IMPACT OF HUMIC SUBSTANCES ON *SPHAGNUM DENTICULATUM* HABITATS

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ABSTRACT

In 10 softwater lakes of NW Poland (5 very acid and 5 slightly acid) three kinds of *Sphagnum denticulatum* Bridel [= *S. auriculatum* Schimper] habitats have been studied: oligohumic ($<2.0 \text{ mg C}_{\text{DHS}} \text{ dm}^{-3}$), α -mesohumic ($2.0\text{--}4.0 \text{ mg C}_{\text{DHS}} \text{ dm}^{-3}$) and β -mesohumic ($4.1\text{--}8.0 \text{ mg C}_{\text{DHS}} \text{ dm}^{-3}$). During habitats humification in very acid lakes some water and sediment characteristics, such as pH, conductivity, TDS, and calcium concentration are low and almost invariable, whereas variable are the colour and clearness of the water. In low-acidity lakes the values of habitat characteristics are higher and also nearly invariable. The optimum habitats for *S. denticulatum* are oligohumic ($<1.8 \text{ mg C}_{\text{DHS}} \text{ dm}^{-3}$), very acid (pH 4.0-4.4) sites found at depths from 4 to 8 m, where the species forms large and close carpets. In slightly acid lakes it is rare, grows at depths below 5 m and forms populations of very low density. In mesohumic habitats in both kinds of lakes *S. denticulatum* is a frequent species, but its populations are very thin there.

KEY WORDS: *Sphagnum denticulatum* Bridel, submerged aquatic habitat, humic substances.

INTRODUCTION

In softwater lakes with pH values ranging from very acid to slightly acid bryophytes are a significant component of the submerged vegetation. They usually occupy highly reduced habitats that are inaccessible to vascular plants. In such lakes they also grow in deep sites (Grahn 1977; Hendrey and Vertucci 1980; Roelofs 1983), because they withstand shade easily, are resistant to a high hydrostatic pressure (Hutchinson 1975; Smith 1982), and form mostly close, monospecific aggregations (Szmeja 1994a, b, c).

Like many other submerged peatmosses, *Sphagnum denticulatum* Bridel [= *S. auriculatum* Schimper] occurs in soft water with a low calcium concentration ($<6 \text{ mg Ca dm}^{-3}$). Optimum conditions for growth of this plant exist in acid habitats (pH 5.0-5.5), with a low conductivity and total hardness (Malme 1978; Thiebaut et al. 1998). It colonizes sediments rich in organic matter and strongly hydrated, where it forms close submerged lawns. In the Pomeranian Lakeland (NW Poland) this peatmoss grows in water with a calcium concentration ranging from 2.5 to 3.0 mg dm^{-3} (Szańkowski 1998).

The habitats of submerged aquatic plants, like those of terrestrial plants, show signs of a long-lasting anthropopressure. In the Pomeranian Lakeland one of the important factors is lake humification, that is, enrichment of lakes with allochthonous humic substances from peat bogs and bog forests that are being drained (Szmeja 1998).

If the humic substances introduced into a lake come from well hydrated peat bogs, the concentration of active

humic acids in the lake rises, and the water becomes acidified, coloured, and enriched with organic matter, but impoverished by the loss of mineral components. Many ions become blocked by chemically active humic acids, and are not available during the process of plant growth and development (Jackson and Hecky 1980; Stewart and Wetzel 1982; Guildford et al. 1987). However, if the humic substances introduced into a lake come from peat bogs that have been reclaimed, then there occurs an increase of concentration of mineral-humic complexes which cause acidification, coloration and enrichment of the water by releasing nitrogen and phosphorus compounds into it (Górniak 1996; Wojciechowski 1997). Such complexes have large molecular weights, and they sediment and quickly cover up the habitats of submerged plants.

The aim of the research was to study the physical and chemical characteristics of the habitats of *S. denticulatum* – a submerged bryophyte frequently found in softwater lakes of northern Europe. In view of the fairly common introduction into the lakes of Pomeranian Lakeland of allochthonous humic substances (Gos et al. 1998), it was intended to determine their effect on the habitats and population abundance of this plant.

