SOLIGENOUS WETLANDS OF NORTH-WESTERN POLAND AS AN ENVIRONMENT FOR ENDANGERED MIRE SPECIES

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(Received: June 4, 2001. Accepted: November 5, 2001)

ABSTRACT

Environmental conditions and the occurrence of protected and rare species have been studied in 18 groundwater-fed wetland complexes in north-western Poland. The plant cover of studied objects consisted of 81 syntaxa of water-, spring-, rush and sedge-, mire-, meadow-, tall-forb-, willow carr- and alderwood communities, as well as of 4 syntaxa of the mesophytic forests. Their microhabitat differentiation has been discussed. The expression of environmental conditions in the groundwater-fed communities has been analysed on the basis of Ellenberg's indicator values and the occurrence of protected and rare species. A significant negative correlation has been found between the occurrence of rare species and the trophy index. The special position of the mesotrophic rich fen communities, concerning their role in preservation of a large number of endangered species, as well as of rare plant communities is emphasized.

KEY WORDS: soligenous wetlands, vegetation, environmental factors, endangered plant species.

INTRODUCTION

Wetlands supplied with groundwater, among them the so-called soligenous mires, are frequently found in young post-glacial areas of north-western Poland. According to their stratigraphic and landscape ecological properties soligenous mires can be classified as percolating mires (Kulczyński 1949; Jasnowski 1962; Żurek 1968; Succow 1988) and spring mires, divided further into cupola mires and hanging mires (Hess v. Wichdorf and Range 1906; Steffen 1922, 1931; Żurek 1993; Tobolski 2000; Wolejko 2001).

Several past and present attempts to drain and utilise soligenous wetlands have brought them on the verge of extinction (Wolejko 1996; Łachacz 2000). Earlier studies have revealed the importance of these ecosystems for the survival of rare, endangered and protected plant species, as well as, of interesting and often rare plant communities (Herbich and Stasiak 1971; Jasnowski 1975; Herbich and Górski 1993; Kępczyński and Załuski 1987; Herbich 1994; Wolejko 2000a). It has been recognised that the successful protection of the biotic components of soligenous wetlands depends, in a major part, on preservation of their specific habitat conditions (Grootjans and van Diggelen 1995).

The aim of this study is to present the differentiation of plant communities and their typical habitats found within groundwater-fed wetland complexes in north-western

Poland. As the investigated sites are habitats for endangered and protected species of bryophytes and vascular plants, the species occurrence is analysed in relation to selected environmental variables. Some light is to be shed also on the hydro-ecological processes governing the development and functioning of groundwater-fed wetlands, which therefore play the most important role in enabling the survival of their valuable biotic components.

MATERIALS AND METHODS

Study area

The study objects were 18 valley wetland complexes consisting entirely, or in major part, of groundwater-fed ecosystems (Fig. 1). Each wetland complex consists of a number of individual sites. The groundwater influence has always been manifested within the sites in form of springs, outflows or seepage.

The earlier stratigraphic and hydrological studies (Wolejko 1991, 2000a, 2001; Wolejko et al. 1994, 2001) have revealed that the majority of the investigated wetland complexes consist of various types of soligenous mires. This includes percolating mires and spring mires at different stages of development, among which mires supplied spatially (*sensu* Okruszko 1982 and Dembek 1993) are the most common. Their water supply is confined mostly by

Fig. 1. Location of investigated soligenous wetland complexes in relation to hydrology and geographical division of north-western Poland. 1 – locations, 2 – geographic mesoregions (after Kondracki 2000), Bob – Bobolice, DPN – Drawa National Park, DS – Diabli Skok Reserve and Rurzyca River Valley, Grz – Grzmiąca, Ila – Ilanka River Valley, Kla – Klasztorne Reserve, Lub – Lubogószcz, LuD – Lubiechów Dolny Reserve, ML – Młyńskie Lasy, Nos – Nosowo, Pli – Pliszka River Valley, Plo – Płonia River Valley, Raj – Rajsko, Ślu – Ślutowo, Sto – Storkowo, T – Tuczno, Wie – Wielgoszcz, WL – Wielin Reserve.

impermeable gyttia layers and clay deposits, sometimes generating a considerable water pressure. The groundwater can reach the surface through the „hydrological windows” – the mineral islands within mires, or at the upper margins (at the connection with the mineral grounds) where peat layers are thin.

The erosion process played an important role in modifying the spatial relation between mire components of the complexes. As a result, several sites have lost their peat-accumulating properties and have been transformed into erosive systems. These sites consist of different types of springs and associated water courses. Usually some remainders of previous mires are present close to the springs, and undergo secondary modifications due to influence of spring waters and their biota.

Typical habitat types found within eroding parts of the studied objects were sandy flats permanently covered by shallow layer of water, which end up in small spring outflows. Fallen trees, branches, stones and broken travertine blocks, sprinkled with spring water are forming microhabitats, occupied mostly by bryophytes. Sometimes deeper erosion „wells” are formed, some of them attaining a considerable depths. Peculiar microhabitats are deeply submerged roots of trees, colonised by rare species of freshwater red algae (Wolejko et al. 1994).

The studied sites are situated within young glacial landscapes of north-western Poland. The relief of the region has been formed mainly during a deglaciation period, at the end of the pleistocene and at the beginning of the Holocene. Both the accumulative and the erosive forces of

the melt-out waters had contributed to the formation of the landscape. The northern part of the area, covering a western part of the Western Pomerania region, correspond to the Pomeranian phase of the Baltic glaciation. The south-western fragment, covering a western part of the Lubusian region, represents an older, Poznan stage of the same glaciation (Kondracki 2000).

