Roczniki Akademii Rolniczej w Poznaniu CCCXC

Botanika – Steciana

15, 2011, 91-104

www.up.poznan.pl/steciana

ISSN 1896-1908

PARTICIPATION OF BRYOPHYTES IN FOREST AND SHRUB COMMUNITIES IN THE ANTROPOGENICALLY DEGRADED ŁUGI PEAT BOG AREA (CENTRAL POLAND)

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(Received: March 4, 2011. Accepted: July 1, 2011)

ABSTRACT. We studied moss and liverwort diversity in forest and shrub communities in the Ługi peat bog area and in its surroundings (researched area located near the Warta River Valley, in the vicinity of the "Jeziorsko" water reservoir). The plant cover underwent considerable anthropogenic changes and is still subject to modifications due to previous and current human impacts such as peat deposit exploitation (in the past), drainage and intensive forest management (at present). The taxonomical and ecological diversity of the bryophyte flora (in total 73 species; 67 mosses and six liverworts) in the phytocoenosis developed by the processes of natural plant succession (willow brushwood *Salicetum pentandro-cinereae* in boggy areas, and in wet and moist coniferous forests: *Vaccinio uliginosi-Pinetum*, *Molinio-Pinetum* and *Leucobryo-Pinetum* communities) and in anthropogenic communities (forest substitute communities of Scots pine and black alder forest) were analysed. The diversity of the species composition in 16 distinguished types of plant communities was analysed using Detrended Correspondence Analysis (DCA). The Canonical Correspondence Analysis (CCA) showed the bio-indicative position of bryophyte species in the evaluation of habitat changeability, especially in the description of the variability of moisture. Numerous rare and endangered bryophytes were noted in the species-rich bryoflora of the studied area, so the Ługi peat bog is recognised as a floristically valuable locality. The occurrence of eight species of peat mosses in this anthropogenically deformed peat bog determines its natural value.

KEY WORDS: bryophyte flora, vegetation, peat bog, anthropopressure, bioindicators, Ługi near the Warta River, Central Poland

INTRODUCTION

Bryophytes are an intrinsic element of the majority of plant communities. They settle on specific substrates, including rocks, decomposing wood or tree trunks, and build distinct micro-phytocoenoses or form clusters of diverse terrestrial species, which are quite variable spatially and ecologically (Kornaś 1972). In forest and shrub communities, both the species composition of micro-bryo-coenoses as well as the species and spatial structure of the herb layer are strongly connected to the tree stand structure and composition. The overstorey modifies the light and moisture conditions, as well as nutrient availability (Urbanek 1966, Longton 1992, Klama et al. 1999, Vellak et al. 2003).

Many liverworts and mosses (especially peat mosses) are stenotopic organisms. Human impacts induce their retreat from natural habitats (Szweykowski 1992, Klama 2003, 2004, Żarnowiec 2004, Żarnowiec et al. 2004), so bryophytes can be used as bio-indicators or diagnostic species of anthropogenic disturbances (Żarnowiec 1995, 2004, Klama et al. 1999, Klama 2003, 2004). Moreover, those plants are very useful to estimate the degree of naturalness of biotopes occurring under anthropopressure (Szweykowski and Tobolewski 1959, Jędrzejko 1985, 1990, Balcerkiewicz and Rusińska 1989, Klama et al. 1999, Klama 2003, Żarnowiec 2004). Mosses and liverworts respond much faster than vascular plants to changes in environmental conditions, especially to changes in water availability, light intensity, acidity and soil fertility due to their unique anatomy (the lack of covering tissues) (Carleton 1990, Miserere et al. 2003, Vellak et al. 2003, Hokkanen 2004, 2006, Mälson et al. 2008, Illomets et al. 2010). The bio-indicative role of mosses and liverworts has become used universally, especially in studies of vegetation (Ingerpuu et al. 2001, Mäkipää and Heikkinen 2003, Miserere et al. 2003, Hájkowá and Hájek 2004, Hokkanen 2004, 2006, Stefańska 2007, Fudali 2008, Fritz et al. 2009, Stefańska-Krzaczek 2011).

In this paper, 1) we describe the diversity of the bryophyte flora in forest and shrub communities in a degraded peat bog area and its surroundings, 2) we make an attempt to use bryophytes in an assessment of anthropogenic deformation of plant communities and 3) we estimate the possibility of natural regeneration of the peat bog vegetation.

STUDY AREA

The Ługi peat bog area is located in the north-eastern part of the Warta district (Łódź province), about 3 km east of the "Jeziorsko" water reservoir (Fig. 1), in the eastern part of the Kotlina Sieradzka mesoregion (Kondracki 2002). The area encompasses an extensive depression (about 100 ha), surrounded in the south, west and north-west by sandy dunes. The peat deposit fills the plain basin (about 123 m above sea level) of the Holocene valley of the Warta River (Klatkowa and Załoba 1992, Forysiak 2005).

Originally, the plain surface of the peatland was strongly transformed as a result of anthropogenic activities. The most drastic changes were connected to intensive exploitation of the peat deposit and drainage of the exploited area, which took place in the second half of the 19th century and in the first half of the 20th century. The peat bog area was divided into parallel strips of land, 10-15 m wide, oriented from east to west. The lines determining the borders of private properties were the plots, where the removed "worthless" surface layers of peat bog were stored. Gradually, a system of drained causeways and exposed peat fields for peat excavation was formed. The exposed peat deposit had been extracted successively in a system of square or rectangular holes, separated by 0.5-2 m narrow fragments of non-exploited peat land, which were perpendicular to the causeways. It was a general rule that the peat seam was exploited almost completely, up to the mineral substratum. The owners returned to their activity on causeways and crosswise strips many times after depleting of all the resource within the "peat-fields". This caused a break in border line continuity. The end result was that the peat deposit was depleted almost completely. The remains of "living" peat bog survived within causeways and in non-exploited patches located between peat pits.

About 80% of the degraded peat bog area was abandoned and excluded from any management. The strongly drained fragments have gradually been converted into grasslands (meadows and pastures). The boggy places were afforested with black alder or Scotch pine. Similarly, the small private fields have been successively excluded from cultivation, abandoned and systematically afforested with pine, birch or poplar. The current vegetation of the Ługi area is the outcome of considerable human impacts and the natural processes of plant succession and regeneration (Woziwoda 2011).

