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Shallow humic lakes of the Wielkopolska region – relation between dystrophy and eutrophy in lake ecosystems

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Abstract: The present study analyses 13 shallow lakes developed in the process of succession located in the Wielkopolska region, taking into account physical and chemical parameters of water, the development of macrophyte vegetation and chlorophyll-a concentration. The analysed lakes are compared with 12 water bodies showing a strongly marked dystrophic character. The lakes developed in the process of succession display features characteristic for both eutrophic and dystrophic lakes. They exhibit a high concentration of DOC and basically low colour of water. Moreover, they are also rich in nutrients. In comparison to dystrophic lakes, they are markedly different as far as their reaction, conductivity and the concentration of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and Cl^{-} are concerned. Different, too, is the degree of development of macrophyte vegetation and chlorophyll-a concentration. The study discusses the classification and typology of basins which are the last stages of lake ecosystems' evolution, with special attention to the alloiotrophic type of lakes.

Key words: lakes developed in the process of succession, humic lakes, eutrophy, dystrophy, macrophytes, chlorophyll-a, phytoplankton, water chemistry

Introduction

In the Wielkopolska region, most of the natural, postglacial water basins have either shallowed, or have disappeared completely (Choiński, 1995). It is estimated that in the young glacial landscape of the Wielkopolska, 67% of the water basins' area have been filled with sediments since the moment of their creation (Choiński, 1995). Moreover, it is often pointed out that the shallowing of water basins' was considerably speeded up by melioration, particularly intense at the beginning of the 19th century (Choiński, 1995; Łachacz, Olesiński, 2000). One of its results was a vast diminishing of the water table of some reservoirs and the creation of quagmire, appearing on the sediment-filled parts of the lakes.

There is little data describing the functioning of shallow lakes developed in the process of succession. The basins of this type, because of their small size and relatively difficult access, are usually omitted in limnological and hydrobiological studies (Hillbricht-Ilkowska, 1998a).

Similarly, water reservoirs which constitute last stages in water lakes' evolution have not acquired so far a uniformed limnological classification or typology. Particularly debatable is their treatment as a stage in the development lines of dystrophic lakes (e.g. Naumann, 1921, 1929, 1932; Thienemann, 1921, 1925; Höll, 1928; Stangenberg, 1936; Wiszniewski, 1953; Górniak, 1996; Wojciechowski, 1999; Hutorowicz, 2001). Interesting, too, is the problem of classifying and describing the processes observable in the shallow water ecosystems in the context of the alternative stable states theory of the 'shallow lakes' type of water bodies (Scheffer, 1989, 1990, 2001a,b; Scheffer et al., 1993; Scheffer, Jeppesen, 1998).

The aim of the present study was to present the characteristics of physico-chemical and biotic parameters of lakes developed in the process of succession in comparison to clearly dystrophic lakes. Particular attention was paid to the determination of the relationship between the macrophyte vegetation cover and the degree of development of plankton algae (chlorophyll-a concentration), as this relationship implies the theory of alternative stable states.

Methods

The analyses concentrated on two groups of lakes located in two lake districts of the Wielkopolskie voyvodship: the Wielkopolskie and the Southern Pomerania lake districts. The lakes were characteristic of wide zones of peat-bog and rush vegetation, and in most cases, of the domination of water plants within the limits of the water table. The basins were filled with organic sediments of considerable hydration and thickness. To a large extent, the catchment areas of both types of lakes were covered with woods with the domination of *Pinus sylvestris*. Because of their significant natural values, most of the lakes are under protection as nature reserves. Their ecosystems are only slightly anthropogenically influenced.

Group I comprised 13 small-size shallow lakes (3.2 m max. depth, from 1 to 21 ha area). They represented the last stage of the development of glacial water basins: they were considerably developed in the process of succession. The researches was done in the lakes: Czarne - N 52°28'6" E 17°53'4", Drążynek – N 52°26'4" E 17°16'2", Kańskie – N 52°24'8" E 18°01'5", Kociołek – N 52°31'8" E 17°05'7", Kuźnik Duży – N 53°12'00" E 16°45'5", Kuźnik Mały – N 53°11'9" E 16°44'4", Kuźnik Olsowy – N 53°12'4" E 16°43'5", Mnich Mały – N 52°39'0" E 16°01'9", Rzecińskie – N 52°45'7" E 16°45'7", Smolary – N 53°17'8" E 16°44'0", Zamorze – N 52°30'6" E 16°12'6" and Zgniłe – N 52°45'6" E 16°01'5".