Methods

The majority of data were collected during the years 1990-1999 on a network of 46 transects (with a total length of 11 318 m) set in the valleys. Sampling points were selected on transects subjectively, according to physiognomical change in vegetation and in hydro-topographical structure of the area. In the majority of points piezometers were installed (PVC, 18 mm diameter). The tubes were emptied one day before sampling in order to allow for refilling with fresh groundwater. In selected points groundwater and surface water samples were taken. The samples were taken and stored in polyethylene bottles. Their pH and electrical conductivity were measured in field. All the samples were stored for 8 days at 4°C in a dark room. In the laboratory the samples were separated into two parts.

50 ml was brought to pH = 2 by addition of 2.5 ml 4% HCl. Cation contents (Ca²⁺, Mg²⁺, Na⁺, K⁺, Fe_i) were measured in this sample using atomic absorption spectrometry (AAS). CO₂ and HCO₃⁻ were measured by titration methods. Cl⁻ and SO₄²⁻ were measured with an auto-analyzer (Skalar). To check the reliability of the analyses, the charge balance as well as the electrical conductivity (EC₂₅) were computed. Unreliable analyses (deviation in the charge balance of more than 10% or a difference in computed versus measured EC₂₅ of more than 15%) were not used.

Vegetation has been described on the basis of over 1000 phytosociological records carried out by Braun-Blanquet's method (Braun-Blanquet 1964). The original vegetation tables are included in a series of earlier publications (Wojtko 2000b-f). The selected relevees were analysed by Ellenberg's indicator species method (Ellenberg et al. 1992). Indicator values for reaction (R) and fertility (N) were calculated. Altogether 418 relevees were used in the calculations. The average values were calculated for each syntaxonomic unit, and later used for statistical analyses. Mesophytic forest communities (*Fagion* and *Carpinion* Alliances), forming an important structural part of analysed wetland complexes, but not sup-

TABLE 1. Chemical analyses of water supplying spring complexes in different landscapes of north-western Poland.

Area code	Object	Number of samples	Hydrochemical parametre								
			pH	EC ₂₅ [µS/cm]	HCO ₃ [mg/l]	SO ₄ [mg/l]	Cl [mg/l]	Ca [mg/l]	Mg [mg/l]	Na [mg/l]	K [mg/l]
Groundwater – older outwash plain											
Pli	Kosobudki I	5	6.80	432.80	266.40	4.04	7.13	86.40	0.29	5.03	0.85
Pli	Kosobudki IIA, B	6	6.83	354.80	188.55	12.68	6.82	66.31	0.17	4.06	1.56
Ila	Ilanka 1	5	6.94	373.40	222.31	8.25	7.01	67.89	0.93	7.27	1.85
Ila	Ilanka 2	5	6.73	431.40	264.82	2.54	8.65	72.21	1.77	14.57	1.10
Ila	Ilanka 12	5	6.99	447.00	279.70	4.44	6.37	72.08	1.98	13.45	4.75
mean			6.86	407.88	244.36	6.39	7.20	72.98	1.03	8.88	2.02
standard deviation			0.11	40.96	37.93	4.10	0.86	7.94	0.83	4.85	1.57
Groundwater – younger outwash plain											
DS	Diabli Skok	5	7.02	399.60	216.92	8.97	5.90	65.82	4.09	5.16	0.51
DS	Krapsko Średnie	7	7.27	367.57	228.49	5.67	6.06	66.29	4.73	5.37	0.80
DPN	Miradz	4	6.76	391.75	223.09	19.90	12.30	79.55	0.64	3.20	0.63
DPN	Kłocie Ostrowieckie	3	6.49	446.66	137.45	8.89	19.41	86.62	1.03	3.27	0.41
DPN	Cieszynka	3	6.45	392.67	122.55	7.03	21.44	90.58	0.43	2.39	0.97
mean			6.80	399.65	185.70	10.09	13.02	77.77	2.18	3.88	0.66
standard deviation			0.35	28.94	51.28	5.65	7.27	11.4	2.06	1.31	0.22
Groundwater – marginal moraine											
ML	Młyńskie Lasy	11	6.97	446.36	259.72	9.92	11.84	59.43	7.20	7.60	10.22
Surface water – open springs											
DPN	Miradz	1	7.38	291.00	179.65	3.61	8.52	55.73	0.84	3.16	0.56
Stu	Recz	1	7.17	–	–	5.55	3.57	57.83	8.38	6.49	1.56
Plo	Źródła Płoni	1	7.41	–	–	52.97	13.03	78.04	8.05	5.92	0.99
Plo	Grądowa Dolina	1	7.60	–	–	30.30	21.94	97.25	10.17	7.01	1.27
Raj	Rajsko	1	7.59	–	–	58.06	29.77	105.32	8.21	9.12	0.49
ML	Młyńskie Lasy I	1	7.80	341.00	–	38.61	6.40	69.79	9.57	4.03	1.05
ML	Młyńskie Lasy II	1	7.33	325.00	–	33.97	9.48	66.41	7.77	4.26	0.94
mean			7.47	319.00		31.87	13.24	75.77	7.57	5.71	0.98
standard deviation			0.21	25.11		21.11	9.36	19.09	3.09	2.06	0.37

TABLE 2. Phytosociological classification and selected Ellenberg indices of plant communities of spring complexes in north-western Poland.

