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ECOLOGICAL AND TROPHIC STATUS OF TWO SMALL HARDWATER LAKES OF THE LUBLIN UPLAND WITH AGRICULTURAL CATCHMENTS

Wojciech Pęczuła, Magdalena Suchora, Magdalena Toporowska

Department of Hydrobiology, University of Life Science in Lublin
Dobrzańskiego str. 37, 20-062 Lublin, wojciech.peczula@up.lublin.pl, magda.suchora@up.lublin.pl, magdalena.toporowska@up.lublin.pl

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Summary. Based on our observations and literature data we have analysed the trophic and ecological status of two small (area < 6 ha) and shallow (mean depth < 5 m) hardwater lakes with agricultural catchments situated in Lublin Upland. Data from the summer of 2009 (pH, conductivity, total phosphorus, transparency, chlorophyll *a*, phytoplankton abundance, trophic state index) showed that the lakes extremely differ with their trophic and ecological status. Lake Syczyńskie (TSI = 78–81) is hypertrophic, phytoplankton-dominated with bad ecological status while Lake Słone (TSI = 44–58) – mesotrophic, macrophyte-dominated with high ecological status. The estimated phosphorus supply from the agricultural catchment and lake loads have shown that, surprisingly, Lake Słone, being in the better state, have higher eutrophication risk related to potential higher P supply and load. In conclusion, we have proposed that this unexpected result is related to the complex of mechanisms including the buffering role of the peatland belt around Lake Słone as well as the stabilizing function of dense macrophyte beds in this lake, which may serve as an example of alternative stable states in shallow lakes.

Key words: small water bodies, hard-water lakes, ecological status, agricultural catchment

INTRODUCTION

Small lakes have an important function in preserving biodiversity in the landscape, especially in the areas with small amount of natural water bodies

[Scheffer *et al.* 2006]. There are more than 500 000 lakes (natural water bodies larger than 1 ha) in Europe, from which about 80% to 90% are small ones with a surface area of between 1 and 10 hectares [Kristensen and Hansen 1994]. Most natural European lakes had been formed or reshaped by the last glaciation, thus they are situated in north and central European plains and lowlands, although some lakes lie in formerly glaciated mountainous areas of western and central part of the continent [Meybeck 1995]. Thus, some European areas are naturally scarce or lacking of natural lakes because of being outside the range of the last glaciation or unfavorable climatic conditions. In Poland almost all natural lakes are situated in the northern, lowland part of the country within the range of Vistulian glaciation (excluding a few mountain ones, several dozen in Polesie Lubelskie and unknown amount oxbow lakes in river valleys). An interesting example of non-glacial natural water bodies situated outside this range are four small karst[1] lakes (Syczyńskie, Słone, Pniówno and Tarnowskie) of the Lublin Upland (Eastern Poland), the area with very scarce surface water system [Dawidek *et al*. 2000]. As the Lublin Upland have relatively small forest cover and has long lasting history of intensive agricultural development, water bodies situated here stay under strong anthropogenic impact. However, both data from the literature [Toporowska and Pawlik-Skowrońska 2014] and field observations [Suchora, unpublished] revealed that, despite the similar origin, morphometric features and the situation in the agricultural landscape, the water quality of Lublin Upland lakes varies comparing one to another. Although some Lublin Upland lakes, particularly Lake Syczyńskie, had been previously an object of paleoecological, hydrological, hydro-chemical and hydro-biological studies [Dawidek *et al.* 2000, Kornijów *et al.* 2002, Halkiewicz 2005, Smal *et al.* 2005, Wiśniewska *et al*. 2007, Dawidek *et al*. 2009, Ferencz and Dawidek 2014, Toporowska and Pawlik-Skowrońska 2014], the knowledge about the trophic and ecological status of the others, including their biocenoses is lacking. This paper will focus on the determination of the actual ecological and trophic status of two Lublin Upland lakes (Syczyńskie and Słone) against their catchment characteristics and degree of the agricultural impact.