Plant communities description
(numbering in accordance with Table 1)

A – Communities from the *Alnetea glutinosae* class and their substitute forest communities

1. *Salicetum pentandro-cinereae* (Almq. 1929) Pass. 1961 **association** – willow brushwood is a spatially dominant community the in investigated area. It is formed by large grey willow (*Salix cinerea*) with a little admixture of eared willow (*S. aurita*), occasionally with *S. pentandra.* Brushes are very thick ((40)80-100%), with characteristic bent branches covered with mosses. Tree stands are undeveloped or built from single specimens of *Betula pubescens* and *B. pendula.* The tree trunks have characteristic wide bases. The herb layer covers 30-95%

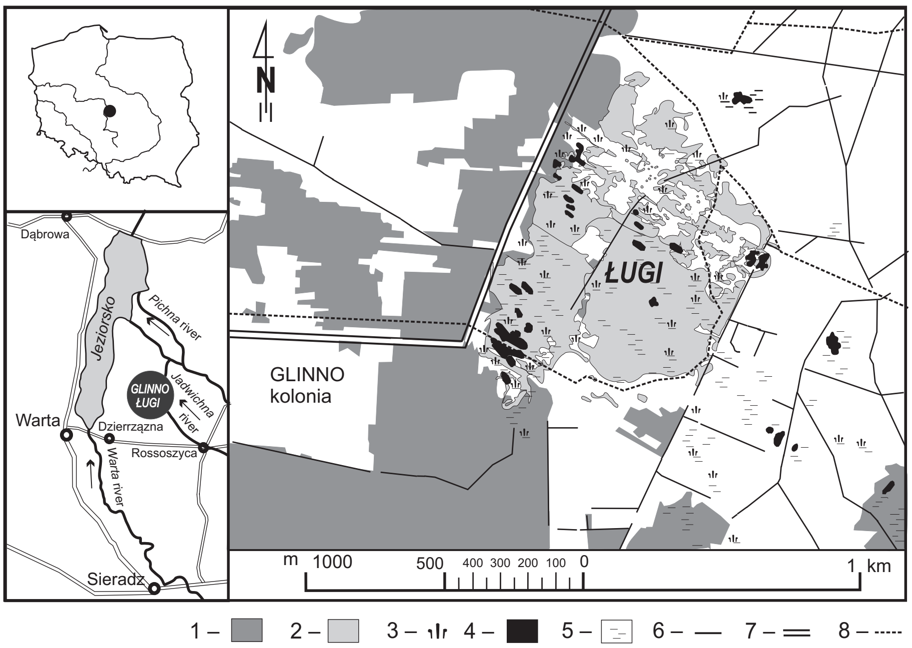

Fig. 1. Location of study area
Explanation: 1 – forest, 2 – thick brush woods, 3 – reed rushes and sedges, 4 – peat pits filled with water, 5 – wet area, wet and fresh meadows and pastures, 6 – permanent flow and drainage ditches, 7 – road from Glinno to Ferdynandów village, 8 – main tracks.

TABLE 1. Mosses and liverworts in plant communities in the Ługi peat bog area (**A** – Communities from the *Alnetea glutinosae* class and their substitute forest communities; **B** – Communities of *Vaccinio-Piceetea* class, growing on boggy and wet habitats within the peat bog area and their substitute forest communities; **C** – Communities of *Vaccinio-Piceetea* class, growing in mineral, moisture ("fresh") or dry habitats (on sandy dunes in the neighbourhood of the peat bog area) and their substitute forest communities

Plant communities	A						B					C				
	Salicetum pentandro-cinereae association	*S. p-c.*, variant with *Frangula alnus*	*Salix cinerea-Frangula alnus* community	Communities with *Alnus glutinosa*	*Betula-Juncus* community	*Alnus glutinosa-Picea abies* community	Boggy pine forest, *Vaccinio uliginosi-Pinetum* association	*Vaccinio uliginosi-Pinetum* with *Phragmites australis*	Wet pine forest, *Molinio-Pinetum* association	*Betula-Molinia* community in the wet pine forest habitat	The Scots pine monoculture in the area of the former peat bog	A fresh coniferous forest, *Leucobryo-Pinetum* association	Monocultures of Scots pine on a fresh coniferous forest habitat	Monocultures of *Pinus sylvestris* growing on poor sandy arable fields excluded from agriculture	Thickets of *Pinus sylvestris* and of *Betula pendula* on sandy dunes	Birch and Eurasian Aspen monocultures in the habitat of coniferous forest
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Number of relevés	24	10	6	5	4	1	8	4	8	2	6	11	21	19	3	9
Mean coverage of a1 layer (%)	20.4	9.4	12.9	70.0	45.0	30.0	45.0	65.5	58.8	60.0	96.7	64.1	61.9	28.4	–	41.1
Mean coverage of a2 layer (%)	10.0	17.2	7.1	15.0	30.0	50.0	20.6	25.0	16.9	20.0	6.7	10.9	20.7	43.4	–	44.4
Mean coverage of b layer (%)	89.3	80.0	84.4	24.0	60.0	30.0	26.3	42.5	37.5	25.0	4.2	27.5	52.9	17.6	43.3	37.2
Mean coverage of c layer (%)	62.1	84.4	78.8	88.0	65.0	20.0	74.4	80.0	86.9	75.0	5.8	20.9	37.9	9.3	66.7	45.6
Mean coverage of d layer (%)	58.2	54.4	27.4	9.0	8.8	10.0	68.8	78.8	19.4	30.0	5.0	94.5	52.9	23.2	5.0	17.8
Total number of bryophyte species	32.0	35.0	32.0	9.0	11.0	12.0	21.0	22.0	29.0	11.0	10.0	15.0	29.0	24.0	5.0	27.0
Mean number of species in relevé	9.3	12.0	8.5	7.2	4.3	12.0	11.3	10.3	8.5	6.3	7.2	5.5	10.1	5.3	3.0	7.9
Species:	Constancy class or number of records $^{\text{mean coverage coefficient}}$															
Bra rut – Brachythecium rutabulum	IV^{913}	V^{745}	V^{500}	V^{1170}	4^{813}	1^{100}	III^{50}	1^{25}	IV^{419}	2^{500}	.	I^{10}	IV^{503}	II^{161}	2^{100}	V^{905}
Poh nut – Pohlia nutans	II^{54}	II^{40}	.	II^{40}	1^{25}	1^{100}	V^{88}	3^{75}	V^{138}	.	IV^{67}	V^{90}	IV^{207}	III^{47}	.	III^{255}
Dic sco – Dicranum scoparium	III^{110}	I^{10}	II^{33}	.	.	1^{100}	IV^{75}	3^{75}	I^{13}	.	IV^{67}	V^{1745}	IV^{1648}	II^{221}	.	II^{30}
Lop het – Lophocolea heterophylla	II^{94}	I^{20}	IV^{67}	III^{60}	2^{50}	1^{500}	III^{50}	.	I^{13}	1^{50}	V^{417}	.	IV^{154}	II^{26}	.	IV^{70}
Sci oed – Sciuro-hypnum oedipodium	I^{4}	.	V^{100}	.	1^{438}	1^{1750}	II^{25}	.	II^{25}	.	.	I^{185}	V^{3023}	V^{663}	.	II^{195}