Code	Syntaxonomic unit	No of analysed records	Rare species index	Ellenberg index	
				Average R	Average N
	Independent bryophytic communities				
1	Cl. <i>Fontinaletea antipyreticae</i> v. Hübschmann 1957 O. <i>Leptodicyetalia riparii</i> Philippi 1956 All. <i>Rhynchostegion riparioidis</i> Waldheim 1944 <i>Rhynchostegietum riparioides</i> Gams 1927 All. <i>Brachythecion rivularis</i> Hertel 1974	6	5	6.47	6.00
2	<i>Brachythecietum rivularis</i> Herzog 1943	3	0	6.14	x
3	<i>Trichocoleetum tomentellae</i> Herzog 1943	3	0	5.95	x
4	Comm. <i>Preissia quadrata</i>	3	0	6.93	6.17
5	Comm. <i>Polytrichum formosum</i> – <i>Plagiochila asplenioides</i>	2	0	3.34	x
	Regeneration stage				
6	Comm. <i>Philonotis</i> – <i>Sagina</i>	1	0	4.31	3.85
	Spring vegetation				
7	Cl. <i>Montio-Cardaminetea</i> Br.-Bl. et R. Tx. 1943 O. <i>Montio-Cardaminetalia</i> Pawl. 1928 All. <i>Cratoneurion commutati</i> Koch 1928 <i>Cratoneuro filicini-Lemnetum trisulcae</i> Wol. 1991	7	3	6.31	5.01
8	<i>Cratoneureto filicinae-Cardaminetum</i> Maas 1959	7	2	6.15	5.00
9	Comm. <i>Pellia endiviaefolia</i>	11	2	7.18	4.86
10	Comm. <i>Cratoneuron commutatum</i> O. <i>Cardamino-Chrysosplenietalia</i> Hinterlang 1992 All. <i>Caricion remotae</i> Kästner 1940	10	3	6.67	3.94
11	<i>Pellieto-Conocephaletum</i> Maas 1959, facies <i>Conocephalum conicum</i>	7	1	6.01	5.94
12	<i>Cardamineto-Chrysosplenietum alternifolii</i> Maas 1959	6	3	6.12	5.80
	Rush and sedge vegetation				
13	Cl. <i>Phragmitetea</i> Tx. et Prsg. 1942 O. <i>Phragmitetalia</i> Koch 1926 All. <i>Phragmition</i> Koch 1926 <i>Glycerietum maximae</i> Hueck 1931	6	0	6.78	6.52
14	<i>Phragmitetum communis</i> (Gams 1927) Schmale 1939	6	2	6.82	5.86
15	<i>Equisetum limosi</i> Steffen 1931	5	0	5.58	4.82
16	<i>Acoretum calami</i> Kobendza 1946 All. <i>Magnocaricion elatae</i> Koch 1926 <i>Phalaridetum arundinaceae</i> (Koch 1926 n.n.) Libb. 1931 <i>typicum</i>	3	0	6.09	6.08
17	<i>Phalaridetum arundinaceae</i> (Koch 1926 n.n.) Libb. 1931 <i>cardaminetosum</i>	7	0	6.49	6.09
18	Comm. <i>Carex riparia</i> – <i>Cardamine amara</i>	3	0	6.51	6.76
19	<i>Caricetum gracilis</i> (Graebn. et Hueck 1931) Tx. 1937	2	0	6.95	5.38
20	<i>Caricetum paniculatae</i> Wangerin 1916	6	2	5.75	4.58
21	<i>Cladietum marisci</i> (Allorge 1922) Zobr. 1935	10	6	6.52	5.09
22	<i>Cicuto-Caricetum pseudocyperi</i> de Boer 1942	2	5	6.30	5.50
23	<i>Iretum pseudocori</i> Eggler 1933	1	0	7.07	6.21
24	<i>Caricetum acutiformis</i> Sauer 1937 <i>typicum</i>	3	8	6.55	5.23
25	<i>Caricetum acutiformis</i> Sauer 1937 <i>typicum</i> facies <i>Equisetum fluviatile</i>	9	5	5.99	5.05
26	<i>Caricetum acutiformis</i> Sauer 1937 <i>typicum</i> facies <i>Equisetum palustre</i>	3	1	6.33	4.57
27	<i>Caricetum acutiformis</i> Sauer 1937 <i>thelypteridetosum</i>	4	3	6.34	4.33
28	<i>Caricetum paradoxae</i> R.Tx. 1937	5	0	5.90	4.84
29	<i>Caricetum rostratae</i> Rübel 1912	7	4	6.04	4.59
30	All. <i>Sparganio-Glycerion fluitantis</i> Br.-Bl. et Siss. in Boer 1942 <i>Cardamino-Beruletum erecti</i> Turonova 1985	4	0	5.14	4.58
31	<i>Glycerietum nemoralis-plicatae</i> Kopecky 1972 facies <i>Glyceria nemoralis</i>	2	0	7.12	5.29
32	Comm. <i>Glyceria declinata</i>	5	7	7.04	5.70
33	<i>Glycerietum fluitantis</i> Wilzek 1935 <i>typicum</i>	2	5	6.34	5.51
34	<i>Glycerietum fluitantis</i> Wilzek 1935 <i>cardaminetosum</i>	4	0	7.21	5.76
35		5	2	6.19	5.81
	Mire vegetation				
36	Cl. <i>Scheuchzerio-Caricetea fuscae</i> (Nordh. 1936) R.Tx. 1937 O. <i>Caricetalia fuscae</i> (Koch 1926) Nordh. 1936 em. Preis ap. Oberd. 1949 All. <i>Caricion lasiocarpae</i> et <i>Caricion nigrae</i> Koch 1926 em. Klika 1934 cf. <i>Peucedano-Caricetum lasiocarpae</i> Tx. 1937	2	0	3.71	2.94
37	cf. <i>Sphagno-Caricetum rostratae</i> Steff. 1931 em. Dierss. 1978	8	8	5.25	4.31
38	Comm. <i>Helodinium blandowii-Carex acutiformis</i>	5	5	5.39	4.58
39	<i>Caricetum diandrae</i> Osvald 1923 em. Jonas 1932 <i>typicum</i>	6	12	5.43	4.19

TABLE 2. cont.