METHODS

Investigations have been carried out in the years 1997-2000, in 10 lakes located in the Pomeranian Lakeland in north-western Poland (Fig. 1). For the research the follow-

Fig. 1. Distribution of the lakes under study:
1 – Wygoda, 2 – Pałsznik, 3 – Rąbówka, 4 – Wysoka, 5 – Salińskie, 6 – Łakie, 7 – Czarnik, 8 – Żubrowo, 9 – Piasek, 10 – Lej.

ing lake types have been selected: 5 very acid and 5 slightly acid, including 5 lakes with oligohumic habitats (<2.0 mg C_{DHS} dm⁻³), 2 α-mesohumic (2.0-4.0 mg C_{DHS} dm⁻³) and 3 β-mesohumic (4.1-8.0 mg C_{DHS} dm⁻³) ones. In each of the lakes *S. denticulatum* was present and occupied

habitats with specific levels of pH and humic substances (Table 1) derived from bogs that are being drained.

S. denticulatum habitats, like those of other submerged plants are multidimensional spaces consisting of sediment and the overlying water. The habitats were assessed on the basis of the characteristics of the sediment and the above-sediment water in sites where *S. denticulatum* was present. The following characteristics were taken into account: pH, redox, conductivity, TDS in sediment and in above-sediment water. Lake characteristics described during one summer stagnation contained surface water characteristics: DHS (dissolved humic substances), colour, pH, Secchi depth, Ca, N_{tot}, P_{tot}, Fe and Al.

In each lake a transect was established at right angles to the shore. Subsequently, in zones 1 m depth apart, down to the lower limit of plant occurrence, a frogman collected habitat samples (water and sediment), and 0.1 m² plant samples, 10 in each zone, at 2.5 m intervals. Plant samples were desiccated for 24 hours at 105°C and weighed. From each zone 0.5 dm³ of the sediment and 1 dm³ of the water immediately above it were collected. A total of 74 samples were collected, including 37 sediment samples.

DHS contents were calculated from the concentration of DOC (Górniak 1996). DOC content was determined from the absorbance of filtered samples at γ = 330 nm on a UV-VIS spectrophotometer (Moore 1985, 1987; Collier 1987; Górniak 1995). Water colour, concentration of calcium, nitrogen and phosphorus were determined according to the

TABLE 1. Hydrochemical characteristics of very acid and slightly acid lakes (*). Each result is an average from three measurements.

Lake types	Trait:	DHS	pH	Colour	Water	Ca	Fe	N _{tot}	P _{tot}	Al
	Lake	mgC/l		mgPt/l	Visibility m	mg/l	mg/l	mg/l	mg/l	mg/l
Oligohumic	Łakie*	1.2	6.89	10	4.0	6.3	0.25	1.06	0.19	0.02
	Piasek*	1.2	6.57	5	5.0	4.5	0.32	0.94	0.24	0.09
	Lej	0.6	4.27	0	7.0	1.4	0.07	0.70	0.01	0.18
	Rąbówka	0.6	3.90	2	6.5	1.4	0.08	0.58	0.14	0.03
	Wygoda	0.8	4.41	2	6.0	1.8	0.03	0.80	0.18	0.14
Mesohumic	α Pałsznik	2.3	4.91	13	3.5	2.8	0.12	1.86	0.09	0.04
	α Salińskie*	2.3	6.73	68	1.5	5.7	0.26	3.03	0.14	0.05
	β Wysoka*	4.5	5.80	60	1.6	5.0	0.28	3.23	0.19	0.04
	β Żubrowo	4.9	4.08	80	1.0	1.2	0.30	3.38	0.08	0.07
	β Czarnik*	4.3	6.67	44	1.6	6.1	0.23	2.84	0.14	0.04

TABLE 2. Physical and chemical traits of habitats in very acid lakes.