Group II consisted of 12 small lakes (< 10 ha) of the Wielkopolska region, slightly deeper (to 7.5 m max. depth) and with a greater participation of peat-bogs in their direct catchment basins: Czarne – N 53°08'1" E 16°55'2", Kuźniczek – N 53°11'5" E 16°44'3", Mały Smólsk – N 53°24'5" E 17°15'3", Modre – N 53°25'6" E 17°20'3", Okoniowie – N 53°11'1" E 16°48'2", Pokraczyn – N 52°47'0" E 16°21'4", Pustelnik I – N 52°46'7" E 16°19'1", Pustelnik II – N 52°46'8" E 16°19'1", Skrzynka – N 52°15'3" E 16°47'2", Święte – N 51°57'7" E 16°46'3", Wilcze Błoto – N 52°49'4" E 16°22'8" and Żurawin – N 52°02'0" E 18°08'5".

Both the biotic and abiotic characteristics of the lakes belonging to group I (i.e. those developed in the process of succession) were compared to the characteristics of the Pinus II lakes, clearly dystrophic in character.

The physico-chemical analyses of water, macrophyte vegetation and chlorophyll-a concentration were carried out in the summer seasons of the years 2001-2004.

Water samples for the analyses were taken from the transects composed of patches of macrophyte vegetation and the mid-lakes. 15 water parameters were analysed: colour, dissolved organic carbon (DOC), turbidity, reaction (pH), conductivity, and the concentration of $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$, total Fe, Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-} and Cl^-. Water analyses followed standard methods of Siepak (1992) and Hermanowicz et al. (1999). The pH value was expressed by the concentration of H^+ ions (Wherry, 1922).

The relative plant cover of the water table and its thickness (SAV) was determined according to 5 classes of categories (Bayley, Prather, 2003): 1 - lakes with no water plants; 2 - v. thin plant cover (<5%); 3 - small plant cover (5%-25%); 4 - extensive plant cover (25%-75%) and 5 - total cover of the water table by plants (>75%). Chlorophyll-a concentration within different sites of the lakes (macrophyte patches and mid-lakes) was determined by the spectrophotometrical method, after the acetone extraction, corrected for phaeopigments. Chlorophyll-a concentration was adopted as an indicator of the level of development (i.e. biomass) of phytoplankton (Eloranta, 1986; Kawecka, Eloranta, 1994). Because of the diversity of physical and chemical parameters of water within the water table of numerous of the analysed lakes (Gąbka, 2005; Gąbka, Owsianny, 2005; Owsianny, 2006), the study took into account all the sites chosen in a given reservoir.

Statistical significance of differences, as far as water features and biological parameters are concerned, was determined with the U Mann-Whitney test. Furthermore, the study presents the most important habitat gradients of the analysed lakes, determined with the PCA method, i.e. the Principal Components Analysis (Ter Braak, Šmilauer, 2002).

Results

The waters of both groups of lakes were characteristic of the high DOC concentration and considerable water colour. The lakes developed in the process of succession were very shallow (1 m deep on average), alkaline and rich in Ca^{2+}, Mg^{2+} and SO_4^{2-} (Tab. 1). In comparison to the lakes of group II, dystrophic in character and slightly deeper (2.3), the lakes of group I were significantly different in reaction, conductivity and the concentration of Ca^{2+}, Mg^{2+}, Na^+, K^+ and Cl^- (Tab. 1). Group I exhibited higher average values, especially of such parameters as Ca^{2+}, Mg^{2+}, Na^+, SO_4^{2-} and Cl^-, and lower values of K^+, in comparison to group II. Most of the analysed lakes

Tab. 1. Physical and chemical properties of water, Chl a and submerged aquatic vegetation (SAV) from sites of shallow humic lakes developed in process of succession (I n= 42) and from dystrophic lakes (II n=26). Ranges and mean values and the result of Mann-Whitney test of differences between groups.