Table 1 – cont.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Ple sch – Pleurozium schreberi	.	.	.	.	.	.	IV^{538}	.	IV^{331}	.	.	V^{7125}	III^{4020}	IV^{671}	.	II^{30}
Hyp cup – Hypnum cupressiforme	II^{444}	IV^{405}	.	I^{20}	2^{50}	1^{100}	I^{13}	2^{463}	II^{281}	.	V^{100}	.	II^{406}	II^{392}	.	III^{215}
Pla aff – Plagiomnium affine	III^{254}	III^{180}	V^{625}	III^{720}	.	.	.	.	.	1^{50}	.	.	IV^{123}	I^{5}	.	I^{185}
Pla cur – Plagiothecium curvifolium	I^{13}	.	.	.	1^{25}	.	II^{25}	.	.	.	V^{100}	I^{20}	IV^{765}	II^{316}	.	I^{10}
Aul and – Aulacomnium androgynum	I^{13}	I^{10}	IV^{67}	.	.	.	III^{50}	.	II^{75}	1^{50}	III^{83}	.	III^{107}	.	.	III^{50}
Sph pal – Sphagnum palustre	III^{558}	II^{225}	.	I^{20}	.	.	V^{1056}	4^{5750}	IV^{575}	2^{2750}	.	.	.	.	.	.
Sph fim – Sphagnum fimbriatum	IV^{1481}	II^{20}	.	II^{120}	.	.	II^{75}	.	II^{125}	1^{875}	V^{50}	.	.	.	.	.
Hyp jut – Hypnum jutlandicum	.	.	.	.	.	.	IV^{488}	1^{25}	IV^{175}	.	.	II^{80}	II^{415}	II^{58}	.	I^{50}
Cal cus – Calliergonella cuspidata	IV^{1321}	I^{175}	V^{1542}	III^{390}	.	.	.	.	.	.	.	.	.	.	.	.
Pol for – Polytrichastrum formosum	I^{46}	I^{10}	.	I^{20}	.	.	.	1^{25}	I^{13}	.	.	III^{90}	III^{217}	I^{11}	.	II^{30}
Bra sal – Brachythecium salebrosum	I^{4}	I^{20}	V^{300}	I^{100}	2^{50}	1^{100}	III^{50}	.	I^{13}	.	.	.	II^{90}	.	.	II^{195}
Aul pal – Aulacomnium palustre	II^{33}	.	V^{100}	.	.	.	V^{88}	1^{25}	II^{38}	1^{50}	.	.	.	.	.	.
Sph squ – Sphagnum squarrosum	IV^{1085}	II^{410}	.	.	.	.	.	2^{963}	.	.	IV^{67}	.	.	.	.	.
Cli den – Climacium dendroides	IV^{808}	I^{20}	V^{350}	I^{20}	.	.	.	.	.	1^{50}	.	.	.	.	.	.
Tet pel – Tetraphis pellucida	III^{92}	I^{10}	.	I^{20}	.	.	IV^{75}	4^{100}	II^{125}	.	.	.	.	.	.	.
Her sel – Herzogiella seligeri	I^{4}	I^{10}	.	.	1^{25}	1^{100}	.	1^{25}	II^{25}	.	V^{100}	.	III^{90}	.	.	I^{20}
Dic pol – Dicranum polysetum	.	.	.	.	.	.	I^{13}	.	II^{25}	.	.	IV^{1860}	II^{227}	II^{21}	.	.
Pla den – Plagiothecium denticulatum	I^{17}	IV^{110}	.	I^{20}	.	.	.	1^{25}	I^{13}	1^{50}	.	.	II^{37}	.	.	.
Amb ser – Amblystegium serpens	II^{156}	I^{20}	.	I^{20}	1^{25}	1^{100}	.	.	.	.	.	.	II^{33}	.	.	I^{10}
Pse pur – Pseudoscleropodium purum	.	I^{60}	.	.	.	.	II^{25}	.	I^{13}	.	.	II^{235}	III^{1940}	I^{32}	.	.
Pla lae – Plagiothecium laetum	II^{25}	I^{20}	.	.	.	.	.	2^{50}	.	.	II^{33}	.	II^{44}	I^{11}	.	.
Pol com – Polytrichum commune	I^{95}	.	.	.	.	.	V^{1663}	3^{375}	III^{100}	.	.	.	.	.	.	I^{20}
Cer pur – Ceratodon purpureus	.	.	II^{33}	.	.	1^{100}			I^{13}	.	.	I^{20}	I^{7}	II^{21}	2^{500}	II^{40}

Table 1 – cont.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Sph fal – Sphagnum fallax	I^{73}	.	.	.	.	.	V^{3388}	4^{4500}	II^{231}	.	.	.	.	.	.	.
Dic het – Dicranella heteromalla	.	.	.	.	.	.	II^{38}	1^{25}	II^{25}	.	.	I^{10}	I^{20}	I^{11}	.	II^{70}
Pla und – Plagiomnium undulatum	II^{135}	II^{80}	.	.	.	.	.	.	I^{13}	.	.	.	.	.	.	.
Atr und – Atrichum undulatum	I^{8}	.	V^{150}	I^{20}	.	1^{100}	.	.	.	.	.	.	I^{7}	I^{5}	.	I^{10}
Mni hor – Mnium hornum	II^{63}	I^{10}	.	II^{370}	.	.	.	1^{125}	.	1^{50}	.	.	.	.	.	.
Cal cor – Calliergon cordifolium	II^{110}	.	.	II^{40}	.	.	.	1^{25}	.	.	.	.	.	.	.	.
Bra vel – Brachytheciastrum velutinum	I^{4}	.	.	II^{40}	.	1^{100}	.	2^{50}	.	.	.	.	I^{7}	I^{5}	.	I^{10}
Leu gla – Leucobryum glaucum	.	.	.	.	.	.	I^{13}	1^{25}	II^{25}	.	.	I^{10}	.	.	.	I^{20}
Bra alb – Brachythecium albicans	.	.	.	.	.	.	.	.	I^{13}	.	.	.	I^{7}	II^{21}	.	I^{10}
Amb rad – Amblystegium radicale	.	.	V^{100}	.	.	.	.	.	.	.	.	.	.	.	.	.
Lep rep – Lepidozia reptans	I^{4}	.	.	.	.	.	.	1^{25}	.	.	.	.	I^{27}	.	.	.
Pla cus – Plagiomnium cuspidatum	II^{38}	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pol jun – Polytrichum juniperinum	.	.	.	.	.	.	.	.	.	.	.	.	.	I^{97}	1^{500}	I^{20}
Lop bid – Lophocolea bidentata	I^{4}	.	.	.	.	.	.	.	.	.	.	.	I^{27}	.	.	I^{10}
Rad com – Radula complanata	I^{17}	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lep rip – Leptodictyum riparium	I^{13}	.	I^{83}	.	.	.	.	.	.	.	.	.	.	.	.	.
Rhi pun – Rhizomnium punctatum	I^{13}	.	.	I^{20}	.	.	.	.	.	.	.	.	.	.	.	.
Rhy squ – Rhytidiadelphus squarrosus	.	.	.	.	.	.	.	.	.	.	.	.	.	I^{118}	.	I^{20}
Hyp fil – Hypnum cupressiforme var. *filiforme*	I^{146}	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I^{175}
Hyp pal – Hypnum pallescens	I^{8}	I^{10}	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ort var – Orthotheciella varia	I^{8}	I^{10}	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pla ell – Plagiomnium ellipticum	I^{42}	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Thu phi – Thuidium philibertii	I^{8}	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Table 1 – cont.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Pol lon – Polytrichastrum longisetum	.	.	II^{33}	.	.	.	.	.	.	.	.	.	.	.	.	.
Amb jur – Amblystegium juratzkanum	I^{4}	.	.	.	I^{25}	.	.	.	.	.	.	.	.	.	.	.
Ort lin – Orthodontium lineare	.	.	.	.	.	.	.	.	.	.	.	I^{10}	I^{17}	.	.	.
Pti cri – Ptilium crista-castrensis	.	.	.	.	.	.	.	.	.	.	.	.	I^{7}	I^{5}	.	.
Pol pil – Polytrichum piliferum	.	.	.	.	.	.	.	.	.	.	.	.	.	I^{197}	I^{5}	.
Sph cap – Sphagnum capillifolium	I^{73}	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sph ter – Sphagnum teres	I^{73}	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pla ela – Plagiomnium elatum	I^{21}	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sph gir – Sphagnum girgensohnii	I^{21}	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Dre pol – Drepanocladus polycarpos	I^{4}	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pla rut – Plagiothecium ruthei	.	.	.	I^{20}	.	.	.	.	.	.	.	.	.	.	.	.
Cam pol – Campylium polygamum	.	.	.	I^{20}	.	.	.	.	.	.	.	.	.	.	.	.
Ort dia – Orthotrichum diaphanum	.	.	.	.	I^{25}	.	.	.	.	.	.	.	.	.	.	.
Cam int – Campylopus introflexus	.	.	.	.	.	.	.	.	I^{13}	.	.	.	.	.	.	.
San unc – Sanionia uncinata	.	.	.	.	.	.	.	.	I^{13}	.	.	.	.	.	.	.
Dic cer – Dicranella cerviculata	.	.	.	.	.	.	.	.	I^{13}	.	.	.	.	.	.	.
Cep bic – Cephalozia bicuspidata	.	.	.	.	.	.	.	I^{25}	.	.	.	.	.	.	.	.
Sph rus – Sphagnum russowii	.	.	.	.	.	.	.	.	.	I^{250}	.	.	.	.	.	.
Pti pul – Ptilidium pulcherrimum	.	.	.	.	.	.	.	.	.	.	.	I^{10}	.	.	.	.
Thu tam – Thuidium tamariscinum	.	.	.	.	.	.	.	.	.	.	.	.	I^{7}	.	.	.
Kin pra – Kindbergia praelonga	.	.	.	.	.	.	.	.	.	.	.	.	.	I^{5}	.	.
Sci sta – Sciuro-hypnum starkei	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I^{50}

