}NO_3$: $N\text{-}NH_4$	0.22	0.40	0.19	0.23	26.64	14.09	0.19	0.21
Eh [mV]	280	270	480	440	540	530	420	280
ODR [$\mu g\,m^{-2}\,s^{-1}$]	35.11	29.32	75.11	69.53	89.53	88.60	65.92	30.81
Layer 25-30 cm								
$N\text{-}NO_3$ [$mg\,dm^{-3}$]	0.90	0.76	1.18	1.45	31.65	17.89	1.12	0.44
$N\text{-} NH_4$ [$mg\,dm^{-3}$]	3.90	1.53	4.91	3.86	1.07	0.82	3.15	4.08
N-mineral [$mg\,dm^{-3}$]	4.80	2.29	6.09	5.31	32.72	18.71	4.27	4.52
$N\text{-}NO_3$: $N\text{-}NH_4$	0.23	0.50	0.24	0.38	29.58	21.82	0.36	0.11
Eh [mV]	260	230	360	240	520	510	290	240
ODR [$\mu g\,m^{-2}\,s^{-1}$]	24.06	23.49	38.37	37.86	88.53	84.18	45.92	28.60
Layer 35-40 cm								
$N\text{-}NO_3$ [$mg\,dm^{-3}$]	1.34	0.26	0.40	1.20	29.06	7.61	0.33	0.47
$N\text{-} NH_4$ [$mg\,dm^{-3}$]	2.75	2.55	6.06	3.47	0.87	0.41	2.89	4.06
N-mineral [$mg\,dm^{-3}$]	4.09	2.81	6.46	4.67	29.93	8.02	3.22	4.53
$N\text{-}NO_3$: $N\text{-}NH_4$	0.49	0.10	0.07	0.35	33.40	18.56	0.11	0.12
Eh [mV]	230	210	280	240	500	510	280	220
ODR [$\mu g\,m^{-2}\,s^{-1}$]	21.06	20.49	34.16	31.76	85.93	83.95	31.93	25.69

In order to characterise the oxidation-reduction conditions existing in peat on studied areas, the measurements of oxygen diffusion rate (ODR) and redox potential (Eh) were carried out. In Study Area C, the results of oxygen diffusion rate (in summer 85.93-89.53 µg m^{-2} s^{-1} and in autumn 83.95-88.60 µg m^{-2} s^{-1}) and the redox potential (in summer 500-540 mV and in autumn 510-530 mV) showed that the peat in this area was characterized by good oxygenation during the growing season. The concentration ratio of oxidized compounds to reduced ones had high values, determined through redox potential (Eh) (whose value of 300 mV is accepted as a boundary between "oxygenated" and "reduced" soil) [GLIŃSKI, STĘPNIEWSKI 1984, GLIŃSKI, STĘPNIEWSKA 1986] in peat of Study Area C. It shows the intensification of oxidation processes in the peat area, which are unfavourable for the protection of hydrogenic soil because irreversible changes in organic matter occur under such conditions.

In peat in Study Areas A, B and D, the aerial and aqueous ratios in the studied organic layers were differentiated during the growing season. In Study Area A, in studied layers had low ODR values (in summer 21.06-35.11 µ g m^{-2} s^{-1} and in autumn 20.49-29.32 µg m^{-2} s^{-1}) and Eh (in summer 230-280 mV and in autumn 210-270 mV), which indicates their permanent anoxia and the existence of reduced conditions in the growing season. Such redox properties of peat favour organic matter accumulation and the development of natural peat formation flora. The peat in Study Area B in the growing season in layers 25-40 cm was characterized by a low oxygen diffusion intensity with low redox potential (ODR). This shows their permanent anoxia and the existence of reduced conditions. The top layers of peat in this area were characterized, however, by good oxidation (ODR in summer was 75.11 µg m^{-2} s^{-1}, in autumn it was 69.53 µg m^{-2} s^{-1} and Eh in summer was 480 mV and in autumn it was 440 mV). In peat of Study Area D, in summer were similar redox conditions as in peat area B (Table 5). In autumn, in peat of area D, when water was at a depth of 5 cm, there was a limitation of oxygen diffusion (30.81-25.69 µg m^{-2} s^{-1}) and lowering of redox potential value (280-220 mV).

PLANT COVER

Although all four study areas were situated in the peat bog terrain, where there was peat of similar genesis, the real present–day vegetation represents a completely different character (Table 1). It is connected with the variation of habitat conditions which influenced the differentiation of the chemical properties of the peat. Peat forming vegetation was maintained only in Study Area A, where the influence of drainage ditches is the lowest. Phytocoenosis existing in that place can be classified as *Ledo-Sphagnetum* plant association. This plant association is distinguished by an abundant moss layer of *Sphagnum* species with medium density of herbaceous layer dominated by species from the *Oxycocco-Sphagnetea* class and low, sparse forest stand created by the *Pinus sylvestris* f. *turfosa*. The contribution of dwarf shrub is quite considerable here, but the layer of underbrush is insignificant.