Property		I			II			
		Mean	Min.	Max.	Mean	Min.	Max.	I-II
Depth of water	m	1.02	0.20	3.20	2.31	0.75	7.50	+
SAV		4.74	2.00	5.00	2.42	1.00	4.00	+
Chlorophyll-a	$\mu g\ l^{-1}$	8.99	1.07	34.11	33.69	4.46	112.27	+
Secchi disc visibility	m	0.96	0.20	1.80	1.09	0.35	2.50	–
Colour	$mg\ Pt\ l^{-1}$	32.95	1.00	69.00	37.50	2.00	147.00	–
DOC	$mg\ C\ l^{-1}$	14.47	5.30	25.76	15.56	5.00	29.14	–
Turbidy	FTU	10.24	0	46.00	13.10	0	40.00	–
pH		7.68	6.50	8.78	6.12	4.20	6.96	+
Conductivity	$\mu S\ cm^{-1}$	434.55	236.00	959.00	65.72	23.70	324.00	+
$N\text{-}NH_4^+$	$mg\ N\ l^{-1}$	0.23	0.04	0.58	0.26	0.05	0.65	–
$N\text{-}NO_3^-$	$mg\ N\ l^{-1}$	0.20	0	0.80	0.17	0.00	0.40	–
$P\text{-}PO_4^{3-}$	$mg\ PO_4\ l^{-1}$	0.13	0	0.91	0.08	0.00	0.35	–
Total Fe	$mg\ Fe\ l^{-1}$	0.04	0	0.17	0.08	0.00	0.33	–
Ca^{2+}	$mg\ Ca\ l^{-1}$	54.73	21.42	104.97	3.68	1.08	7.14	+
Mg^{2+}	$mg\ Mg\ l^{-1}$	8.32	3.04	15.18	1.59	0.02	3.47	+
Na^+	$mg\ Na\ l^{-1}$	5.91	0.71	16.34	2.85	0.68	9.58	+
K^+	$mg\ K\ l^{-1}$	0.72	0.09	2.26	2.73	0.65	8.09	+
SO_4^{2-}	$mg\ SO_4\ l^{-1}$	52.62	0	140.00	2.65	0	29.00	+
Cl^-	$mg\ Cl\ l^{-1}$	13.70	4.00	34.00	7.35	3.00	20.00	+

exhibited a higher concentration of nutrients, especially $N\text{-}NH_4^+$, $N\text{-}NO_3^-$ and $P\text{-}PO_4^{3-}$. Their waters were considerably more mineralised (mean 434 $\mu S\ cm^{-1}$) than those of dystrophic lakes (mean 66 $\mu S\ cm^{-1}$).

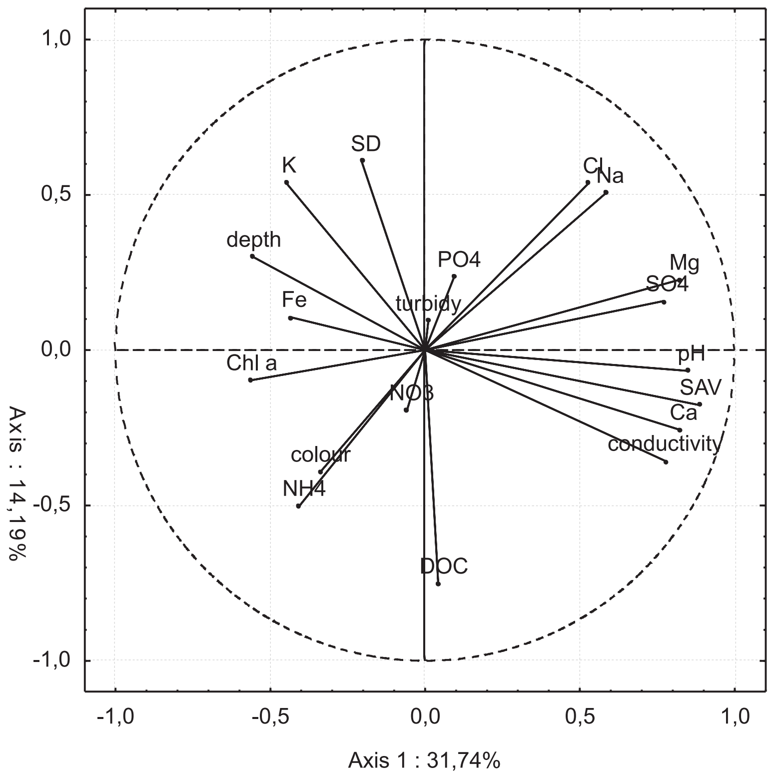
The average chlorophyll-a concentration in the lakes belonging to group I was low and characteristic of poorer waters (oligo- mezotrophy; 8.99 $\mu g\ l^{-1}$). The concentration of chlorophyll-a in acid water dystrophic lakes is, to some extent, similar to the values typical of fertile reservoirs (eu- i hypertrophy; mean 33.69 $\mu g\ l^{-1}$, max 112.27 $\mu g\ l^{-1}$ Chl a).