of the area of these patches. The plant mosaic illustrates the variety of micro-topography: plants are clustered on narrow causeways or on the edges of peat pits and in shallow zones. Numerous herbs and mosses have settled the plant remains which have accumulated between willow branches. A dense muddle of rhizomes of *Phragmites australis* and *Thelypteris palustris* and sedges tussocks is found as well. The species characteristic of *Alnetea glutinosae* and the *Phragmitetea* classes dominate. The plants from the *Molinio-Arrhenatheretea* class are also commonly noted. Sedges from *Scheuzerio-Caricetea fuscae* class are less abundant. The deeper peat-pits with open water surface are covered with hydrophytes from the *Lemnetea* and *Potametea* classes.

2. *Salicetum pentandro-cinereae*, variant with *Frangula alnus* – willow brushwood dominated by alder buckthorn grows in low and 5-10 m wide parts of causeways with diverse micro-topography. Tree stands with *Betula pendula* or *B. pubescsens* are developed in places. The homogeneous herbs layer is very compact and covers 80-100% of the patch surface. The dominance of tussock grasses such as *Deschampsia caespitosa*, higher participation of *Anthoxanthum odoratum* and higher frequency of grassland species from the *Molinio-Arrhenatheretea* class distinguish this community from patches of the typical *Salicetum pentandro-cinerea* association.

3. *Salix cinerea-Frangula alnus* community – brushwood of alder buckthorn and large grey willow grow on a gentle slope of sandy dune "encroaching" on the peat bog area (outside the area of peat-deposits exploitation). The wide spreading clumps of single individuals of *Salix cinerea* are surrounded by dense thickets of *Frangula alnus*. *Betula pubescens* and tree specimens of *B. pendula* appear in the admixture. The multi-species herb layer, at a density of 60-80%, is clustered in alder buckthorn thickets. There are no herbs around the clumps of willows, but bryophytes are present. Meadow species from the *Molinio-Arrhenatheretea* class, with a high proportion of *Deschamsia caespitosa* and species connected to rich, wet soils from *Calthion* and *Filipendulion* alliances are noted in great numbers.

4. Communities with *Alnus glutinosa* – initial forest communities with black alder, including spatially isolated monocultures of different ages. The patches occupy wet and very wet habitats (with stagnant water on the surface). The stand is average- or moderately (40)60-90%. The shrub layer is weakly developed, and in the majority of patches, it is clustered around the trunks of alders. The herb layer is dominated by *Carex acutiformis* or occupied by blackberries *Rubus* sp. Single stumps and blocks of dead wood in different degrees of decay are noted. The structure of the community and the herb species composition refers to natural alder forests as well as the presence of tufts and small valleys which appear in the micro-topography of the forest floor.

5. *Betula-Juncus* community – a small patch of anthropogenic tree stands built by birches or poplars, located in local boggy depressions in the transitional zone between the peat bog and the sandy dune. The boggy topographic low area dries up in the summer season. The upper layer of the tree stand is from 20 to 50-60% dense in separate patches; the lower layer is weakly developed. The undergrowth contains, among others, *Sambucus nigra* and *Frangula alnus*. A significant area is occupied by blackberries (*Rubus* sp.). The herb layer, poor in species, is dominated by tussocks of *Juncus effusus* with high participation of grasses, ferns and clumps of *Urtica dioica*.

6. *Alnus glutinosa-Picea abies* community – Norway spruce and black alder build a two-layered tree stand and undergrowth. The herb layer is very weakly developed due to the deep shade on the forest floor. Only *Urtica dioica* and *Moehringia trinervia* reach a significant coverage.

B – Communities of *Vaccinio-Piceetea* class, growing on boggy and wet habitats within the peat bog area and their substitute forest communities

7. Boggy pine forest, *Vaccinio uliginosi-Pinetum* Kleist 1929 **association** – this occupies narrow (20--30 m wide) and irregular patches located in the neighbourhood of the wet pine forest, the initial alder forest and patches of willow brushwood. The permanently high level of groundwater is a characteristic feature of this habitat. The well-spaced, multilayered tree stand is built by *Pinus sylvestris* and occasionally by *Picea abies*. Young individuals of the species mentioned above form the poorly developed undergrowth. The understorey is made up mainly of mosses forming a characteristic dense "carpet" with hummocks 30 to 40 cm high. Species associated with boggy habitats are commonly noted. *Eriophorum angustifolium* and *Oxycoccus palustris* grow plentifully in the herb layer and *Ledum palustre* and *Calluna vulgaris* shrubs are also frequently noted. Species characteristic of the *Scheuzerio-Caricetea* class also occur. *Molinia caerulea* is a permanent component of the herb layer as well.