Code	Syntaxonomic unit	No of analysed records	Rare species index	Ellenberg index	
				Average R	Average N
40	<i>Caricetum diandrae</i> Osvald 1923 em. Jonas 1932 <i>paludelletosum</i>	3	24	5.46	3.91
41	<i>Menyantho-Sphagnetum teretis</i> Waren 1926 em. Dierss. 1982 <i>typicum</i>	11	27	5.34	3.58
42	<i>Menyantho-Sphagnetum teretis</i> Waren 1926 em. Dierss. 1982 <i>typicum</i> facies <i>Homalothecium nitens</i>	7	25	5.72	3.89
43	<i>Caricetum nigrae</i> Br.-Bl. 1915	6	4	5.17	4.07
	O. <i>Caricetalia davallianae</i> Br.-Bl. 1949				
	All. <i>Caricion davallianae</i> Klika 1934				
44	<i>Eleocharitetum quinqueflorae</i> Lüdi 1921	3	39	5.73	3.90
45	cf. <i>Campylio-Caricetum dioicae</i> Osvald 1923 em. Dierssen 1982	6	17	5.32	3.81
	Meadow and tall forb vegetation				
	Cl. <i>Molinio-Arrhenatheretea</i> Tx. (1937) 1970				
	O. <i>Molinietalia</i> Koch 1926				
	All. <i>Calthion</i> R. Tx. 1936 em. Oberd. 1957				
46	<i>Polygono bistortae-Trollietum europaei</i> (Hundt 1964) Bal.-Tul. 1981 <i>typicum</i>	7	14	6.09	4.65
47	<i>Polygono bistortae-Trollietum europaei</i> (Hundt 1964) Bal.-Tul. 1981 <i>moliniotosum</i> Bal.-Tul. 1981	5	10	5.88	4.34
48	<i>Polygono bistortae-Trollietum europaei</i> (Hundt 1964) Bal.-Tul. 1981 <i>filipendulosum</i>	7	8	6.31	4.86
49	<i>Caricetum cespitosae</i> Steffen 1931 <i>typicum</i>	7	5	5.76	4.61
50	<i>Caricetum cespitosae</i> Steffen 1931 <i>phragmitetosum</i>	5	3	6.11	5.05
51	<i>Urtico-Phragmitetum</i> Succ. 1970	5	3	6.20	6.07
52	<i>Crepido-Juncetum subnodulosi</i> (Libb. 1932) Pass. 1964 <i>typicum</i>	8	8	6.76	4.48
53	<i>Crepido-Juncetum subnodulosi</i> (Libb. 1932) Pass. 1964 <i>thelypteridetosum</i>	5	10	6.36	4.89
54	<i>Cirsio-Polygonetum</i> R. Tx. 1951	6	1	6.12	5.03
55	<i>Epilobio-Juncetum effusi</i> Oberd. 1957	5	2	5.06	4.44
56	<i>Scirpetum sylvatici</i> Knapp 1946	8	1	5.57	4.99
57	<i>Equisetum palustris</i> Steffen 1931 <i>typicum</i> , typical facies	7	7	5.76	4.97
58	<i>Equisetum palustris</i> Steffen 1931 <i>typicum</i> facies <i>Angelica silvestris</i>	2	4	6.39	4.38
59	<i>Equisetum palustris</i> Steffen 1931 <i>typicum</i> facies <i>Carex rostrata</i>	4	2	5.52	4.37
60	Truncated communities of All. <i>Calthion</i>		5		
	All. <i>Alopecurion pratensis</i> Pass. 1964				
61	<i>Deschampsietum cespitosae</i> (Horvatić 1930) Grynia 1961	5	6	5.47	4.64
62	<i>Holcetum lanati</i> Issler 1936	6	5	5.33	4.21
63	Comm. <i>Anthriscus sylvestris</i>	4	1	6.46	6.69
	All. <i>Filipendulo-Petasition</i> Br.-Bl. 1947				
64	<i>Filipendulo-Geranietum</i> Koch 1926	7	2	6.49	5.25
65	Comm. <i>Calamagrostis canescens</i>	3	0	6.54	5.07
66	Tall forb meadow of <i>Petasites hybridus</i>	5	1	6.75	6.77
67	<i>Aegopodio-Petasitetum hybridii</i> R. Tx. 1949	6	2	6.82	7.72
	All. <i>Molinion</i> Koch 1926				
68	<i>Molinietum coeruleae</i> Koch 1926	8	8	5.90	4.24
69	Degraded form of cf. <i>Campylio-Caricetum dioicae</i>	4	21	6.00	3.46
	Forest and willow carr vegetation				
	Cl. <i>Alnetea glutinosae</i> Br.-Bl. et Tx. 1943				
	O. <i>Alnetalia glutinosae</i> Br.-Bl. et Tx. 1943				
	All. <i>Alnion glutinosae</i> (Malc. 1929) Meijer Drees 1936				
70	<i>Cardamino-Alnetum glutinosae</i> (Meijer-Drees 1936) Passarge 1968 <i>typicum</i>	5	6	5.88	5.20
71	<i>Cardamino-Alnetum glutinosae</i> (Meijer-Drees 1936) Passarge 1968 <i>typicum</i> var. <i>Equisetum fluviatile</i>	5	3	6.20	5.41
72	<i>Cardamino-Alnetum glutinosae</i> (Meijer-Drees 1936) Passarge 1968 <i>typicum</i> var. <i>Carex elongata</i>	5	16	5.58	4.94
73	<i>Cardamino-Alnetum glutinosae</i> (Meijer-Drees 1936) Passarge 1968 <i>typicum</i> var. <i>Carex cespitosa</i>	5	6	5.93	5.97
74	<i>Cardamino-Alnetum glutinosae</i> (Meijer-Drees 1936) Passarge 1968 <i>poetosum</i> <i>trivialis</i>	8	11	5.68	5.46
75	<i>Salicetum pentandro-cinereae</i> (Almq. 1929) Pass. 1961	6	7	5.94	5.07
76	<i>Symphyto-Irido-Alnetum</i> (Bodeaux 1955) Pass. 1968	2	3	6.77	5.74
	Cl. <i>Quercu-Fagetum</i> Br.-Bl. et Vlieg. 1937				
	O. <i>Fagetalia sylvaticae</i> Pawl. 1928				
	All. <i>Alno-Padion</i> Knapp. 1942 em. Medw.-Korn. ap. Mat. et Bor. 1957				
77	<i>Circae-Alnetum</i> Oberd. 1953 <i>typicum</i>	7	10	5.86	5.77
78	<i>Circae-Alnetum</i> Oberd. 1953 <i>typicum</i> var. <i>Mercurialis perennis</i>	6	13	6.30	6.17
79	<i>Circae-Alnetum</i> Oberd. 1953 <i>typicum</i> var. <i>Equisetum telmateia</i>	5	5	6.55	6.25
80	<i>Circae-Alnetum</i> Oberd. 1953 <i>typicum</i> var. <i>Equisetum hyemale</i>	2	3	6.57	6.15
81	Comm. <i>Alnus incana</i>	6	4	6.41	6.05
	All. <i>Carpinion betuli</i> Oberd. 1953				
82	<i>Galio silvatici-Carpinetum</i> Oberd. 1957	7	15	n.a.	n.a.
83	<i>Stellario-Carpinetum</i> Oberd. 1953	11	19	n.a.	n.a.
	All. <i>Fagion</i> Tx. ex Diem. 1936				
	SAll. <i>Eu-Fagion</i> Oberd. 1957 em. R.Tx. 1960				
84	<i>Melico-Fagetum</i> Lohm. ap. Seibert 1954	4	13	n.a.	n.a.
	SAll. <i>Luzulo-Fagion</i> Lohm. et R.Tx. 1954				
85	<i>Luzulo pilosae-Fagetum</i> Mat. 1973	14	8	n.a.	n.a.