Trait		Water		Sediment	
		x±s.d.	min-max	x±s.d.	min-max
Oligohumic	pH	4.28±0.10	4.00-4.41	5.63±0.16	5.20-5.87
	Conductivity	38.5±4.9	33-46	42.3±7.1	31-53
	TDS	27±3	23-32	29±5	22-38
	Eh	334±33	275-365	-155±99	-285- -12
α-mesohumic	pH	4.78±0.23	4.63-5.12	5.76±0.09	5.64-5.83
	Conductivity	38.5±1.3	37-40	35.8±14.3	16-50
	TDS	27±1	26-28	25±10	11-35
	Eh	300±7	290-306	-199±17	-212- -175
β-mesohumic	pH	4.41±0.23	4.25-4.81	5.55±0.24	5.30-5.90
	Conductivity	45.0±2.9	40-47	30±18.7	16-51
	TDS	31±2	28-33	21±13	11-36
	Eh	367±18	339-383	-214±70	-267- -93

methods described in the papers of Golterman et al. (1969) and Hermanowicz et al. (1999). Aluminium and iron were determined with a spectrophotometer, conductivity and TDS by an LF-95/SET conductometer with a four-electrode TetraCon 96 system, and pH and redox potential – by a SET-1 pH-meter, with a combined EPH-11 electrode and a METTIER TOLEDO Pt 4808-57/120 electrode, respectively.

RESULTS

Very acid lakes

Oligohumic habitats

In very acid lakes (pH 3.9-4.4) the above-sediment water contains little DHS ($0.6\text{--}0.8\text{ mg C dm}^{-3}$), due to which it is colourless ($0\text{--}2\text{ mg Pt dm}^{-3}$), clear (visibility 6-7 m), strongly acid (pH 4.0-4.4), has a low conductivity ($33\text{--}46\text{ }\mu\text{S cm}^{-1}$) and calcium concentration ($1.4\text{--}1.8\text{ mg dm}^{-3}$). The water is barren because it contains little nitrogen ($0.58\text{--}0.80\text{ mg N}_{\text{tot.}}\text{ dm}^{-3}$) and phosphorus ($0.01\text{--}0.18\text{ mg P}_{\text{tot.}}\text{ dm}^{-3}$; Tables 1, 2).

The sediment has a pH level higher than that of the overlying water (pH 5.6 versus pH 4.3), higher conductivity ($42.3\text{ versus }38.5\text{ }\mu\text{S cm}^{-1}$) and TDS ($29\text{ versus }27\text{ mg dm}^{-3}$). In the sediment, reduction processes prevail, and in the above-sediment oxidation processes go on (Table 2).

Dominant in very acid oligohumic habitats is *Sphagnum denticulatum*, accompanied, especially to a depth of 3 m, by *Juncus bulbosus*, *Wurmstorfia exannulata*, *Sphagnum cuspidatum*, *S. fallax*, *Lobelia dortmanna* and *Isoetes lacustris* (Fig. 2). Below that depth almost all the submerged plant biomass is made up of *S. denticulatum* (Fig. 3).

α -mesohumic habitats

The water contains about $2.3\text{ mg C}_{\text{DHS}}\text{ dm}^{-3}$, that is twice as much as in the oligohumic habitats. It is therefore more coloured (13 mg Pt dm^{-3}) and less clear (visibility 3.5 m). Its reaction is also very acid (pH 4.6-5.1), conductivity ($37\text{--}40\text{ }\mu\text{S cm}^{-1}$) and TDS ($26\text{--}28\text{ mg dm}^{-3}$) are low, too, whereas the concentration of calcium is twice as high (2.8 mg dm^{-3} ; Table 2).

Sediment reaction (pH 5.8), conductivity ($35.8\text{ }\mu\text{S cm}^{-1}$) and TDS (25 mg dm^{-3}) are similar to those found in oligohumic habitats, but the ranges of variation of these traits are slightly wider (Table 2). Sedimental habitats differ from erosion-affected ones; the former have a much lower conductivity ($16\text{ }\mu\text{S cm}^{-1}$) and TDS (11 mg dm^{-3}). In the sediments of α -mesohumic habitats, as in those of oligohu-

Fig. 2. Plant biomass in oligohumic habitats of very acid lakes.

Fig. 3. *S. denticulatum* biomass distribution in the habitat types studied.

Fig. 4. Plant biomass in α -mesohumic habitats of very acid lakes.

mic habitats, reduction processes prevail, and in the water – oxidation processes (Table 2).

In the α -mesohumic habitats of very acid lakes the population density of *S. denticulatum* decreases rapidly, and its spatial organization becomes disturbed (Fig. 4). The plant does not form large aggregations but only small, thin clumps. Shallow habitats are occupied primarily by *Juncus bulbosus*, *Littorella uniflora* or *Isoetes lacustris*.