The analysis of chlorophyll-a concentration indicates its lower concentration in the lakes (group I) with a significant plant cover (expressed by the 5-degree scale). The lakes often exhibited 75% or more of the macrophyte vegetation cover. In the group of lakes developed in the process of succession the macrophytes dominated, represented mostly by charophyte meadows. These lakes hosted altogether 12 species of vascular plants and 8 species of charophytes. In the group of dystrophic lakes we could mainly observe nympheids, with charophytes (*Nitella* species) and bryophytes (submerged form) noted only sporadically.

The lakes of group II were characteristic of small values of the plant cover (SAV), and of frequently higher chlorophyll-a concentration. It has to be pointed out, however, that the higher chlorophyll-a concentration in dystrophic lakes was a result of the specific nature of their phytoplankton and the presence, in most cases, of abundant populations of raphidophyte *Gonyostomum semen* (Ehr.) Diesing.

In the case of the analysed lakes with considerable DOC concentration (group I and II), the most important factors influencing abiotic conditions were the following: reaction, conductivity and the concentration of Mg^{2+} and Ca^{2+} (Fig. 1). Out of physico-chemical water parameters, it was reaction and reaction-related factors that most clearly determined the observed variability. As far as the biotic factors are concerned, the most decisive turned out to be SAV. Parameters correlated with the 1st PCA axis explained 31.7% of variability (SAV gradient and factors connected with hardness), and SD, Na^+ and K^+ accounted for 14.2% of variability on the axis 2.

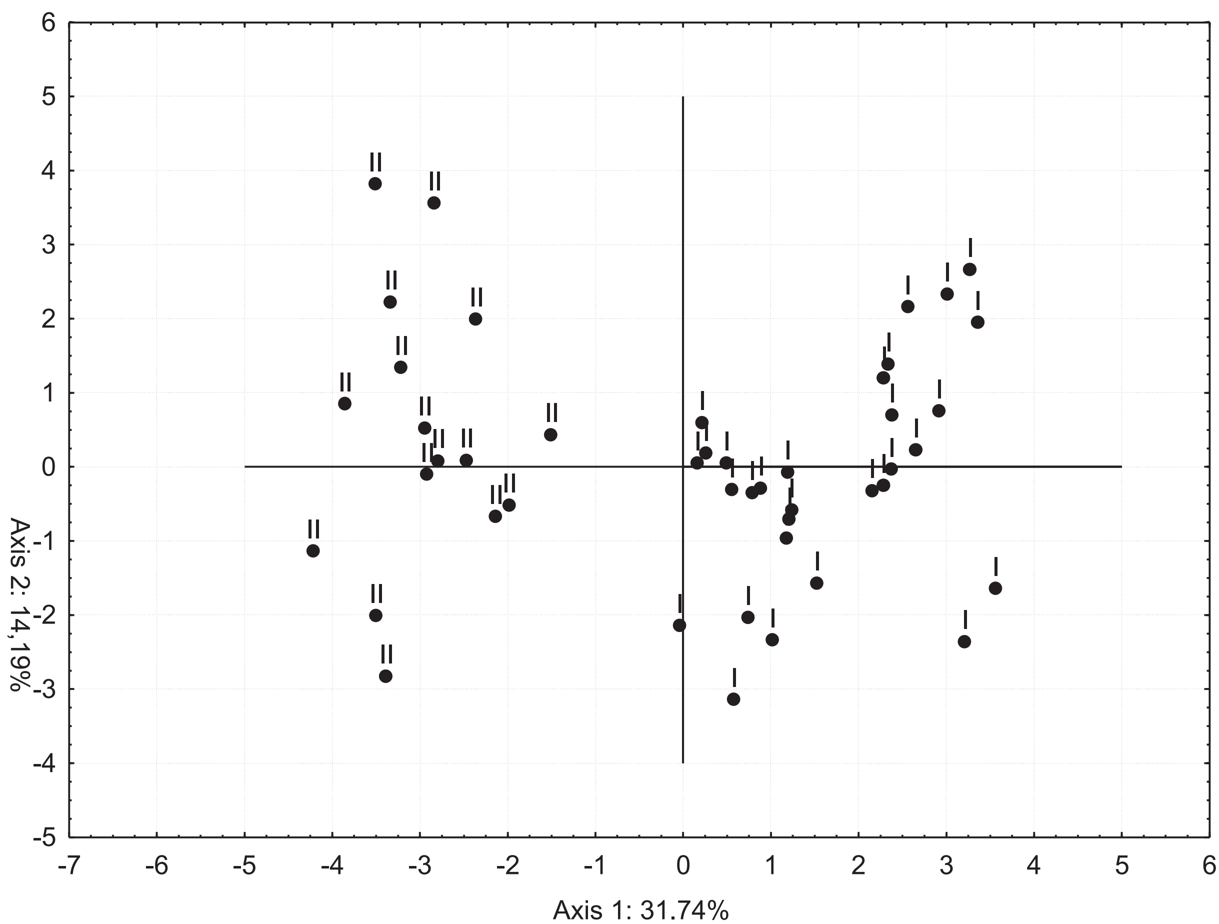
A.