x – no data available; n.a. – not analysed

TABLE 3. Occurrence of protected and rare species in groundwater-fed plant communities in north-western Poland. Numbers (1-85) refer to community codes in Table 2.

Vegetation type	A	B					C										D										E								
Code of syntaxonomic unit	1	7	8	9	10	11	12	14	20	21	22	24	25	26	27	29	32	33	35	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
<i>Actaea spicata</i>																																			
<i>Amblystegium tenax</i>	V																																		
<i>Calamagrostis stricta</i>												IV	I						I															I	
<i>Cardamine flexuosa</i>																																			
<i>Carex diandra</i>											I			I							I	V	V	III	I	I	V	I							
<i>Carex dioica</i>																																			
<i>Carex disticha</i>																																			
<i>Carex lepidocarpa</i>																																			
<i>Carex limosa</i>																																			
<i>Cladium mariscus</i>																																			
<i>Conium maculatum</i>																																			
<i>Convallaria majalis</i>																																			
<i>Dactylorhiza incarnata</i>																																			I
<i>Dactylorhiza maculata</i>																																			
<i>Dactylorhiza majalis</i>																																			
<i>Daphne mezereum</i>																																			
<i>Dentaria bulbifera</i>																																			
<i>Digitalis grandiflora</i>																																			
<i>Drosera rotundifolia</i>																																			
<i>Dryopteris cristata</i>																																			
<i>Eleocharis quinqueflora</i>																																			
<i>Epilobium obscurum</i>																																			
<i>Epipactis palustris</i>																																			
<i>Equisetum telmateia</i>																																			
<i>Eriophorum latifolium</i>																																			
<i>Festuca altissima</i>																																			
<i>Frangula alnus</i>																																			
<i>Galium odoratum</i>																																			
<i>Glyceria declinata</i>																																			
<i>Glyceria nemoralis</i>																																			
<i>Hedera helix</i>																																			
<i>Helodium blandowii</i>																																			
<i>Hierochloe odorata</i>																																			
<i>Homalothecium nitens</i>																																			
<i>Juncus subnodulosus</i>																																			
<i>Listera ovata</i>																																			
<i>Melandrium rubrum</i>																																			
<i>Ononis repens</i>																																			
<i>Ophioglossum vulgatum</i>																																			
<i>Oxycoccus palustris</i>																																			
<i>Paludella squarrosa</i>																																			
<i>Platanthera bifolia</i>																																			
<i>Polemonium coeruleum</i>																																			
<i>Polypodium vulgare</i>																																			
<i>Primula veris</i>																																			
<i>Ribes nigrum</i>																																			
<i>Rumex aquaticus</i>																																			
<i>Rumex sanguineus</i>																																			
<i>Sparganium minimum</i>																																			
<i>Stellaria uliginosa</i>																																			
<i>Trollius europaeus</i>																																			
<i>Utricularia intermedia</i>																																			
<i>Utricularia minor</i>																																			
<i>Valeriana dioica</i>																																			
<i>Valeriana sambucifolia</i>																																			
<i>Viburnum opulus</i>																																			
<i>Viola epipsila</i>																																			
<i>Viola mirabilis</i>																																			

A – Independent bryophytic communities; B – Spring vegetation; C – Rush and sedge vegetation; D – Mire vegetation;

plied directly with groundwater, were excluded from calculations.

The relative spatial importance of each elementary syntaxon has been evaluated, as well as their degree of rarity (Knapp et al. 1986; Brzeg and Wojterska 1996).