MATERIAL AND METHODS

Lake Syczyńskie (51°17’13’’N, 23°14’15’’E) and Lake Słone (51°18’17’’N, 23°21’55’’E) are situated within Chełm Hills (Pagóry Chełmskie) a northern part of Lublin Upland [Chałubińska and Wilgat 1954], being in the borderland zone between Polish Uplands and Polish Lowland (Łęczna-Włodawa Lakes) (Fig. 1). The studied area consist of flat hills, from which the most elevated

[1] The genesis of lakes situated in Lublin Upland is still under discussion and probably is more complicated. For details see: Dobrowolski [2006].

reach about 220 m a.s.l. The whole area is situated on the calcareous Cretaceous formations (opoka, marl, chalk) deposited at rather shallow depths under the ground level which strongly influences the chemical composition of the lake's water. The total mineral content of these hard-water lakes (with calcium and bicarbonate ions predominating) exceeds 500 mg dm^{-3}, while the total hardness oscillates between 5.14 and 6.57 mval dm^{-3} [Dawidek *et al.* 2000]. Both lakes are small (area < 6ha) and shallow (mean depth < 5m). Basic morphometrical parameters of studied lakes are shown in Table 1.

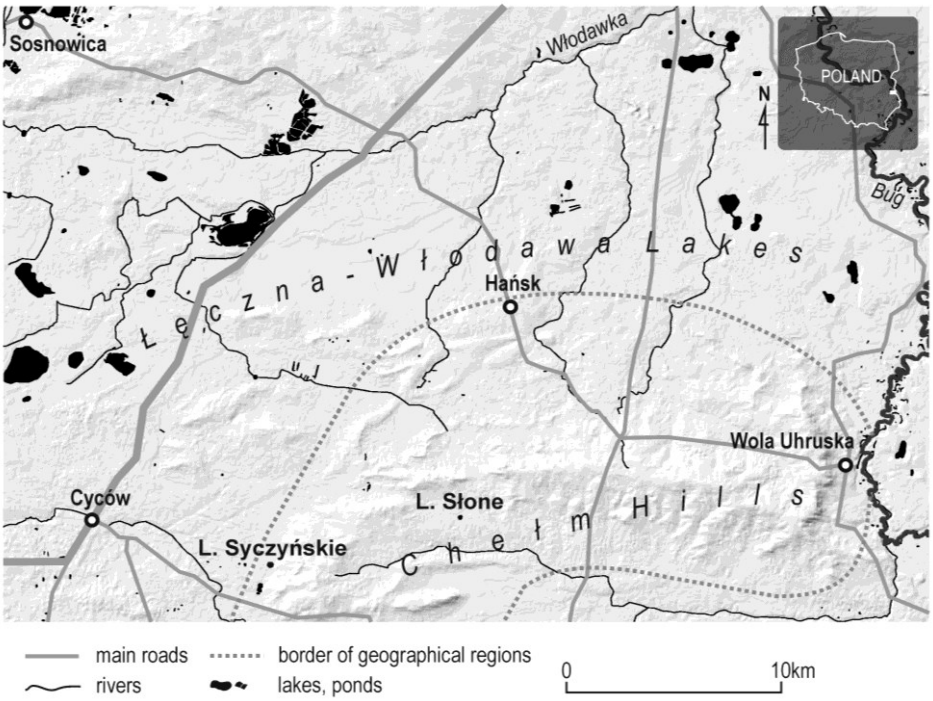

Fig. 1. The situation of the studied lake (a map of land relief by dr Leszek Gawrysiak from Department of Geoinformatics, UMCS in Lublin was used as a base)

Table 1. Basic morphometric parameters of the studied lakes [after: Michalczyk and Wilgat 1998]

Specification	Syczyńskie	Słone
Altitude, m a.s.l.	179.6	185.6
Area, ha	5.6	3.4
Max depth, m	2.9	8.0
Mean depth, m	0.9	4.6
Volume, m^3	51 200	209 000

We have analyzed data obtained both from the published paper [Toporowska and Pawlik-Skowrońska 2014] in the case of Lake Syczyńskie and our field studies in Słone Lake. Both datasets come from summer of 2009 (July and August, sampling once a month). The data cover: water transparency (Secchi disc), pH, electrolytic conductivity and dissolved oxygen content (measured in situ by the use of YSI 556 Multi Probe), total phosphorus content [Hermanowicz *et al.* 1999], chlorophyll *a* concentration [ISO 1992] and phytoplankton abundance determined by the Utermöhl method [1958]. Measurements and sampling (2 dm^3 Ruttner sampler) were done from the surface water level (0.5 m) in the central part of both lakes.