8. *Vaccinio uliginosi-Pinetum* with *Phragmites australis* – some patches of boggy pine forest with an herb layer dominated by reeds encroaching there spontaneously from the adjacent rushes. The ground layer is formed by a fragmented blanket of mosses, hummocks and small shallow topographic lows periodically filled with water. Numerous decomposing logs and stumps are noted everywhere.

9. Wet pine forest, *Molinio-Pinetum* W. Mat. et J. Mat. 1973 **association** – distinguished in small patches with wet mineral soils between the peat bog area and sandy dunes. The mature, average-species tree stand is built by *Pinus sylvestris* with an admixture of *Betula pubescens*. The shrub layer is built by *Betula pubescens* and/or *Salix cinerea*, all of which grow plentifully. Young individuals of Scots pine and the Norway spruce are frequently noted as well. The main component of the dense herb layer is *Molinia caerulea*. Small clusters of *Vaccinium myrtillus* and *Anthoxanthum odoratum* varied the grassy understorey. Mosses and liverworts cover the hollows among the clusters and the decaying remnants of grasses. Numerous logs, stumps and bases of trunks are also covered by a diverse flora of bryophytes.

10. *Betula-Molinia* community in the wet pine forest habitat – the tree stand is dominated by *Betula pubescens* or *B. pendula*. The undergrowth is very sparse. The herb layer is homogeneous, built by *Molinia caerulea*. The share of other herb species is scarce.

11. The Scots pine monoculture in the area of the former peat bog – the very dense tree stand is built by trees planted in straight rows on high peaty soil embankments which are separated by 1-1.5 m deep furrows (= drainage channels). The ground layer is very poor. Herbs and mosses are gathered in the wet shallows. Decaying pine branches and needles are found on the forest floor.

C – Communities of *Vaccinio-Piceetea* class, growing in mineral, moisture ("fresh") or dry habitats (on sandy dunes in the neighbourhood of the peat bog area) and their substitute forest communities

12. A fresh coniferous forest, *Leucobryo-Pinetum* W. Mat. (1962)1973 **association** – a coniferous forest grows on the sandy dunes in the southern and north--western parts of the studied area. Scots pine builds the upper layer of the even-aged stand. *Betula pendula* and *Quercus robur* are noted as an admixture and they form the lower tree stand layer. The undergrowth is dominated by *Frangula alnus* and *Sorbus aucuparia*, highly dense in places. The herb layer is characterised by the presence of acidophilous species associated with coniferous forests such as *Vaccinium myrtillus* and *Calluna vulgaris*. The moss layer is conspicuous and forms a carpet covering up to 100% of the patch.

13. Monocultures of Scots pine on a fresh coniferous forest habitat – this occupies the undulating areas of low dune hills. There are initial stages of fresh pine community established after repeated afforestation of the logging area. The monocultures are diversified in tree stand age from 40 to 110 years. Separate patches display great diversity in terms of the species composition of the undergrowth and the herb layer as well.

14. Monocultures of *Pinus sylvestris* growing on poor sandy arable fields excluded from agriculture – the tree stands of separate patches are highly well-stocked (70-90%) and diversified in age. Most of them lacks developed undergrowth and the herb layer is very sparse or there are no herb species altogether. The forest floor is covered with thick layer of pine needles and many branches left after forest clearing and thinning.

15. Thickets of *Pinus sylvestris* and of *Betula pendula* on sandy dunes – these are young communities with widely-spaced tree stands, which developed naturally in a succession process (thicket of Scots pine) or planted (thicket of birch) on acid, sandy soils. The herb layer is floristically rich, built by xerophilous and thermophilous species characteristic of the *Koelerio-Corynephoretea* class, species associated with arable fields of the *Stellarietea mediae* class and ruderal species of the *Arthemisietea* class as well. The bryophyte layer is quite poor.

16. Birch and Eurasian Aspen monocultures in the habitat of coniferous forest – narrow (15--20 m in wide) patches with *Betula pendula* or *Populus tremula* grow isolated from each other. The young tree stand is widely spaced and highly exposed to sunlight. The grassy herb layer is mainly built by species from the *Molinio-Arrhentheretea* class.

MATERIAL AND METHODS

The brylogical data were gathered during phytosociological field research performed in from 2007-2009. In total, 1124 records of bryophyte species collected in 141 phytosociological relevés were studied. Bryophytes were collected from the mineral soil, peat, the base of trunks and fragments of rotten wood. The abundance of species was estimated using a seven-grade Braun--Blanquet (1964) quantitative scale. Species richness and bryophytes coverage were analysed in 16 forest and shrub communities occurring in the study area (see: Plant communities description).

We analysed the diversity composition of the species in the bryophyte flora. For each species, we determined the constancy and mean value of the coverage coefficient.

Detrended Correspondence Analysis (DCA) was used to identify differences in bryophyte species composition, as well as the main gradients of variability of the vegetation. Analysis was performed using the package CANOCO for Windows, version 4.5 (ter Braak and Šmilauer 2002). For each species, the following mean degrees of coverage were adopted for consecutive quantitative degrees: 5 = 87.5, 4 = 62.5, 3 = 37.5, 2 = 17.5, 1 = 5, + = 0.5, r = 0.1 (Van der Maarel 1979). The calculated DCA length of the gradient (5.5 SD) was the basis for selecting DCA as the ultimate technique to organise the data (Jongman et al. 1987).

Ecological diversity of bryophytes was determined with the ecological numbers. To recognise the most important habitat factors determining species composition, species were grouped according to their habitat preferences and assessed by the indicator values (Düll 1991). Among the examined factors were light, soil moisture and soil acidity. The means of the indicator values were calculated for each plot and used as environmental data in the Canonical Correspondence Analysis (CCA) (Jongman et al. 1987). The values of variables (= species) were cover scale points transformed into mean cover values (van der Maarel 1979).

The nomenclature of mosses was adopted after Ochyra et al. (2003), that of liverworts after Klama (2006), while the nomenclature of vascular plants was given after Mirek et al. (2002).

RESULTS

General characteristics of the bryophyte flora

In the studied plant communities of the Ługi peat bog area, bryophytes are an important structural element. In 141 analysed patches of vegetation, the absence of bryophytes was found at only one site (an anthropogenic pine stand with a very high share *Padus serotina*). Overall, in forest and shrub communities, 73 taxa of bryophytes were found (66 species, one variety of moss and six species of liverworts), 11 of which occurred in more than half of the 16 plant communities recognised in the area (Table 1). Despite a significant diversity of habitats in the investigated area, the liverwort flora was poorly represented. Of the six listed species, only *Lophocolea heterophylla* achieved a high constancy; the rest were recorded sporadically. The greatest mean number of bryophyte species was recorded in *Salicetum pentandro-cinereae*, a variant of *Frangula alnus* (12.0) and in boggy pine forest, *Vaccinio uliginosi-Pinetum* (11.3) (Table 1). The poorest areas floristically were thickets of *Pinus sylvestris* and of *Betula pendula* on sandy dunes, where the relevés were found only three species. The mean coverage of the bryophyte layers varied considerably between communities from just 5.0% in the Scots pine monoculture in the area of the former peat bog and in thickets of *Pinus sylvestris* and *Betula pendula* to 94.5% in patches of *Leucobryo-Pinetum* (Table 1). The most frequently listed were eurytopic taxa: *Brachythecium rutabulum*, found in 15 communities; *Pohlia nutans* and *Lophocolea heterophylla*, in 13 communities; as well as *Dicranum scoparium* and *Hypnum cupressiforme*, noted in 12 communities. Species with a wide range of ecological demands make up over 17% of the studied bryoflora. Nearly 30% of the recorded species of bryophytes are hygrophilous. Of this group, the highest constancy was found for *Sphagnum fimbriatum*, *S. squarrosum*, *Calliergonella cuspidata* and *Climacium dendroides* (Table 1).