A floristic list was composed, which was exclusively based on relevees representing groundwater-fed plant communities. Nomenclature follows Mirek et al. (1995) for vascular plants, Corley et al. (1981) for mosses, and Frahm and Frey (1983) for hepatics. The protection status of species was adopted after Zarzycki et al. (1992) and Żukowski and Jackowiak (1995). Occurrences of rare and endangered species were obtained from constancy values, derived from phytosociological tables (Wojtko 2000b-f). The constancy values were summarised for each syntaxon, and the sums were used as the „rare species index” (RSI).

Normality of the variables (R, N and RSI) was tested by means of the Kolmogorow-Smirnow and Lilliefors tests. The distribution of the RSI did not meet the condition of normality. For that reason the dependance of RSI and N was analysed by the non-parametric Spearman test (R_s). The dependence of N and R was tested by means of Pearson correlation coefficient (R) and by the linear regression.

RESULTS

Water chemistry

The results of hydrochemical analysis, presented in Table 1, show a relatively small variation in the groundwaters influencing the investigated spring complexes. All water samples represent a fresh water type, calcareous-carbonate subtype (Stuyfzand 1986). The water is always calcareous due to dissolution in the subsoil of minerals containing high amounts of calcium (for example calcite). Judging from the high degree of saturation with ions, the water has spent considerable time in the water-bearing strata. This characteristic is reflected also in the relatively high values of electrical conductivity (EC). There is little difference between waters appearing in outwash plain and morainic areas. Surface water has a slightly higher pH than the groundwater obtained from the same sites.

Vegetation

The investigated spring complexes harbour in total 85 syntaxa of various rank (associations, sub-associations, variants and facies) representing communities of independent bryophyte, spring, rush and sedge, mire, meadow and tall forb, alderwood and willow carr, as well as mesophytic forest vegetation (Table 2). Original relevees, synoptic phytosociological tables and the syntaxonomic discussion has been presented in a series of earlier publications (Wojtko 2000b-f).

The community list contains a number of communities rare and disappearing in the region (Knapp et al. 1986; Brzeg and Wojterska 1996). Taking into consideration the existence of specific spring-related subassociations, variants and facies of otherwise common plant associations, it can be estimated that about 60% of all plant communities found in the studied soligenous wetlands represent rare and endangered syntaxa. Detailed distribution data are given in Wojtko (2000a). It is worthy of notice, that all brown

moss-small sedge communities are endangered. Some of the tall sedge, meadow and tall forb communities, now recorded as endangered, have been relatively common within the region, for example *Caricetum gracilis*, *Caricetum paradoxae*, *Cirsio-Polygonetum*, *Scirpetum sylvatici* or *Filipendulo-Geranium* (Jasnowski 1962). The alderwood *Circaeo-Alnetum*, not specified on the red lists of communities (e.g. Brzeg and Wojterska 1996), has indeed been observed as increasing of its area on expanse of other phytocoenoses. However, several lower syntaxa of this association are much rarer, such as the facies with *Equisetum telmateia* and with *Equisetum hyemale*.

Occurrence of rare species

The vascular and moss flora of the studied objects consists of 502 species, including 408 species of vascular plants, 79 mosses and 15 hepatics (Wojtko 2000a). Among them are 58 species of plants protected by law, threatened and listed on national and regional „Red Lists” (Zarzycki et al. 1992; Żukowski and Jackowiak 1995). Their occurrence within particular syntaxonomic units is presented in Table 3.

Analysis of Ellenberg indices

The Ellenberg indices calculated for investigated plant communities (Table 2) reveal a range of environmental conditions with respect to substrate reaction (R) and fertility (N). The statistical analysis has shown that there is a positive correlation between the two parameters (Fig. 2). A clear clustering of community groups is visible. The lower left corner of the graph is occupied by the mesotrophic rich fen communities (*Caricetalia fuscae*) with relatively low pH indices. In cluster I the group of rich fen communities is accompanied by communities of abandoned meadows, classified within *Alopecurion* Alliance, as well as by few communities of *Calthion*, such as *Epilobio-Juncetum effusi* and a facies with *Carex rostrata* of *Equisetum palustris*. The tall sedge association *Caricetum rostratae* and a *Phragmition* community *Equisetum limosi* also belong to the same cluster.

The extreme position with respect of low trophy and reaction is occupied by *Peucedano-Caricetum lasiocarpae*. The extremely low values of both parameters in this community are probably a result of the dominance of *Sphagna* and could be a sign of a localised but rapid transition into a poor fen, resulting from a change from groundwater to rain water supply. The position of the peculiar *Philonotis-Sagina* community, developing in spring mires in places disturbed by animals (Wojtko 2000b) still needs explanation, based on further synecological research.

Only two plant associations are displaying mesotrophic and highly calcareous conditions, forming the cluster II. These are the spring community of *Cratoneuron commutatum* and a wet meadow association *Crepido-Juncetum subnodulosi* typicum. Both are renowned for the occurrence of species indicating calcareous conditions, and there is an on-going discussion concerning their syntaxonomic position (comp. Wojtko 2000b and d).

Cluster III occupies a central position in respect to the analysed parameters. It is composed of the majority of spring communities (*Montio-Cardaminetia* Class), as well as of the most of meadow (*Calthion*) and tall sedge (*Magnocaricion*) communities. Within this cluster slightly

Fig. 2. Relation of Ellenberg's indicators of fertility (N) and reaction (R) in plant communities supplied with groundwater. Numbers in the graph (1-81) refer to community codes in Table 2. Community clusters (I-V) are explained in the text.

higher fertility values are displayed by swampy alderwoods (*Alnion*).

Cluster IV is formed by a small group of communities displaying conditions of higher trophic and extremely high pH. All of these communities are related to flowing water: a spring community of *Pellia endiviaefolia*, most communities of *Sparganio-Glycerion* Alliance and some tall sedge communities.