Critical phosphorous loads for lakes [Vollenveider 1976] from the catchment were estimated to asses the anthropogenic (particularly agricultural) impact and were calculated using coefficients proposed by Soszka [2010], on the basis of catchment land use data for Lake Syczyńskie [Smal *et al.* 2005] and Słone (own measurements). To estimate actual trophic status we have calculated Trophic State Index (TSI) [Carlson 1977] using water transparency, concentration of chlorophyll *a* and total phosphorous. Additional measure was phytoplankton structure evaluated on the basis of its abundance. Ecological status was estimated according to recent Polish environmental regulations [Rozporządzenie... 2011].

RESULTS

Water of both lakes had high level of the total mineral content which was reflected in high conductivity values (414–506 μS cm^{-1}) and slightly alkaline pH (7.7–8.5). However, main trophic parameters differ significantly between lakes. Syczyńskie was characterized by high total phosphorus content (0.590–0.657 mg dm^{-3}) and phytoplankton amount (chl *a*: 147.8–256.9 μg dm^{-3}, total abundance: 25 948–41 285 thousands of ind. dm^{-3}) and consequently very low visibility (0.3 m). In Lake Słone these parameters were more than over a dozen times lower – in the case of TP, chlorophyll *a* and phytoplankton abundance or several times lower in the case of water transparency (Tab. 2). These differences between two studied lakes were reflected in the values of TSI, which amounted to 78–81 in Lake Syczyńskie and were almost twice as low in Lake Słone (Tab. 2).

Except the total abundance, the phytoplankton structure also significantly differed between the lakes. In Syczyńskie there was a distinct domination of cyanobacteria, which accounted for 74–94% of the total phytoplankton abundance with filamentous *Planktothrix aghardii* (Gomont) Anagnostidis & Komárek predominating. Phytoplankton of Lake Słone was more diverse. About 50% of the total abundance comprised of chlorophytes with various small chlorococcal algae like *Crucigenia tetrapedia* (Kirchner) Kuntze or desmids (*Closterium acutum*

Brębisson). Other groups were represented by diatoms (small centric species), cyanobacteria (with coccal *Aphanocapsa holsatica* (Lemmermann) G. Cronberg & Komárek) or chrysophytes with *Dinobryon sociale* Ehrenberg (Fig. 2).

Table 2. Basic hydrochemical and biological parameters of the studied lakes in 2009

Specification	Syczyńskie[1]		Słone	
	July	August	July	August
pH	8.5	8.4	7.7	8.2
Conductivity, µS cm^{-1}	414	439	506	505
Transparency, m	0.3	0.3	1.1	2.2
Total phosphorus, mg dm^{-3}	0.590	0.657	0.074	0.010
Chlorophyll *a*, µg dm^{-3}	147.8	256.9	7.6	5.2
Total phytoplankton abundance, 10^3 ind. dm^{-3}	25 948	41 285	1 298	620
TSI	78	81	58	44
Ecological status	V (bad)	V(bad)	I (high)	I (high)

[1] after: Toporowska and Pawlik-Skowrońska 2014, Toporowska and Pawlik-Skowrońska, unpublished

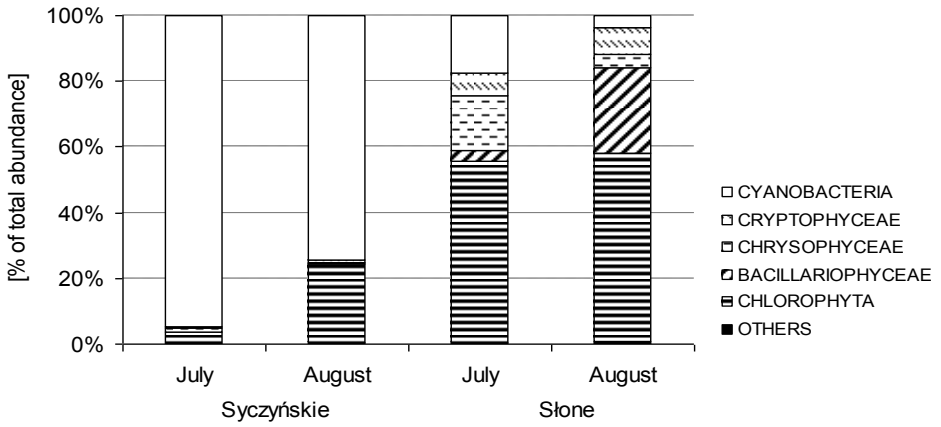

Fig. 2. The percentage share of taxonomic groups in the total phytoplankton abundance in studied lakes in 2009 (chart with Lake Syczyńskie on the basis of data from: Toporowska and Pawlik-Skowrońska 2014, Toporowska and Pawlik-Skowrońska, unpublished)

Ecological status of the studied lakes differed extremely. In Lake Słone it was assessed as „high" (the highest rank in the five-class Polish system) on the basis of chlorophyll *a*, transparency, conductivity and total phosphorus. The ecological status of Lake Syczyńskie was classified as „bad" (the lowest rank).