A significant share in the bryoflora of the Ługi peat bog area also included species from fresh forest sites. The most frequent were *Dicranum scoparium*, *D. polysetum*, *Sciuro-hypnum oedipodium*, *Pleurozium schreberi* and *Plagiothecium curvifolium* (Table 1). Less common components of the lowest undergrowth of forest communities were *Ptilium crista-castrensis* and *Leucobryum glaucum*.

The ecological-floristic differences between the plant communities

The DCA analysis showed a considerable variation of bryophytes in terms of habitat preferences (Fig. 2 a). The eigenvalue for Axis I was very high at 0.89. Based on the arrangement of samples and species in the ordination space, the gradient represented by Axis I was interpreted as decreasing moisture level in the substrate (Fig. 2 a-b).

a) ordination of species (explanations: species codes see Table 1)

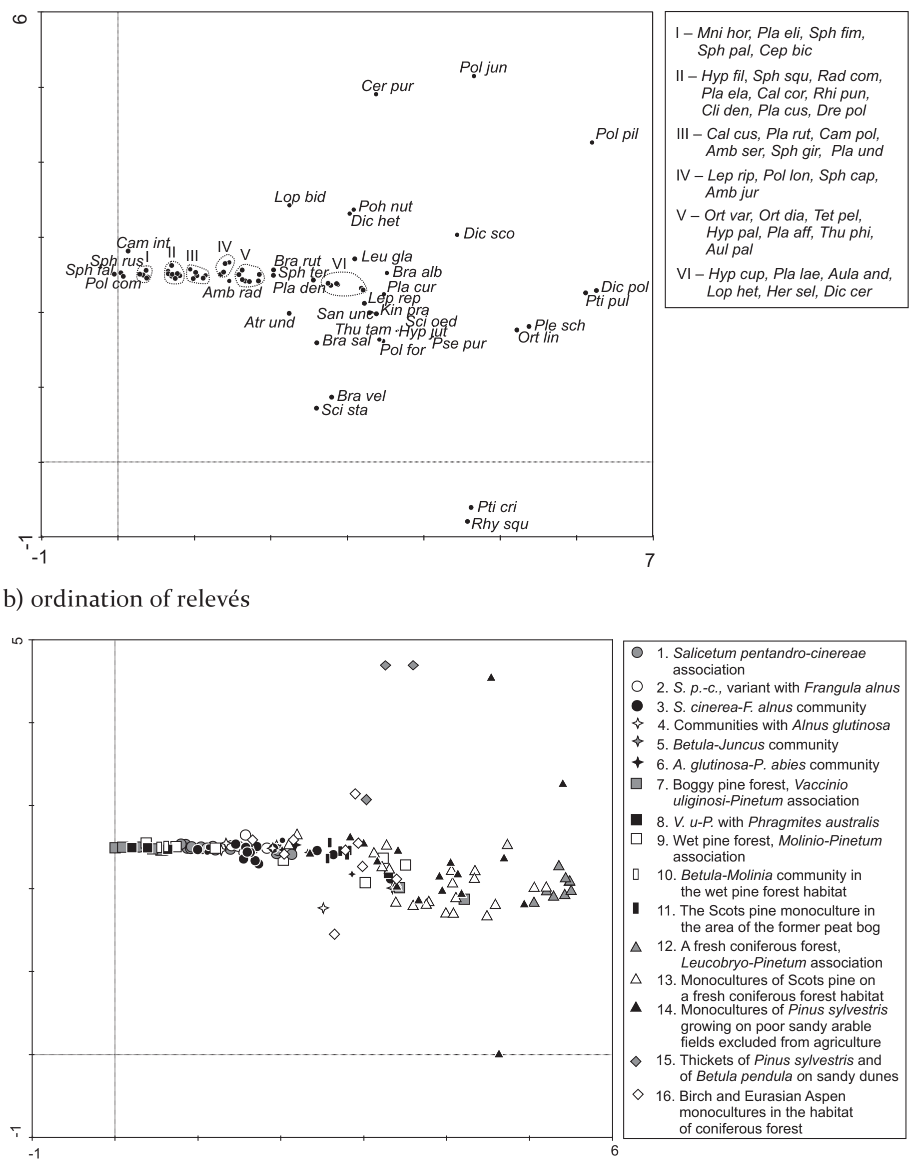

FIG. 2. Ordination diagram based on Detrended Correspondence Analysis (DCA Axis I λ_1 = 0.89 and Axis II λ_2 = 0.65)

On the extreme left side of the diagram, a large group of hygrophilous species is located, including *Sphagnum russowii*, *S. fallax*, *S. palustre*, *Calliergon cordifolium* and *Polytrichum commune*. On the right side of the diagram are located mesic habitat species such as *Dicranum polysetum* and *Ptilidium pulcherrimum*. The CCA analysis confirmed that this factor had a huge impact on the distribution of bryophytes in the studied communities. The second equally important factor was soil acidity (Fig. 3).

A group of communities of the *Alnetea glutinosae* class was distinguished by high distinctiveness of the bryoflora; 23 species of bryophytes were noted only here (Table 1). Among these, a significant proportion was hygrophilous taxa, including *Amblystegium radicale*, *Drepanocladus polycarpos*, *Leptodictyum riparium*, *Plagiomnium elatum*, *P. ellipticum*, *Plagiothecium ruthei* or *Polytrichastrum longisetum*. In the analysed group of communities, are typically acidophilous forest species poorly represented, and their occurrence is mainly accidental.