β -mesohumic habitats

β -mesohumic habitats have been formed by allochthonous humic substances which occur there in amounts of $4.9\text{ mg C}_{\text{DHS}}\text{ dm}^{-3}$. As a result, the above-sediment water has become less clear than in α -mesohumic habitats, and changed its colour from light-brown to brown (80 mg Pt dm^{-3}). Visibility in the water has dropped from about 3.5 m to as low as 1.0 m (Table 1), water pH from 4.8 to 4.4, and calcium concentration from 2.8 to 1.2 mg dm^{-3} , that is, by more than a half. There has occurred a slight increase of conductivity ($45.0\text{ }\mu\text{S cm}^{-1}$) and TDS (31 mg dm^{-3}), and a

Fig. 5. Plant biomass in β-mesohumic habitats of very acid lakes.

considerable increase in the concentration of iron (0.3 mg dm^{-3} ; 150% increment) and aluminium (0.07 mg dm^{-3} ; an increase by 75%).

The sediment is strongly acid (pH 5.6), its conductivity ($30.0 \mu\text{S cm}^{-1}$) and TDS (21 mg dm^{-3}) are small, similar to the values found for α-mesohumic habitats (Table 2). The range of variation of these traits in both habitat types is similar.

β-mesohumic habitats are occupied almost exclusively by bryophytes (*S. denticulatum*, *S. cuspidatum* and *Warnstorfia fluitans*), with *Isoetes lacustris* being the only vascular plant found there sporadically (Fig. 5). The dominant species in habitats of this kind is *S. denticulatum* whose proportion ranges from 50 to 75%, the amount of its biomass being small (Fig. 3).

Slightly acid lakes

Oligohumic habitats

In slightly acid lakes (pH 6.6-6.9) the water contains $1.2 \text{ mg C}_{\text{DHS}} \text{ dm}^{-3}$, is almost colourless ($5-10 \text{ mg Pt dm}^{-3}$) and clear (visibility 4-5 m). The above-bottom water has a pH 5.8-6.2, conductivity of $51 \text{ to } 67 \mu\text{S cm}^{-1}$ and TDS of $36 \text{ to } 47 \text{ mg dm}^{-3}$ (Table 3). The values of these characteristics are higher than those found for the oligohumic habitats of

very acid lakes. The greatest difference concerns the concentration of calcium ($4.5-6.3 \text{ mg dm}^{-3}$), nitrogen ($0.94-1.06 \text{ mg N}_{\text{tot}} \text{ dm}^{-3}$) and phosphorus ($0.19-0.24 \text{ mg P}_{\text{tot}} \text{ dm}^{-3}$).

The sediment is slightly acid (pH 6.1-6.5). Its pH is similar to that of the overlying water (pH 5.8-6.2). The redox of the sediment varies considerably (between -117 and +87). This trait varies in relationship to the depth, sediment structure and kind of dominant species. Conductivity ($59-87 \mu\text{S cm}^{-1}$) and TDS ($41-61 \text{ mg dm}^{-3}$) are much higher than found for the oligohumic habitats of very acid lakes ($31-53 \mu\text{S cm}^{-1}$, $22-38 \text{ mg dm}^{-3}$, respectively; Table 3).

In slightly acid lakes, the oligohumic habitats are occupied by vascular plants and bryophytes; the former are dominant in shallow (0-5 m), the latter in deep (5-12 m) sites. At depths below 5 m *S. denticulatum* grows in considerable dispersion. Other bryophytes present there include *Drepanocladus aduncus*, *D. tenuinervis*, *Fontinalis antipyretica* and *F. delecarlica* (Fig. 6).

α-mesohumic habitats

The water contains $2.3 \text{ mg C}_{\text{DHS}} \text{ dm}^{-3}$, that is, 60% more than in oligohumic habitats. It is therefore more coloured (68 mg Pt dm^{-3}) and less clear (visibility 1.5 m). The pH of the above-bottom water (pH 6.1-6.3), its conductivity ($53-60 \mu\text{S cm}^{-1}$), TDS ($37-42 \text{ mg dm}^{-3}$) and calcium concentration (5.7 mg dm^{-3}) are similar to those found in oligohumic habitats (Table 3).