Very interesting results were obtained from the catchment analyses. Studied lakes have extensive catchment areas, what taken together with its small areas, gives unfavorable conditions as regarding the eutrophication risk: both Ohle and Schindler indices amounted to high values (Tab. 3). However, the land use in both catchments varies one to another. Lake Syczyńskie has typical agriculture-dominated catchment with almost 70% of the area covered by arable lands (Tab. 3). Catchment of Lake Słone is more diverse, containing almost 20% of forests

Table 3. Catchment properties and estimated phosphorus (P) supply and load of studied lakes

Specification	Syczyńskie[1]	Słone
Catchment area, ha	458.2	714.6
Ohle index	80.2	211.0
Schindler index	89.5	34.3
Land use, ha (%)		
– arable lands & orchards	317.5 (69%)	363.5 (51%)
– meadows & pastures	106.5 (23%)	171.5 (24 %)
– forests & shrubs	1.6 (<1%)	160.0 (19%)
– other	26.7 (6%)	19.5 (3%)
Estimated P supply from the catchment, kg $year^{-1}$	124.3	164.8
Estimated P load of the lake, g m^{-2} $year^{-1}$	2.18	4.85

[1] catchment data after Smal *et al.* 2005

within, however, the total area of arable lands in both catchments is similar (Syczyńskie: 317 ha, Słone: 363 ha). Differences in the catchment characteristics were reflected in the amount of phosphorus which potentially may be imported to the studied lakes. The estimated total supply from studied catchments amounted to 124.3 kg $year^{-1}$ in Lake Syczyńskie and 164.8 kg $year^{-1}$ in Lake Słone. Nevertheless, because of the differences between lakes in their surface areas, phosphorus annual load of Słone is twice as high as in Syczyńskie and amounts to 4.85 g m^{-2} $year^{-1}$ (Tab. 3).

DISCUSSION

The present study was designed to determine the actual trophic and ecological status of two small lakes of Lublin Upland. Our results have shown that despite both lakes have similar field situation, agricultural catchments and lake basin morphometry, extremely differ one to another with studied parameters.

The values of basic chemical parameters in Lake Syczyńskie pointed to its hypertrophy, which was revealed in previous studies [Kornijów and Pęczuła 2005, Toporowska i Pawlik-Skowrońska 2014, Ferencz *et al.* 2014]. Also the phytoplankton abundance and structure in Lake Syczyńskie were typical for hypetrophic, phytoplankton-dominated lakes [Moss *et al.* 2003]; those type of the community is rarely found in other lakes of Łęczna-Włodawa Lakes [Wojciechowska and Solis 2009]. Thus, the hypertrophic conditions in 2009 were also reflected in bad ecological status of the lake, the lowest rank in Polish five-class monitoring system.

Hydro-chemical parameters and phytoplankton amount found in Lake Słone (both chl *a* and the abundance) as well as the structure was typical for mesotrophic, macrophyte-dominated lakes in good ecological status [Moss *et al.* 2003]. In Łęczna-Włodawa Lakes similar phytoplankton structure can be found in shallow, clear water, macrophyte-dominated lakes like Kleszczów [Kornijów *et al.* 2002] or Skomielno [Pęczuła 2013]. The macrophyte-dominated status of Lake Słone is also reflected by the presence of charophyte beds (*Chara intermedia*) which can be found within the littoral zone of the lake [Rarak 2014]. Together with the other parameters, it can suggest, that Lake Słone form a special type of freshwater habitat: *Hard oligo-mesotrophic waters with benthic vegetation of Chara spp*., protected under European Union Habitat Directive (code: 4310) and should be included in Polish wildlife monitoring system, especially that the actual ecological status was estimated as high.