	Axis 1	Axis 2
SAV	0,885767	-0,176686
pH	0,848043	-0,066051
Mg	0,823393	0,226517
Ca	0,821462	-0,256438
conductivity	0,776739	-0,356886

Ryc. 1. Results of PCA of physical and chemical properties of water, Chl a and submerged aquatic vegetation (SAV) investigated lakes (A) and value of first and second component of mid-lake sites (B): I – shallow humic lakes development in process of succession, II – dystrophic lakes.

B.



Discussion

Peat-bog zones surrounding lakes are a source of humic substances that significantly shape the conditions of water bodies (Hillbricht-Ilkowska, 1998b). Ecological conditions of these types of reservoirs are usually identified as dystrophic, indicating the shortage of nutrients in water and its low reaction (Thienemann, 1921; Naumann, 1931; Stangenberg, 1936). In contrast, high trophy and considerable amount of dissolved humic substances in the waters of some lakes allow for their classification as mixed in type (alloiotrophic, humotrophic, humoeutrophic), standing on the verge between dystrophy and eutrophy (e.g. Hansen, 1962; Nürnberg, Show, 1998; Williamson et al., 1999; Wojciechowski, 1999). It has to be pointed out, however, that there exists no uniformed system of classifying water bodies characteristic of considerable concentration of humic substances, which may be seen in the studies of, among others: Nürnberg, Show (1998), Williamson et al. (1999 and references there), Hutorowicz (2001 and references there), Pęczuła (2002). Moreover, the studies suggest that the status of humic lakes may be a combined result of both dystrophic and eutrophic processes, dependant on the domination of one of them in the peat-bog areas of the catchment basin (Wojciechowski et al., 1990; Wojciechowski, 1999).

In Wielkopolska, the lakes developed in the process of succession display the features characteristic of both eutrophic and dystrophic lakes. The average concentration of dissolved nutrients, especially of $N\text{-}NH_4^+$ and $P\text{-}PO_4^{3-}$, was similar to that of mezo- and eutrophic waters. Yet, we may assume that the natural abundance in nutrients is connected also with the organogenic character of the catchment area. Additionally, the heightened trophy of analysed waters may be related to the seasonal decomposition of complex humic substances, with the ensuing discharge of ammonium and phosphate ions into the waters (Koenings, Hooper, 1976; Franco, Heath, 1982; Wojciechowski, Górniak, 1990; Wojciechowski, 1999; Górniak, 1996).

The lakes developed in the process of succession were richer in mineral substances (e.g. Ca^{2+}, Mg^{2+}, Na^+) and showed high conductivity, which distinguished them from quasi-oligotrophic lakes of dystrophic character. In most of the analysed lakes of group I, high nutrient availability in water was not reflected in the productivity of water algae communities. Low productivity is expressed by low average values of chlorophyll-a, often characteristic of poor waters (Holopainen et al., 2003). We cannot rule out the possibility that, in some cases, the low value might result from allelopathic influence of macrophyte communities, especially charophyte meadows (van Donk, van de Bund, 2002; Berger, Schagerl, 2004 and references there). No phytoplankton bloom could be observed in the lakes of group I; more importantly, there was no trace of much development of filamentous cyanobacteries. Nevertheless, the group was very diverse as far as plankton algae are concerned; in some instances a considerable development of chlorophyceae and dinoflagellates could be observed (Gąbka, Owsianny, 2005; Owsianny, 2006). In the lakes of group II, the average chlorophyll-a concentration took on much higher values. In most cases, it was a result of the numerous participation of *Gonyostomum semen* populations. The increased number of this species is often manifested by unusually high values of chlorophyll (Hutorowicz, 2001; Gąbka et al., 2004).

In the case of the shallow lakes of group I, particularly striking were a high DOC concentration and water colour. The average DOC concentration value in this group of lakes came close to that determined for dystrophic reservoirs (group II), and was higher than the value noted in the studies of eutrophic lakes of the Wielkopolska region (Barałkiewicz, Siepak, 1994).