The sediment is slightly acid (pH 6.1), its conductivity ($61.5 \mu\text{S cm}^{-1}$) and TDS (43 mg dm^{-3}) are similar to those recorded for oligohumic habitats, whereas the oxidation-reduction potential is exclusively negative (Table 2).

In slightly acid lakes, *S. denticulatum* grows in very high dispersion in both habitat types, and its biomass per unit area is low (Fig. 3). Shallow mineral habitat fragments are occupied by vascular plants, e.g.: *Juncus bulbosus*, *Littorella uniflora*, *Isoetes lacustris* and *I. echinospora*, while deeper ones (to 4 m) have been colonized by bryophytes (*Sphagnum denticulatum*, and *Fontinalis antipyretica*; Fig. 7).

β-mesohumic habitats

In comparison with the former habitats in slightly acid lakes, the water is richer in humic substances ($4.3-4.5 \text{ mg C}_{\text{DHS}} \text{ dm}^{-3}$), but its colour ($44-60 \text{ mg Pt dm}^{-3}$), and clear-

Fig. 6. Plant biomass in oligohumic habitats of slightly acid lakes.

TABLE 3. Traits of habitats in slightly acid lakes.

Trait				Water		Sediment	
				x±s.d.	min-max	x±s.d.	min-max
Oligohumic	pH			6.04±0.17	5.79-6.22	6.22±0.15	6.06-6.46
	Conductivity	[µS/cm]		54.6±7.0	51-67	68.4±11.1	59-87
	TDS	[mg/l]		39±5	36-47	48±8	41-61
	Eh	[mV]		272±14	252-289	-41±93	-117-87
α-mesohumic	pH			6.17±0.17	6.05-6.29	6.08±0.19	5.94-6.21
	Conductivity	[µS/cm]		56.5±4.9	53-60	61.5±4.9	58-65
	TDS	[mg/l]		39±3	37-42	43±3	41-45
	Eh	[mV]		275±46	242-308	-235±39	-263- -208
β-mesohumic	pH			6.72±0.05	6.68-6.75	6.33±0.23	6.16-6.49
	Conductivity	[µS/cm]		65.0±14.1	55-75	87.5±21.9	72-103
	TDS	[mg/l]		45±11	38-53	63±16	51-74
	Eh	[mV]		215±5	211-218	-245±12	-253- -236

Fig. 7. Plant biomass in α-mesohumic habitats of slightly acid lakes.

Fig. 8. Plant biomass in β-mesohumic habitats of slightly acid lakes.

ness (visibility 1.6 m) are fairly similar. The pH of the above-bottom water (6.7) is slightly higher than in α-mesohumic habitats (pH 6.2), and so are the conductivity (65 versus 56.5 µS cm⁻¹) and TDS (45 versus 39 mg dm⁻³). In contrast to the habitats of very acid lakes, the water is in the whole range of humic habitats richer in calcium (4.5-6.3 mg dm⁻³), and iron (0.23-0.32 mg dm⁻³), but poorer in aluminium (0.02-0.09 mg dm⁻³; Table 1).

The sediment is in a reduced state (redox potential -253 to -236), slightly acid (pH 6.3), that is, similar to that found in α-mesohumic habitats, while its conductivity (87.5 µS cm⁻¹), and TDS (63 mg dm⁻³) are clearly higher (Table 3).

In slightly acid lakes, shallow zones of β-mesohumic habitats are occupied almost exclusively by vascular plants (*Littorella uniflora*, *Lobelia dortmanna*, *Isoetes lacustris*, *Elodea canadensis*, *Myrophyllum alterniflorum* and *Potamogeton* sp.), while deep ones – by bryophytes, mainly dispersed *S. denticulatum* individuals (Fig. 8).

DISCUSSION

According to Kattunen and Toivonen (1995), traits that fairly well explain the occurrence of specified submerged

aquatic plant species are the pH, conductivity and clearness of the water. The present studies confirm that finding. Conductivity and TDS determine the total contents of salts, including nutrients for plants. According to Thiebaut et al. (1998), the species composition of bryophytes, and abundance of their population depend, among other things, on the degree of water mineralization, mainly on the concentration of Ca²⁺, as well as on its acidification. I noticed such a relationship when studying *Sphagnum denticulatum* habitats.