Interesting, although unexpected, finding was that Lake Słone has a very high eutrophication risk related to its agricultural catchment phosphorus supply. Very high P load of this lake is several dozen higher than dangerous according to Vollenveider's criteria [1976] and higher for those estimated for Lake Syczyńskie. Surprisingly, Słone Lake has high ecological status in contrast to Lake Syczyńskie being in the other end of the ecological status scale. These differences can be explained in several ways, although all of them are speculative, due to the lack of detailed research. The first one may point to the underestimation of the phosphorus loads in Syczyńskie Lake in which build-up areas are located very close to the shoreline [Smal *et al.* 2005]. The second explanation may be related to the lower Schindler's index in Lake Słone, thus suggesting the major role of lake depth and volume as factors enhancing natural lake resilience [Schindler 1971]. Additionally, Słone Lake is surrounded by the broad belt of fen-type peatlands which may 1) play a role as a local sink for the phosphorus transport from the catchment [Reddy *et al.* 1999] and/or 2) determine the export of humic compounds to the lake. The second one is suggested by the brownish water colour observed occasionally [Rarak 2014, Suchora and Pęczuła, unpublished data] and may act in the way of bonding the phosphorus by the humic compounds, thus making it unavailable for phytoplankton [Wetzel 1992]. Another possible explanation can be related to the alternative stable state concept [Scheffer *et al.*

1993]. Dense charophyte beds occurring in Słone Lake may play a crucial role (via several possible mechanisms) in phytoplankton development and nutrient amount control, thus providing good ecological status of the lake. However, because of the complex nature of catchment-lake system functioning it is likely that the complex of mechanisms may play a role, therefore it is impossible in this preliminary study to explain observed relations. It is recommended that further research be undertaken in the other Lublin Upland hardwater lakes, particularly in the area of freshwater biocenoses as well as the impact of their upland agricultural catchments on their trophic and ecological status.

CONCLUSIONS

1. Our results have shown, that two studied lakes of Lublin Upland had extremely different hydrochemical and hydrobiological status: Syczyńskie being hypertrophic, phytoplankton dominated with bad ecological status and Słone being mesotrophic, macrophyte-dominated with high ecological status.

2. Surprisingly, the estimated phosphorus supply from the catchment is much higher in Słone Lake, although both lakes have agricultural catchments, high Schindler ratio and above dangerous phosphorus loads.

3. We have proposed, that this unexpected result is related to the complex of several mechanisms including the buffering role of the peatland belt around Lake Słone as well as the stabilizing function of dense macrophyte beds in this lake, which may serve as an example of alternative stable states in shallow lakes.

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STATUS EKOLOGICZNY I TROFICZNY DWÓCH MAŁYCH TWARDOWODNYCH JEZIOR WYŻYNY LUBELSKIEJ O ZLEWNIACH ROLNICZYCH

Streszczenie. Na podstawie własnych badań i danych literaturowych przeanalizowano stan troficzny i ekologiczny dwóch małych (< 6 ha) i płytkich (śr. gł. < 5 m) twardowodnych jezior o zlewniach rolniczych, położonych na Wyżynie Lubelskiej. Dane z okresu letniego 2009 r. (pH, przewodność, fosfor ogólny, przeźroczystość wody, chlorofil *a*, liczebność fitoplanktonu, wskaźnik stanu trofii) wskazują, że status troficzny i ekologiczny badanych jezior różnił się ekstremalnie. Jezioro Syczyńskie (TSI = 78–81) to zbiornik hypertroficzny, zdominowany przez fitoplankton, o złym stanie ekologicznym, podczas gdy Jezioro Słone (TSI = 44–58) – zbiornik mezotroficzny, zdominowany przez makrofity, o bardzo dobrym stanie ekologicznym. Oszacowana dostawa fosforu ze zlewni rolniczych oraz obciążenie jezior wykazały, że Jezioro Słone, pomimo lepszych parametrów jakości wody, jest bardziej zagrożone eutrofizacją, co wiąże się z zewnętrzną dostawą fosforu ze źródeł obszarowych. We wnioskach zaproponowano, że ten nieoczekiwany rezultat może być wyjaśniony szeregiem współwystępujących mechanizmów, w tym buforującą rolą pasa torfowisk wokół Jeziora Słone oraz stabilizującą funkcją makrofitów w tym jeziorze, co może być przykładem stabilnych stanów alternatywnych.

Słowa kluczowe: drobne zbiorniki wodne, jeziora twardowodne, stan ekologiczny, zlewnia rolnicza