The PCA analysis points to different characters of abiotic conditions in the ecosystems of both analysed groups of lakes. In the case of the lakes of group I, the concentration of nutrients, so characteristic of eutrophic lakes, was less decisive for the shaping of habitat conditions (Pełechaty, 2004). Most important turned out to be the Ca^{2+} concentration, and the parameters correlated with it. This correlation has been also observed in the case of acid water dystrophic lakes. Nevertheless, the lakes of group I were either significantly or very rich in calcium, while in the lakes of group II, calcium, being at the oligotrophic level, decisively conditioned dystrophy. Lakes rich in humic substances and calcium have been described in some studies as alloiotrophic (Höll, 1928; Wiszniewski, 1953). The term depicts accurately the specificity of group I lakes because, besides the two characteristics mentioned above, it also suggests the semi-neutral or alkaline water reaction and the heightened nitrogen and phosphorus concentration. However, the studies of classical examples of this type of lakes emphasise the abundant waterlife, manifested in frequent water blooms (Höll, 1928; Wiszniewski, 1953). In most of the analysed alloiotrophic lakes we could observe a massive development of hydromacrophytes, especially the charophyte meadows (extremely high SAV). The limited development of phytoplankton (expressed by low chlorophyll-a values), observed in most of them, resulted most probably from the compensatory activity of macrophyte plant communities, according to the concept of alternative stable states of the 'shallow lake' types of lakes (Scheffer, 1989, 1990, 2001a,b; Scheffer et al., 1993; Scheffer, Jeppesen, 1998).

So far, alloiotrophic lakes have not been extensively documented. They form a specific group of peat bog lakes and require further studies. Especially worth studying seem to be the ecological processes taking place in them, as their dynamics is different from that described for eutrophic and dystrophic lakes.

References

Bayley S. E., Prather C. M., 2003. Do wetland lakes exhibit alternative stable states? Submersed aquatic vegetation and chlorophyll in western boreal shallow lakes. Limnol. Oceanogr. 48(6): 2335-2345.

Barałkiewicz D., Siepak J., 1994. The contents and variability of TOC, POC and DOC concentration in natural waters. Polish Journal of Environmental Studies. 32: 1-15.

Berger J., Schagerl M., 2004. Allelopathic activity of Characeae. Biologia (Bratislava) 59/1: 9-15.

Choiński A. 1995. Zarys limnologii fizycznej Polski (Physical limnology profile of Poland). Wyd. Nauk. UAM, Poznań (in Polish): 1-298.

Eloranta P., 1986. Phytoplankton structure in different lake types in central Finland. Holarctic Ecology, 9: 153-159.

Franco D. A., Heath R. T., 1982. UV-sensitive complex phosphorous: Association with dissolved humic material and iron in a bog lake. Limnol Oceanogr. 27(3): 564-569.

Gąbka M., 2004. Wybrane aspekty siedliskowe występowania ramienic w zarastających jeziorach śródleśnych Wielkopolski (Chosen habitat aspects of the occurrence of charophytes in overgrowing lakes). In: Burchardt L. (ed.), Zasługi prof. dr hab. Izabeli Dąmbskiej w kształtowaniu dzisiejszego wizerunku ochrony przyrody. Sesja Naukowa w 20 rocznicę śmierci Prof. dr hab. Izabeli Dąmbskiej (1927-1984). Uniwersytet im. A. Mickiewicza w Poznaniu, Wydział Biologii, Poznań (in Polish): 29-45.

Gąbka M., Owsianny P. M., Sobczyński T., 2004. Acidic lakes in the Wielkopolska region – physico-chemical properties of water, bottom sediments and the aquatic micro- and macrovegetation. Limnological Review, 4: 81-88.

Gąbka M. 2005. Zbiorowiska roślinne jezior humusowych Wielkopolski na tle ich uwarunkowań siedliskowych. Manuskrypt pracy doktorskiej (Plant vegetation of humic lakes on the background their habitat requirements. PhD manuscript). Zakład Hydrobiologii, Uniwersytet im. A. Mickiewicza, Poznań (in Polish): 1-194.

Gąbka M., Owsianny P. M., 2005. Occurrence of charophytes in humic lakes of the Wielkopolska region on the background of light conditions and their interrelations with algal floristic composition. In: Toxic Cyanobacteria – problem of the future. XXIV International Symposium of the Phycological Section of the Polish Botanical Society. Krynica Morska, May 19-22, 2005. Fundacja Rozwoju Uniwersytetu Gdańskiego, Gdańsk.

Górniak A., 1996. Humic substances and their role in functioning of freshwater ecosystems. Miss. Univ. Vars., 448, Białystok (in Polish): 1-151.

Hansen K., 1962. The dystrophie lake type. Hydrobiologia, 19: 183-191.