Plant associations representing the highest trophic status are the most diversified syntaxonomically and covering the widest reaction range. To this group (cluster V) belong drying-out alderwoods (*Alno-Padion*), abandoned meadows with tall forb vegetation (*Filipendulo-Petasition*), some of reed and tall sedge communities (*Phragmition* and *Magnocaricion*) and a few of spring communities. An extreme position, representing the highly eutrophic conditions, is occupied by a tall forb community *Aegopodio-Petasitetum hybridii*.

The special role of mesotrophic conditions for the existence of rare and protected species is illustrated in Fig. 3. The peak occurrences of species are found within Ellenberg's fertility index values (N) contained between 3.5 and 4.5. These are conditions typical of percolating mires (Table 3), with undisturbed, peat-forming vegetation. Fig. 3 presents also a significant negative correlation between the fertility index and the abundance of rare and protected species (RSI).

DISCUSSION

The ionic concentrations of calcium exceeding 70 mg/l, and of magnesium exceeding 10 mg/l are found in mire waters of extremely rich and rich fens (Vaughan and Bellamy 1984; van Wirdum 1991; Kooijman 1993). Such values are encountered in several analysed water samples, especially from sites situated within the morainic land-

scapes of Western Pomerania. However, rich fen vegetation is generally very rare in the investigated spring complexes and at present occupies only a very small area. This points to other factors, modifying the hydrochemical template.

Wolejko (2001) presented a hypothetical model on the formation of the present-day groundwater-fed ecosystems, in which two phases can be distinguished: the accumulation phase and the erosion phase. The accumulation phase usually includes the formation of a percolation mire. Peat forming cupola- or hanging-type spring mire are much more rare. A growing percolating mire is characterised by a good hydraulic conductivity of its active surface layer, comparable to an acrotelm in bogs (Ingram 1967). This hydrologically active surface layer is formed by a peat-forming vegetation, dominated by brown mosses and sedges. Secured by continuous supply of calcium-rich groundwater this vegetation retains its mesotrophic conditions.

Ecological conditions enabling the development and continuous existence of mesotrophic mires are now in focus of scientific research in Western Europe, due to their almost complete disappearance and social pressure for their restoration (Wheeler 1988; Wassen 1990; Wassen et al. 1996; Grootjans and van Diggelen 1995; Pfadenhauer and Grootjans 1999). This is also true in respect to calcareous mossy fens, forming an initial phase in the development of percolating mires (van Wirdum 1991; Kooijman 1993). In extreme cases restoration attempts utilise completely artificial water sources, such as transportation canals (Boeye et al. 1996), or whole mires are transplanted (Klötzli 1987) and pumps are sometimes used to supply them with water.

The successional changes in calcium-rich mesotrophic mires are, in their major part, related to hydrological changes, mainly the decrease in supply of calcareous ground water to vegetation, causing acidification and eutrophication (Grootjans 1985). If water levels remain

Fig. 3. Relationship between abundance of rare species and fertility (Ellenberg's N index) in groundwater-fed plant communities in North-western Poland.

relatively high, the main factor is a change in chemical composition of mire waters resulting from the change in proportion of ground-, rain- and surface waters. The natural tendency in mire ecosystems to acidify derives from release of protons during decay and ionic exchange in plants and soil (Giller and Wheeler 1988; Kooijman 1993). As long as enough calcareous water reaches the mire's surface, it is protected from acidification.

During the course of succession related to acidification, the typical mosses of calcareous fens, such as *Scorpidium* spp. and *Drepanocladus* spp. are substituted by sphagna, for example *Sph. subnitens* (Kooijman 1993; van Wirdum 1994). At the transition stage to ombrotrophic mires within the sphagnum carpet, such species as *Carex lasiocarpa*, *C. rostrata*, *C. limosa* and *Cladium mariscus* may still be present.

During eutrophication the typical mosses of calcareous fens are substituted by ubiquitous mosses such as *Calliergonella cuspidata* and *Calliergon cordifolium*. In the case of common occurrence of acidification and eutrophication the first bog stages are dominated by *Sph. squarrosum* preceding the development of *Sph. fallax* (Kooijman 1993).

In the studied objects all the above mentioned stages are observed within small patches of still existing percolating mires. In particular conditions of the studied regions of North-western Poland the nutrient load in exfiltrating groundwater is relatively low, especially in outwash-plain areas. More nutrients are released by internal eutrophication (for example by mineralisation of peat). This points to negative changes in mires, resulting mainly from partial desiccation, due to drainage.

The erosion phase in soligenous mire complexes is most likely induced by a drainage proceeding step-wise upstream the river valley, not necessarily as a result of a conscious human activity. The hypothetical mechanisms, leading to the change of the phases, can be reconstructed

from palaeo-ecological records (Wojewko et al. 1994, 2001). It can be summarised as the lowering of the erosion base and the initiation of backward erosion, which produces partial drainage of the percolating part of the mire. This leads to shrinkage of peat which than can not contain the whole volume of the incoming groundwater, and eventually, to the formation of the surfacial outflows on the sloping mire surface, thus further enhancing the drainage and erosion processes. Due to drainage the surface peat layer undergoes rapid mineralisation resulting in increase in availability of nutrients to plants. Under such conditions eutrophic wetland vegetation develops that does not produce peat. The luxurious growth of herb layer is impeded only by inadequate light availability and/or the erosive force of the spring water outflows (Grootjans et al. 1999).