The vegetation in area B creates a truncated forest community from the *Vaccinio-Piceetea* class, with the character of a strongly-modified boggy forest (*Vaccinio* *uliginosi-Pinetum*). The forest stand is made up of ordinary pine (*Pinus sylvestris*) and pubescent birch (*Betula pubescens*) while the strongly developed underbrush is comprised mainly of young trees of pubescent birch, common alder buckthorn (*Frangula alnus*) and rowan tree (*Sorbus aucuparia*) with an admixture of spruce (*Picea abies*). The coverage of the moss layer amounts to about 30% and there are no *Sphagnum* mosses in it. The stingy herbaceous layer mainly creates the bilberry (*Vaccinium myrtillus*). Vegetation in area C, both considering its physiognomy as well as its species composition, is similar to a continental fresh forest (*Peucedano-Pinetum*). However, it is also a strongly modified boggy forest (*Vaccinio uliginosi-Pinetum*) where there is a thick layer of peat deposit, the presence of a marsh tea (*Ledum palustre*) and cloudberry (*Rubus chamaemorus*).

In Study Area D, only pioneer herbaceous flora is a main component. The main component is narrow-leaved cotton-grass (*Eriophorum angustifolium*) – the characteristic species for the *Scheuchzerio-Caricetea nigrae* class.

DISCUSSION

The different character of flora in selected areas of discussed peat bog arises from the changes in its habitat conditions that began with the drainage of the terrain. The flora differentiation arises from the various degree of water drainage in individual areas, as is shown by the registered level and moisture in the top layers of peat (Table 3). In the terrain of the reserve (areas A, B and C), the level of ground water of the peatbog clearly drops from its central part in the direction the peat mine. That gradient correlates with the content of mineral nitrogen in layers to 40 cm as well as the existing redox conditions (Table 3).

Natural, peat forming flora was preserved only in the central part of the reserve where the water level lasts near the soil area for the whole year. Therefore, the existing reduced oxygen diffusion conditions dominated the reducing processes in conversions of organic matter. Even the slight lowering of underground water initiates mineralisation and humification processes (SZAJDAK 2002) that additionally create unfavourable habitat conditions for plant species in the raised peat bog.

Apart of suitable water conditions, the low content of mineral nitrogen in soil is an essential factor for the functioning of the raised peat bog ecosystem in soil. Its growth is "toxic" for peat mosses which play the role of "engineers" in that ecosystem. An increase in mineral nitrogen content is followed by the withdrawing of peat mosses and an increase in the share of herbaceous plants and young trees (WIEDERMANN 2008). It seems that an excessive concentration of mineral nitrogen in a raised peatbog leads to changes in flora and causes the degradation of the whole ecosystem. The results of these studies show that the optimal conditions to preserve raised bog plant species require maintenance of very low $N\text{-}NO_3$ and $N\text{-}NH_4$ content levels and stabilizing the ratio of these two forms of mineral nitrogen.

The studies in the growing season on the potential possibilities of mineral nitrogen release in a raised bog under different habitat conditions indicate that to maintain the peat forming properties of the ecosystem, the content of mineral nitrogen should not exceed about 5 mg dm^{-3} and to restrict oxygen diffusion. This can be seen by comparing area A, where covering peat mosses amounts to 100%, with area B, where there are no such mosses or plants typical for raised bog remaining (Table 3). As regards the crucial role of moisture and the mineral nitrogen concentration in the top layers of peat which cause changes in flora is also the fact that differences between the individual areas concerning the other physical and chemical parameters of peat are small.

Obviously, a very important factor which permits the development of *Sphagnum* mosses, as well as other raised peat bog plants, is also the low reaction and the accessibility of light (TOBOLSKI 2000; RYDIN, JEGLUM 2008). As long as the soil reaction (pH) in the top layers of peat was almost identical in analysed areas (Table 3), the degree of the peatbog surface shading through young trees was very diverse (Table 1). For some plants in the raised peat bog, the light factor seems to be the most important and, in certain ranges, can compensate for other, unfavourable, habitat factors. Among the plants in the peat bog, is a rare relict species – *Rubus chamaemorus*. In the "Zielony Mechacz" reserve, the best conditions for cloudberry development exist in its central, the most natural part, where it has the highest coverage and it blooms and bears fruit (area A). Apart from that, its stands are also at the banks, in the most transformed parts of the reserve (area C). *Rubus chamaemorus* does not appear, however, in places where, in spite of better moisture conditions and a lower concentration of mineral nitrogen (area B), the light conditions are unfavourable. This shows that it is possible to use active protection for the conservation of an endangered species if full peat bog renaturation is impossible (KAŹMIERCZAKOWA, ZARZYCKI 2001). Treatment consisting in the removal of underbrush and parts of the forest stand could contribute to the creation of suitable habitat conditions and increasing the population of that species in the reserve. That proposal, however, should be treated as a necessity. A better solution, both for the conservation of the *Rubus chamaemorus* stand as well as the whole ecosystem of raised peat bog, is carrying out a complex renaturation programme where the restoration of natural water conditions should be the main aim. Leaving the current state as is will cause further degradation of the peat bog and the disappearance of peat- forming flora.

The analysis of water conditions and physical and chemical properties of peat in the area following the exploitation of the peat bog (area D) shows a large similarity to the central part of the reserve (area A). It is promising to create conditions for regeneration of raised peat bog in that area. These studies show that the process of the peat bog degradation and the extinction of the peat bog flora requires urgent action. These preliminary results can be useful in the implementation of a renaturation project in the "Zielony Mechacz" reserve.

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