Hermanowicz W., Dożańska W., Dojlido J., Koziorowski B., Zerbe J., 1999. The physico-chemical analyses of water and wastewater. Arkady, Warszawa (in Polish): 1-847.

Hillbricht-Ilkowska A. 1998a. Biological diversity of freshwater habitats – problems, requirement, activity In: Kraska M. (ed.), Bioróżnorodność w środowisku wodnym. Idee Ekologiczne, Tom 13, Ser. Szkice, nr 7: 13-54. Wyd. Sorus, Poznań (in Polish).

Hillbricht-Ilkowska A. 1998b. Humic lakes: functioning, protection, endangering. In: Hillbricht-Ilkowska A., Dusoge K., Ejsmont-Karabin J., Jasser I., Kufel I., Ozimek T., Rybak J. I., Rzepecki, M., Węglenska T. (eds) Long term effects of liming in a humic lake: Ecosystem processes, biodiversity, food web functioning (Lake Flosek, Masurian Lakeland, Poland). Pol. J. Ekol. 46(4): 348-355.

Holopainen A. L., Niinioja R., Rämö A. 2003. Seasonal succession, vertical distribution and long term variation of phytoplankton communities in two shallow forest lakes in eastern Finland. Hydrobiologia, 506-509, 1-3: 237-245.

Hutorowicz A. 2001. Phytoplankton of the humic lake Smolak against a background physico-chemical changes caused by liming and fertilization. Idee Ekologiczne, Tom 14, Seria Zeszyty, (7): 5-130 (in Polish).

Höll K. 1928. Oekologie der Peridineen. Studien über den Einfluss chemischer und physikalischer Faktoren auf die Verbreitung der Dinoflagellaten im Süsswasser. In: Kolkwitz R. (ed.), Pflanzenforschung. Heft 11. Gustav Fischer, Jena.

Kawecka B., Eloranta P. V. 1994. Profile of algae ecology in freshwater and land environment. Wyd. Nauk. PWN, Warszawa (in Polish): 1-157.

Koenings J. P., Hooper F. F. 1976. The influence of colloidal organic matter on iron-phosphorus cycling in an acid bog lake. Limnol. Oceanogr. 21: 684-696.

Łachacz A., Olesiński L. 2000. Flora and vegetation of a quagmire know as Jeziorki in the Masurian Lakeland (Pojezierze Mazurskie – north-eastern Poland). Fragm. Flor. Geobot. Polonica 7: 129-143 (in Polish).

Naumann E. 1921. Einige Grundlinien der regionalen Limnologie. Lunds Universitets Årsskrift. N. F. II. 17.

Naumann E. 1929. Einige neue Gesichtpunkte zur Sistematik der Gewässertypen. Mit besonderer Berücksichtigung der Seetypen. Archiv für Hydrobiologie 20.

Naumann E. 1931. Limnologische Terminologie. Handbuch der biologischen Arbaitsmethoden, ABT. IX. Teil 8, Berlin, Urban und Schwarzenberg: 1-776.

Naumann E. 1932. Grundzüge der regionalen Limnologie. In: Thienemann A., (ed.), Die Binnengewässer 11. Einzeldarstellungen aus der Limnologie und ihren Nachbargebieten. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

Nürnberg G. K., Show M. 1998. Productivity of clear and humic lakes: nutrients, phytoplankton, bacteria. Hydrobiologia 382: 97-112.

Owsianny P. M. 2006. Dynamika procesów ekologicznych zróżnicowanych zlewniowo jezior Rezerwatu Przyrody "Kuźnik" (Wielkopolska) na tle badań fykologicznych i geochemiczno-hydrologicznych. (Dynamic of chosen ecological processes of three lakes with different catchments - studies on the background phycological, geochemical and hydrological analyses (the Kuźnik Nature Reserve, Poland)) PhD-thesis. Department of Hydrobiology, Adam Mickiewicz University (in Polish): 1-351 + appendixes.Pęczuła W. 2002. Lake Płotycze – between dystrophy and eutrophy (about difficulties in obtaining trophic status of some lakes). Limnological Review 2: 303-311.

Pełechaty 2004. Spatial and temporal heterogeneity of abiotic conditions in large, shallow lake in the light of principal components analysis (PCA). Limnological Review 5: 205-214.

Scheffer M. 1989. Alternative stable states in eutrophic freshwater systems. A minimal model. Hydrobiol. Bull. 23: 73-83.

Scheffer M. 1990. Multiplicity of stable states in freshwater systems. Hydrobiologia 200/2001: 475-486.

Scheffer M. 2001a. Alternative Attractors of Shallow Lakes. The Scientific World 1: 254–263.