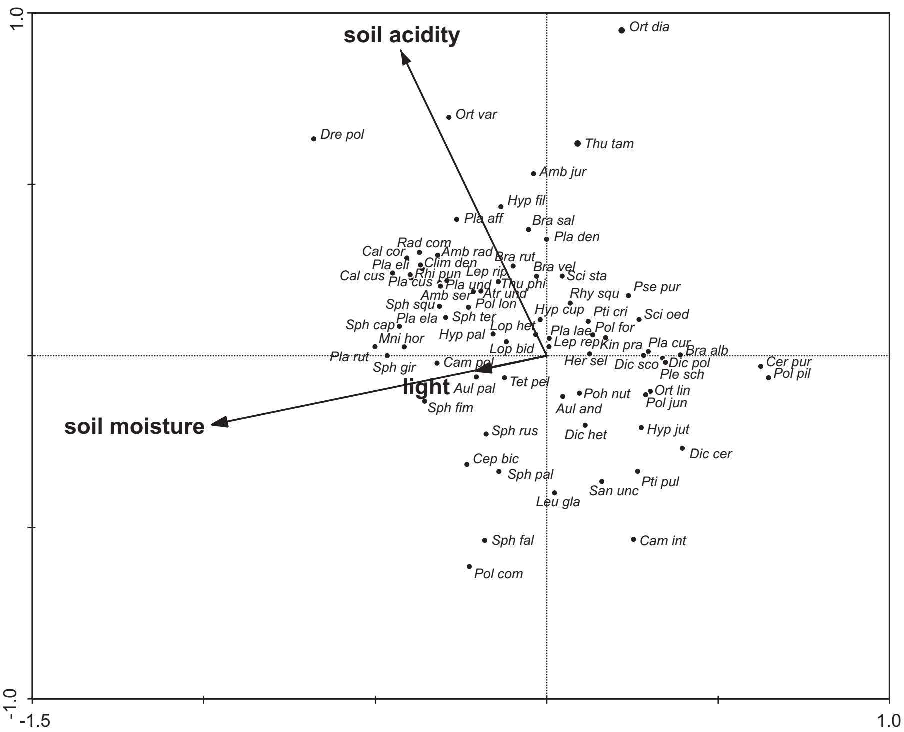

FIG. 3. Species composition of bryophytes in dependence on selected habitat factors based on Canonical Correspondence Analysis (CC Axis I $\lambda_1 = 0.65$ and Axis II $\lambda_2 = 0.51$) (explanations: species codes see Table 1)

In the study area, communities of the *Alnetea glutinosae* class occupy diverse habitats in terms of moisture conditions, as evidenced by the significant dispersion of samples in the ordination space. This especially concerns patches of the *Salix cinerea-Frangula alnus* community and to a lesser extent *Salicetum pentandro-cinereae* (Fig. 2 b). In communities from group A, more than half of all identified species of bryophytes were hygrophilous taxa, which often occur with high constancy and abundance (e.g. *Calliergonella cuspidata*, *Climacium dendroides*) (Table 1). We also noted the presence of up to seven (of eight found in the entire area) *Sphagnum* species. However, their presence was limited primarily to the typical patches of *Salicetum pentandro-cinereae* and patches of *Salicetum pentandro-cinereae*, variant with *Frangula alnus*, of which the highest recorded constancy and abundance was noted in *Sphagnum fimbriatum*, *S. squarrosum* and *S. palustre.* Small turfs of *Sphagnum palustre* and *S. fimbriatum* were also found in patches in communities with *Alnus glutinosa*.

The bryoflora from phytocoenoses of the *Vaccinio-Piceetea* class, including pine bog forests and their wet forest accumulation replacements, also indicates the diversified habitat in terms of moisture (Fig. 2 b). Individual communities vary significantly in terms of the mean number of mosses and liverworts species noted in the plant patches, from 6.3 in the *Betula-Molinia* community in the wet pine forest habitat to 11.3 in *Vaccinio uliginosi-Pinetum*, and also in terms of the mean cover of the bryophytes layer, from only 5.0% in the Scots pine monoculture in the area of the former peat bog to 78.8% in *Vaccinio uliginosi-Pinetum* with *Phragmites australis* (Table 1). The localisation of most samples from the boggy pine forest and the boggy pine forest with common reeds on the left of the DCA diagram indicates that these communities grow in very moist habitats. Definitely, drier habitats are occupied by the monoculture of *Pinus sylvestris* planted in the area of the former peat bog (Fig. 2 b). Also, in the phytocoenoses of *Molinio-Pinetum*, the presence of a large group of hygrophilous species was found, including *Sphagnum* (*S. fallax* and *S. palustre*). At the same time (although with a lower constancy, Table 1), the species with the optimum occurrence in pioneering psammophilous associations were recorded, for example *Brachythecium albicans* or *Ceratodon purpureus*. Such a bryophyte flora composition clearly indicates microhabitats with strong internal differentiation in patches of *Molinio-Pinetum*.

Compared with communities of the *Alnetea glutinosae* class, the phytocoenoses of the bryoflora from group B were characterised by: 1) significant increases in the share of acidophilous hydrophilous species such as *Aulcomnium palustre*, *Sphagnum fallax*, *S. palustre* or *Polytrichum commune* and fresh habitat species, such as *Dicranum polysetum*, *Pohlia nutans*, *Sciuro-hypnum oedipodium*, *Plagiothecium curvifolium*, *Pleurozium schreberi*, *Dicranum polysetum*, *Hypnum jutlandicum* and *Leucobryum glaucum*, 2) little or no share of the habitats of hydrophilous bryophytes from fertile or moderately fertile habitats, and 3) a much smaller group of exclusive species, which includes only five mosses: *Campylopus introflexus*, *Sanionia uncinata*, *Dicranella cerviculata*, *Cephalozia bicuspidata* and *Sphagnum russowii*, all of which were found in single patches (Table 1, Fig. 3). A characteristic feature of this group of communities was also the presence of species belonging to the obligatory epixylic species, *Lophocolea heterophylla*, *Aulacomnium androgynum*, *Tetraphis pellucida* and *Herzogiella seligeri*.

For the third group of communities (group C), consisting mainly of different-aged pine forests on the mineral soil of mesic forest sites and dry habitats, the mean cover of the bryophyte layer ranged from 5.0% in thickets of *Pinus sylvestris* and *Betula pendula* on sandy dunes to 94.5% in patches of *Leucobryo-Pinetum* (Table 1). Communities assigned to group C were characterised by poor richness of bryophyte species. The exception was a monoculture of Scots pine on a fresh pine forest habitat in which the mean number of species in a patch was found to be 10.1. This value is almost two times higher compared to patches classified as *Leucobryo-Pinetum*. For all the communities from the third group (with the exception of thickets of *Pinus sylvestris* and *Betula pendula* on sandy dunes), one characteristic is the dominance of acidophilous species from fresh forest sites, such as *Pleurozium schreberi*, *Dicranum polysetum*, *D. scoparium*, *Polytrichastrum formosum*, *Hypnum jutlandicum*, *Plagiothecium curvifolium*, *Pohlia nutans* and *Sciuro-hypnum oedipodium*. Moreover, *Orthodontium lineare*, *Ptilium crista-castrensis*, *Ptilidium pulcherrimum* and *Thuidium tamariscinum* were found only here. In monocultures of Scots pine in a fresh pine forest habitat, several species were also found which were listed or noted much less frequently in other communities of this group. These are: *Lophocolea heterophylla*, *Aulacomnium androgynum*, *Brachythecium salebrosum*, *Hypnum cupressiforme*, *Plagiothecium denticulatum*, *Atrichum undulatum*, *Herzogiella seligeri* and *Plagiomnium affine*.