Malme (1987) thinks that *S. denticulatum* finds optimum conditions for growth in habitats with a pH ~ 5. My studies indicate that in north-western Poland optimum population growth of this species occurs in much more acid habitats (pH 4.0-4.5), which are at the same time oligohumic. In more acid habitats, extremely poor, the biomass per unit area of this plant is conspicuously lower. A similar situation was seen at pH values above the optimum, and at higher cation concentrations. Under such conditions submerged habitats are occupied by *Fontinalis antipyretica* and *Drepanocladus tenuinervis*.

My present studies suggest that the composition of the above-sediment water has the strongest effect on the abundance of *S. denticulatum* populations. This finding agrees

with that reported by Brandrud and Johansen (1994) who have shown that bryophytes, e.g. species of the genus *Sphagnum*, take up mineral nutrients and inorganic carbon through their leaves. For this reason, they very quickly respond to changes in the chemistry of lake waters (Jaynes and Carpenter 1986). The distribution and population abundance of submerged plants may be affected also by the kind of the bottom, water movement and competitive action of other species (Sørensen 1948).

A concentration of DHS greater than 2.0 mg C dm⁻³ leads to the recession of *S. denticulatum* from submerged habitats. In deep zone this is caused by a lowering of light intensity, whereas in shallow sites – by strong waves and creation of erosion habitats. Further enrichment of habitats with DHS results in a gradual decrease of the size of *S. denticulatum* population and its restriction to the shallowest parts of a habitat. An increase in DHS concentration above 8 mg C dm⁻³ brings about a complete elimination of this plant from a lake. The only species that grows under such conditions is *Fontinalis antipyretica* (Gos et al. 1998) – a sciophilous moss that endures strong water waves.