Intensification of outflow always results in initiation of erosion, both of the mire itself and the surrounding mineral slopes. With time the relief changes, which may lead to a decrease in outflow and to hydrological isolation of certain areas. In such inactive places secondary accumulation of organic matter is possible – and initial stage of formation of humus cupolas. At the beginning, when some protection by cold spring water still exists, the biomass decomposition and nutrient release are low. The second factor limiting fertility of such sites is the lack of light. This is the result of the typical position of eroding springs, developing usually at the bottom of deep gorges and erosion „circuses” and strongly shaded by trees growing on the slopes (Wojewko et al. 1994; Grootjans et al. 1999). Disappearance of limiting factors (by further desiccation and/or cutting down of trees) induces fast transformation of spring vegetation (*Montio-Cardaminetia* Class) into communities dominated by common nitrophytes (e.g. *Urtica dioica*).

Extremely difficult living conditions exist in typical spring habitats, tolerated only by a small group of spe-

cialised plant species (Grootjans et al. 1999). The set of conditions consists of high flow velocity, low nutrient content, and low water temperature throughout the year. The maximal flow velocities, reaching 1.8 m/s, were tolerated only by *Berula erecta*. Other species could only tolerate the following flow velocities: *Agrostis stolonifera* – 1.5 m/s; *Cardamine amara* – 1.2 m/s; *Veronica beccabunga* – 1.0 m/s; *Epilobium palustre* – 0.9 m/s; *Mentha aquatica* 0.9 m/s; *Lemna trisulca* – 0.8 m/s. With such flow velocities the majority of organic particles, which is formed due to decomposition of plant remnants growing in springs or supplied as fall-out (leaves, branches) from outside, is quickly washed away. The apparent discrepancy between low fertility of springs and the occurrence of plant species, known as indicators of eutrophic conditions, e.g. *Glyceria fluitans*, *Agrostis stolonifera*, *Lemna* spp. (Ellenberg 1992), can be explained by the ability of these species to obtain considerable nutrient load per time unit from poor water, but of high flow velocity (Damman 1986; van Diggelen et al. 1995).

The dynamic tendencies in semi-natural and secondary vegetation of groundwater-fed wetlands have been presented for example by Succow (1988) and Zechmeister and Steiner (1995). Numerous works are devoted to successional changes on abandoned meadows (e.g. Dubiel 1988; Falińska 1989; Barabasz 1994; Kucharski 1997; Herlich 1998b). The strong tendency for succession of such biotopes to forest communities – mainly different types of alderwood – have been observed also in this study. The mass occurrence of this problem is probably a result of disturbances in hydrological conditions (which is a common case in most of Polish lowland valleys). In this respect, the potential of initiating successional changes towards mesotrophic fens deserves particular attention. Further studies are needed to establish a set of necessary environmental conditions enabling such succession, and thus successful regeneration of the ecosystem. These studies should aim at the development of management methods counteracting the eutrofication and acidification effects. Among possible solutions there are both the traditional agricultural activities, such as mowing and grazing, as well as more drastic restoration measures, including top soil removal (e.g. Grootjans and van Diggelen 1995).

CONCLUSIONS

Almost all studied wetland complexes are supplied by clean, calcareous groundwater of chemical composition adequate for the formation of mesotrophic or even calcareous oligotrophic fens. However, at present, mires of such type cover only a minor portion of the studied areas. On the contrary, the majority of vegetation types display a high trophic status, indicated by high values of the Ellenberg fertility index. It is concluded, that factors other than hydrochemical conditions govern the distribution of the species and plant communities found in the studied objects.

A very high degree of habitat heterogeneity is an expression of dynamic transformations within the studied areas. Erosion and peat accumulation can coexist very close to each other in relatively small areas. Both processes are modified by a number of natural and anthropogenic factors,

also variable with time. The hydrology plays a key role in setting the direction of the habitat-forming processes.

The high differentiation of habitat conditions is reflected in the richness of plant associations and flora found in the studied objects. Communities with a lowest nutrient status usually harbour the largest number of endangered and protected species. The brown moss-small sedge communities, in particular, are the most important for the preservation of floristic rarities. Successful protection of these mesotrophic mires depends mostly on securing their hydrological properties and especially their regulation mechanisms in respect to nutrient availability.

The groundwater-fed wetlands are the areas with a very high value for nature protection, in spite of the widespread human impact in the past. This is shown on the level of species, phytocoenoses, biotopes and landscape elements. Thus, there is a need for elaboration of methods for their effective protection. These include both the passive protection, as well as a set of active management methods. Among them the restoration of traditional, extensive agricultural practices plays an important role.

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MOKRADŁA SOLIGENICZNE POLSKI PÓŁNOCNO-ZACHODNIEJ JAKO SIEDLISKA ZAGROŻONYCH ROŚLIN TORFOWISKOWYCH

STRESZCZENIE

W 18. kompleksach mokradłowych Polski północno-zachodniej, zasilanych wodami podziemnymi, rozpoznano zróżnicowanie roślinności i przeanalizowano występowanie chronionych, rzadkich i zagrożonych gatunków roślin. Stwierdzono występowanie 81 elementarnych syntaksonów zasilanych bezpośrednio wodami podziemnymi i 4. mezofilnych zbiorowisk leśnych. Określono ich warunki siedliskowe. Przy użyciu liczb wskaźnikowych Ellenberga przeanalizowano wybrane parametry siedliska zbiorowisk zasilanych wodami podziemnymi i ich związek z występowaniem gatunków chronionych i rzadkich. Stwierdza się istotny spadek liczby tych gatunków, skorelowany ze wzrostem żyzności siedliska. Podkreślona została szczególnie istotna rola mezotroficzných, torfo-twórczych mechowisk w zachowaniu licznych ginących gatunków i rzadkich zbiorowisk roślinnych.

SŁOWA KLUCZOWE: mokradła soligeniczne, roślinność, warunki siedliskowe, zagrożone gatunki roślin.