A totally different character was found in the bryoflora in thickets of *Pinus sylvestris* and *Betula pendula* on sandy dunes. Difficult habitat conditions (strong sun, oligotrophic soils and low humidity) have resulted in an exceptionally poor bryoflora. Species that represent this habitat, e.g. *Polytrichum juniperinum*, *P. piliferum*, *Ceratodon purpureus* and *Brachythecium albicans*, are photophilous and nutritionally non-demanding.

DISCUSSION

The Ługi peat bog area has been highly transformed as a result of drainage of the land, exploitation of peat deposits and due to forest management. Contemporary distorted bog vegetation is a mosaic of anthropogenic communities and communities resulting from the spontaneous processes of succession. Direct human impact, resulting in progressive occupation of new areas for afforestation and shaping the structure and species composition of forest crops, affects all components, including the bryophyte flora, in a significant way. Despite the relatively large study area and the diversity of major plant communities, the richness of mosses and liverworts species was not high. The total number of recorded species comprised 23% of the known bryophytes of central Poland (Staniaszek-Kik and Wolski 2009). The liverwort flora was extremely poor, represented only by common species widely noted throughout the country. There were no stenotopic liverworts sensitive to anthropogenic environmental transformations. The process of plants disappearing from this group often occurs very quickly, and many factors, including water level changes and forestry, are a real threat to them (Klama 2002, 2003). Economic pressure drives the creation of pine monocultures, which are artificially established stands, and are usually characterised by a simplified internal structure, and often an altered microclimate. These are the main factors which significantly affect the decrease in mosses and liverworts sensitive to human impacts (Balcerkiewicz and Rusińska 1989, Szweykowski 1992, Hájek 2002, Klama 2002, 2003, 2004, Lachance and Lavoie 2004, Żarnowiec 2004, Żarnowiec et al. 2004, Vermaat et al. 2007).

Peat bogs today are the most valuable but also most threatened ecosystems in Poland (Jasnowski 1972, Herbich and Herbichowa 2002, Pawlaczyk et al. 2002, Żarnowiec 2003, Herbichowa et al. 2004, Kucharski 2004, Zarzycki and Szeląg 2006). The area which they occupy has decreased significantly under the influence of various forms of human activity (Herbich and Herbichowa 2002). Drastic, often irreversible, changes in peat bogs are caused by exploitation of peat (Jasnowski et al. 1968, Jasnowski 1972). Drainage treatments lead to lowering the water level and peat mineralisation, which involves a succession of vegetation in the direction of willow shrubs and forest communities (Jasnowski 1972, Herbich and Herbichowa 2002, Linderholm and Leine 2004, Pellerin et al. 2009, Woziwoda and Michalska-Hejduk 2009). The Ługi peat bog area, thanks to traditional methods of obtaining peat, retained small, intact, mechanically or poorly transformed pieces of the old peat bogs. Thanks to these areas, it was possible for at least part of the bog vegetation (with their specific flora of mosses and liverworts) to survive (Woziwoda and Komperda 2011). Studies by Podbielkowski (1960), Brzeg et al. (1995) and Herbich and Herbichowa (2002) showed that after the cessation of such exploitation of peat, while maintaining a high level of water in the ground, there is a chance for regeneration of a peat bog. Such conditions require the presence of a large group of hygrophilous bryophytes, including *Sphagnum*, inhabiting places such as dike edges and peat bog beds; these conditions are found in *Ługi*. In many analysed patches, *Sphagnum* species produced large carpets, often exceeding the abundance of the appropriate mosses. At the same time, almost no fresh habitat species were present, which seemed to not be getting through (with the exception of the most overdried patches) from the adjacent Scots pine stands.

Although advantageous humidity conditions exist, the occurring changes in the vegetation may make it difficult or even in some areas prevent the spontaneous regeneration of peat bog (Herbich et al. 1991). In the Ługi peat bog area, considerable shading of the lowest undergrowth because of thick willow thickets causes the development and dominance of shade-liking and shade-tolerating species, and also stops the development of the turf by some mosses, mainly of the *Sphagnum* kind. To preserve the *Sphagnum*, it would be advisable to remove the willow thickets in selected areas. Additionally, a considerable mass of decomposing leaves and dead branches of willow leads to eutrophication of the habitat.

Threats to the duration of *Sphagnum* species and other peat bog bryophytes in the phytocoenoses *Vaccinio uliginosi-Pinetum* with *Phragmites australis* include the mass occurrence of *Molinia caerulea*. In favourable habitat conditions (low, even temporarily, water levels) *Molinia caerulea* is a very expansive species. Its compact clumps restrict light access to the moss layer, and consequently lead to the disappearance of this group of plants. The occurrence of *Molinia caerulea* also points to the advanced process of mineralisation of the upper layers of peat (Pawlaczyk et al. 2002), which also means the recession of *Sphagnum* (Jeglum and He 1995, Anderson and Davis 1997). These adverse changes in the peat bog ecosystem were also confirmed by the high constancy and coverage by *Polytrichum commune*, noted in patches of *Vaccinio uliginosi-Pinetum*, and also in communities of *Molinio-Pinetum*. Development of *Polytrichum* clumps, the penetration of forest species and the simultaneous disappearance of *Sphagnum* is a phenomenon often observed in forested peatlands (Linderholm and Leine 2004, Pellerin et al. 2009). These changes are often accompanied by the development of forest cover changes, lowered groundwater levels, increased shading and progressive recession of peat, and are reflected in the structure and composition of ground vegetation species (Laine and Vanha-Majamaa 1992, Laine et al. 1995, Ohlson et al. 2001, Tousignant et al. 2010).

The bryoflora of the studied area reflects well the diversity of plant communities, while it also highlights the diversity of their inner habitat, caused among other factors by humidity differences in the substrate. Bryophytes clearly indicate that patches of the studied communities are more overdried. Typical hygrophilous species, mostly *Sphagnum*, are associated with peat bogs, and are more sensitive to changes in ground moisture content compared to the noted vascular plants (Malmer et al. 1994) which accompany them; they disappear first from transformed habitats. Similar results were obtained by Hokkanen (2004, 2006), who in his work emphasised the indicative values of bryophytes and suggested the need to consider this group of plants in studies on vegetation.

Despite a significant distortion of vegetation in the *Ługi peat bog,* the investigated area can be considered as bryological (and naturally) valuable. It is still the refuge of rare bryophytes, including *Sphagnum* species, which are mosses belonging to the most vulnerable groups in Poland.

Acknowledgements

The Authors wish to express our thanks to Dr Ewa Stefańska-Krzaczek from Department of Biodiversity and Plant Cover Protection, Wrocław University for many valuable advices on statistical analysis.

This study has been financially supported by the Polish Ministry of Science and Higher Education within the research project No. N305 091 32/3125: *Anthropogenic changes of plant cover of peat bogs in the Warta River valley in the vicinity of the "Jeziorsko" water reservoir.*

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For citation: Staniaszek-Kik M., Woziwoda B. (2011): Participation of bryophytes in forest and shrub communities in the antropogenically degraded Ługi peat bog area (Central Poland). Rocz. AR Pozn. 390, Bot. Stec. 15: 91-104.