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LITERATURE CITED

- BRANDRUD T.E., JOHANSEN S.W. 1994. Effects of acidification on macrophyte growth in the humex Lake Skjervatjern, with special emphasis on *Sphagnum auriculatetum*. *Environmental International*, 20: 329-342.
- COLLIER K.J. 1987. Spectral properties of some West Coast waters and their relationship with dissolved organic carbon. *Mauri Ora*, 14.
- GOLTERMAN H.L. (ed.) 1969. *Methods for chemical analysis of fresh waters*. IBP Handbook 8 – Blackwell Sc. Publ., Oxford, 166 pp.
- GOS K., BOCIĄG K., BANAŚ K. 1998. Roślinność podwodna w kwaśnych jeziorach Pomorza (Submerged aquatic vegetation in acid lakes of Pomerania). In: Park Narodowy Bory Tucholskie. Banaszak J., Tobolski K. (eds), Wydawnictwo Uczelniane WSP w Bydgoszczy, pp. 261-278 (in Polish with English summary).
- GÓRNIĄK A. 1995. Spektrofotometryczna metoda oznaczania stężeń i jakości rozpuszczonego węgla organicznego w wodach. *Gospodarka Wodna*, 2: 31-33.
- GÓRNIĄK A. 1996. Substancje humusowe i ich rola w funkcjonowaniu ekosystemów słodkowodnych. Dział Wydawnictw Filii UW w Białymstoku, Białystok, 151 pp.
- GRAHN O. 1977. Macrophyte succession in Swedish lakes caused by deposition of airborne acid substances. *Water, Air and Soil Pollution*, 7: 295-305.
- GUILDFORD S.J., HEALEY F.P., HECKY R.E. 1987. Depression of primary production by humic matter and suspended sediment in limnocorral experiments at Southern Indian Lake, northern Manitoba. *Can. J. Fish. Aquat. Sci.*, 44: 1408-1417.
- HENDREY G. R., VERTUCCI F. 1980. Benthic plant communities in acidic lake Golden, New-York: *Sphagnum* and the algae mat. *Proceedings of International Conference of Ecology' Impact Acid Precipitation*, Drablos D. and Tollan D., Norway, pp 314-315.
- HERMANOWICZ W., DOJLIDO J., DOŻAŃSKA W., KOZIO-ROWSKI B., ZERBE J. 1999. Fizyczno-chemiczne badanie wody i ścieków. Arkady, Warszawa, 556 pp.
- HUTCHINSON G.E. 1975. *A Treatise on Limnology*. III. Limnological Botany. Wiley, New York, 660 pp.
- JACKSON T., HECKY R.E. 1980. Depression of primary production by humic matter in lake and reservoir waters of the boreal forest zone. *Can. J. Fish. Aquat. Sci.* 37: 2300-2317.
- JAYNES M.L., CARPENTER S.R. 1986. Effects of vascular and nonvascular macrophytes on sediment redox and solute dynamics. *Ecology*, 67: 875-882.
- KARTTUNEN K., TOIVONEN H. 1995. Ecology of aquatic bryophyte assemblages in 54 small Finnish lakes, and their change in 30 years. *Ann. Bot. Fennici*, 32: 75-90.
- MALME L. 1978. Floristic and ecological studies of bryophytes in some Norwegian inland lakes. *Norwegian J. Bot.*, 25: 271-279.
- MOORE T.R. 1985. The spectrophotometric determination of dissolved organic carbon in peat waters. *Soil Sci. Soc. Amn. J.*, 49: 1590-1592.
- MOORE T.R. 1987. An assessment of a simple spectrophotometric method for the determination of dissolved organic carbon in freshwaters. *New. Zeal. J. Mar. Fresh. Res.*, 21: 585-589.
- ROELOFS J.G.M. 1983. Impact of acidification and eutrophication on macrophyte communities in soft waters in the Netherlands. I. Field observations. *Aquat. Bot.* 17: 139-155.
- SMITH A.J.E. 1982. *Bryophyte ecology*. Chapman & Hall, London, 511 pp.
- SØRENSEN H. 1948. Studies on the ecology of Danish Water and bay mosses. *Dansk Bot. Ark.* 12: 19-47.
- STEWART A.J., WETZEL R.G. 1982. Influence of dissolved humic materials on carbon assimilation and alkaline phosphatase activity in natural algal-bacterial assemblages. *Freshwater Biol.*, 12: 369-380.
- SZAŃKOWSKI M. 1998. Ekologiczny status roślinności jezior łobeliowych w Polsce (Ecological status of the vegetation of Lobelia lakes in Poland). *Wydz. Biol. UW, mscr.*, 145 pp (in Polish with English summary).
- SZMEJA J. 1994a. An individual's status in populations of isoetid species. *Aquatic Bot.* 48: 203-224.
- SZMEJA J. 1994b. Effect of disturbances and interspecific competition in isoetid populations. *Aquatic Bot.* 48: 225-238.
- SZMEJA J. 1994c. Dynamics of the abundance and spatial organisation of isoetid populations in an oligotrophic lake. *Aquatic Bot.* 49: 19-32.
- SZMEJA J. 1998. Geneza, specyfika i zagrożenia jezior pomorskich. In: Szata Roślinna Pomorza – zróżnicowanie, dynamika, zagrożenia, ochrona. Herbich J., Herbichowa M. (eds). Wydawnictwo UG, pp. 223-232.
- THIEBAUT G., VANDERPOORTEN A., GUEROLD F., BOUTOT J., MULLER S. 1998. Bryological patterns and stream-water acidification in the Vosges Mountains (N.E. France): an analysis tool for the survey of acidification processes. *Chemosphere*. Vol. 36, 2: 1275-1289.
- WOJCIECHOWSKI I. 1997. Funkcjonowanie ekosystemów torfowiskowych. Akademia Rolnicza w Lublinie, Katedra Ekologii Ogólnej, Lublin, 23 pp.

WPLYW SUBSTANCJI HUMUSOWYCH
NA SIEDLISKA *SPHAGNUM DENTICULATUM* BRIDEL

STRESZCZENIE

W 10 miękkowodnych jeziorach z północno-zachodniej Polski (5 bardzo kwaśnych i 5 lekko kwaśnych; ryc. 1), zbadano trzy rodzaje siedlisk *Sphagnum denticulatum* Bridel [= *S. auriculatum* Schimper]: oligohumusowe ($<2,0 \text{ mg C}_{\text{DHS}} \text{ dm}^{-3}$), (β -mezohumusowe ($2,0\text{-}4,0 \text{ mg C}_{\text{DHS}} \text{ dm}^{-3}$) i β -mezohumusowe ($4,1\text{-}8,0 \text{ mg C}_{\text{DHS}} \text{ dm}^{-3}$).