Scheffer M. 2001b. Ecology of shallow lakes. Kluwer Academic Publishers: 1-356.

Scheffer M., Hosper S. H., Meijer M. L., Moss B., Jeppesen E. 1993. Alternative equilibria in shallow lakes. Trends Ecol. Evol. 8: 275-279.

Scheffer M., Jeppesen E. 1998. Alternative stable states. In: Jeppesen E., Søndergaard M., Søndergaard M., Christoffersen K. (eds), The structure role of submerged macrophytes in lakes. Ecological Studies 131: 387-406.

Siepak J. (ed.) 1992. Physico-chemical analysis of water and soils. (in Polish) 193. UAM, Poznań.

Stangenberg M. 1936. Szkic limnologiczny na tle stosunków hydrochemicznych Pojezierza Suwalskiego (Limnological characteristic of lakes from Suwałki Lakeland on the background of hydro-chemical correlations). Rozpr. Spraw. Inst. Badaw. Las. Państw, A. 19: 7-54 (in Polish).

Thienemann A. 1921. Seetypen. Die Naturwissenschaften. 18: 1-3.

Thienemann A. 1925. Die Binnengewässer Mitteleuropas. Die Binnengewässer 1. E. Schweizerbart'sche Verlagsbuch-handlung, Stuttgart.

van Donk E., van de Bund W. J. 2002. Impact of submerged macrophytes including charophytes on phyto- and zooplankton communities: allelopathy versus other mechanisms. Aquatic Botany 72: 261-274.

Wherry E. T. 1922. Note on specific acidity. Ecology 3: 346-347.

Williamson C. E., Morris D. P., Pace M. L., Olson O. G. 1999. Dissolvet organic carbon and nutrients as regulators of lake ecosystems: resurrection of more integrated paradigm. Limnol. Oceanogr. 44(3): 795-803.

Wiszniewski J. 1953. Remarks about typology of Polish lakes. Pol. Arch. Hydrobiol. 1 (XIV): 11-23 (in Polish).

Wojciechowski I. 1999. The conditions of working of the peat boggy and water-peat boggy ecosystems in Poland. In: Radwan S., Kornijów R. (ed.), Problemy aktywnej ochrony ekosystemów wodnych i torfowiskowych w polskich parkach narodowych. Wydawnictwo UMCS, Lublin, 57-63 (in Polish).

Wojciechowski I., Górniak A. 1990. Influence of the brown humic and fulvic acids orginating from nearby peat bogs on phytoplankton activity in the litoral of two lakes in Mid-Eastern Poland. Verh. Internat. Verein. Limnol., 24, 295-297.

Wojciechowski I., Górniak A., Rule J. H. 1990. Wpływ substancji humusowych pochodzących z przyległych torfowisk na wody litoralu dwóch jezior na Pojezierzu Łęczyńsko-Włodawskim (Influence of humic substances originating from nearby peat bogs on littoral waters of two lakes from Łęczna-Włodawa Lakeland (Poland). In: Użytki ekologiczne w krajobrazie rolniczym). Mat. CPBP 04.10.01. Wyd. SGGW-AR. Warszawa, 107-123 (in Polish).

Ter Braak C.J.F, Šmilauer P. 2002. CANOCO Reference Manual and User's Guide to Canoco for Windows: Software for Canonical Community Ordination (version 4.5). Microcomputer Power. Ithaca, NY, USA.

Streszczenie

W pracy scharakteryzowano 13 płytkich jezior zaawansowanych w procesie sukcesyjnym na terenie Wielkopolski w oparciu o parametry fizyczno-chemiczne wód, stopień rozwinięcia roślinności makrofitowej i koncentrację chlorofilu a fitoplanktonu. Jeziora te porównano z 12 zbiornikami o silnie wyrażonym dystroficznym charakterze w regionie. Jeziora zaawansowane w procesie zarastania wykazywały zarówno cechy charakterystyczne dla jezior eutroficznych i dystroficznych. Charakteryzowały się wysoką koncentracją DOC i zasadniczo znacznym zabarwieniem wody (tab. 1). Były również zasobne w biogeny. W porównaniu z jeziorami dystroficznymi różniły się istotnie pod względem odczynu, przewodnictwa elektrolitycznego, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} i Cl^{-}. Różniły się również stopniem rozwinięcia roślinności makrofitowej i koncentracji chlorofilu a (tab. 1, ryc. 1). W pracy przedyskutowano klasyfikację i typologię jezior będących końcowymi stadiami ewolucji ekosystemów jeziornych, zwracając szczególną uwagę na zbiorniki typu allorotroficznego.