W jeziorach bardzo kwaśnych siedliska *S. denticulatum* posiadają wiele cech niezmiennych w procesie humizacji. Wzrost stężenia rozpuszczonych substancji humusowych (DHS), od stadium oligo- przez α -mezo- do β -mezohumusowego, powoduje zabarwienie wody nad osadem ($0 \rightarrow 80 \text{ mg Pt dm}^{-3}$), jej odczyn jest bardzo kwaśny (pH 4,3; 4,8; 4,4), przewodnictwo ($38,5; 38,5; 45,0 \text{ }\mu\text{S cm}^{-1}$), TDS ($27; 27; 31 \text{ mg dm}^{-3}$) i stężenie wapnia ($1,5; 2,8; 1,2 \text{ mg dm}^{-3}$; tab. 1, 2) są małe. W gradiencie wzrastających stężeń DHS odczyn osadu jest zawsze wyższy niż wody. Przewodnictwo ($42,3; 35,8; 30,0 \text{ }\mu\text{S cm}^{-1}$) i TDS ($29; 25; 21 \text{ mg dm}^{-3}$) osadu są w tym gradiencie coraz mniejsze.

W jeziorach lekko kwaśnych, w całym ciągu siedlisk humusowych, odczyn wody i osadów jest wyższy (pH wody 6,0; 6,2; 6,7; osadu 6,2; 6,1; 6,3), większe jest również stężenie wapnia ($5,4; 5,7; 5,6 \text{ mg dm}^{-3}$), przewodnictwo elektrolityczne i zawartość rozpuszczonych soli ($54,6; 56,5; 65,0 \text{ }\mu\text{S cm}^{-1}$ w wodzie i $68,4; 61,5; 87,5 \text{ }\mu\text{S cm}^{-1}$ w osadach oraz TDS odpowiednio $39; 39; 45 \text{ mg dm}^{-3}$ i $48; 43; 63 \text{ mg dm}^{-3}$; tab. 3). W procesie humizacji ulegają zmianie te same cechy co w siedliskach jezior bardzo kwaśnych, czyli barwa, widzialność krążka Secchiego i stężenie DHS.

Optymalnymi siedliskami dla *S. denticulatum* są siedliska oligohumusowe w jeziorach bardzo kwaśnych, leżące między 4 a 8 m głębokości, gdzie tworzy rozległe i zwarte kobierce o dużej biomase (ryc. 2). Na siedliskach oligohumusowych w jeziorach lekko kwaśnych roślina ta trafia się rzadko, rośnie poniżej głębokości 5 m i tworzy bardzo słabo zagęszczone populacje o niewielkim udziale w biomase roślin (ryc. 6). Na siedliskach mezohumusowych w obu rodzajach jezior *S. denticulatum* jest gatunkiem stanowiącym znaczny udział w biomase roślin ($60\text{-}80\%$, ryc. 4, 5, 7, 8), lecz wartości bezwzględne biomasy są bardzo małe. Silny spadek biomasy *S. denticulatum*, w stosunku do osiąganey na siedliskach oligohumusowych w jeziorach bardzo kwaśnych (ryc. 3), jest tu związany przede wszystkim ze wzrostem barwy wody i spadkiem jej przezroczystości w wyniku wzrostu zawartości DHS. Zostaje wtedy wyraźnie zawężona strefa występowania makrofitów do płytkiego litoralu. Panujące tam warunki (np. mineralny osad i silne falowanie) nie pozwalają na bujny rozwój *S. denticulatum*, nawet na siedliskach oligohumusowych.

A zatem obecność substancji humusowych, pochodzących z torfowisk wysokich ogranicza obfitość populacji *S. denticulatum* w miękkowodnych jeziorach, głównie poprzez zmianę właściwości komponenty wodnej siedlisk.

SŁOWA KLUCZOWE: *Sphagnum denticulatum* Bridel, siedlisko podwodne, substancje humusowe.