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Role of Lake Symsar in the reduction of phosphorus concentration in surface runoff from agricultural lands

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Abstract

The study was aimed at assessing the role of Lake Symsar in the reduction of phosphorus delivered mainly by the Symsarna River. Studies were carried out since March 2011 till October 2013 in the catchment basin of Lake Symsar situated in north-eastern Poland. Every month surface water samples representative for the catchment were taken for phosphate-phosphorus (PO_4-P) and total phosphorus (TP) analyses. Obtained results were analysed with the distinction of vegetative and non-vegetative season.

Lake Symsar is the last water body in the Symsarna River system. The river divides the lake into main basin and a bay part. Concentrations of PO_4-P were higher by 17% in the former than in the latter part, TP concentrations showed reverse proportions. The highest concentrations of TP were noted in a forest stream and the highest concentrations of PO_4-P in the Tolknicka Struga. Reduced concentrations of both P forms were found in waters of the Symsarna River downstream its outflow from the lake. With respect to the concentrations of PO_4-P and TP, waters of the Symsarna River up- and downstream the lake were ascribed to the 1st class of water quality. Through-flow Lake Symsar improves the quality of waters (the Symsarna River and smaller streams) draining agricultural catchment by the reduction of concentrations of phosphorus compounds.

Key words: *concentrations, lake agricultural catchment, phosphate-phosphorus content, surface waters, total phosphorus*

INTRODUCTION

Phosphorus is characterised by limited migration in aquatic environments due to bioaccumulation, sorption and low solubility. Surface runoff of total phosphorus largely depends on the soil grain size structure. In more compact soils it is more strongly combined with soil particles, which limits its transport. Therefore, TP is easily washed out from light permeable soils [GRABIŃSKA *et al*. 2004].

Phosphorus cycling consists of many transformations from mineral to organic forms and *vice versa*. In the literature, these transformations are presented as a small cycle operating in the vegetation season and a large cycle which involves TP deposition in bottom sediments.

Undoubtedly, temperature is of greatest importance in these processes since it affects the development of plankton and higher aquatic vegetation, both responsible for assimilation of mineral nitrogen and phosphorus forms. Phosphorus may be also removed from cycling due to sedimentation and bioaccumulation [KOC, SKWIERAWSKI 2003] or resuspended from sediments due to anaerobic processes in bottom sediments. Phosphorus is often mentioned in the literature as the main nutrient responsible for eutrophication. Low concentrations of this element make it (contrary to nitrogen) a factor limiting primary production in surface waters. Many authors have attempted classifying water quality with respect to phosphorus abundance. Classification presented in the decree of the Minister of Environment of 9 November 2011 on the classification of uniform parts of surface waters and on environmental quality norms for priority substances is in effect in Poland and in the European Union.

MATERIAL AND METHODS

Studies on the effect of the Symsarna River on phosphorus content in Lake Symsar were carried out since March 2011 till October 2013. Lake Symsar is a through-flow lake, the last one on the Symsarna water course before its outlet to the Łyna River. It has an area of 135.5 ha, maximum depth 9.6 m and volume 6649.5 thousand m^3. Agriculture is the main type of land use in the catchment basin of the Symsarna River, 10% of its area is covered by wetlands. Apart from the Symsarna, Lake Symsar is fed by smaller streams, among others by a reclamation ditch Tolknicka Struga which receives primary treated waste waters from residential settlement in the Klutajny village and by two forest streams (stream I and II) that drain agricultural-forest lands. Direct catchment of Lake Symsar is characterised by steep slopes. Forests situated in its north-eastern part occupy 45% of the catchment area. Arable lands and grasslands cover 40% and 5% of the area, respectively. Recreational grounds with numerous bungalows occupy 10% of the catchment. Results of earlier studies qualified the lake to the 3rd class of water quality and to the 3rd class of susceptibility to degradation [SIDORUK, POTASZNIK 2011].

Every month water samples were taken at the inlet to and outlet from the lake. Samples were collected to 5 dm^3 polyethylene containers, fixed and transported to the laboratory of the Department of Reclamation and Environmental Management in Olsztyn.

Water samples were analysed for phosphate-phosphorus (PO_4-P) and total phosphorus (TP) colorimetrically with ammonium molybdate and tin (II) chloride according to standard methods. In the field, oxygen concentration was measured with the YSI 6600 oxygen meter. Chemical analyses were performed in the vegetation season (April–September) and non-vegetation season (October–March).

The aim of this study was to assess the role of Lake Symsar in limiting phosphorus concentrations in waters of the Symsarna River downstream the lake.

RESULTS AND DISCUSSION

Available literature data indicate a decrease of water pollution by phosphorus from point sources in the last three decades. However, phosphorus outflow from dispersed and surface sources (mainly from arable lands) is still large and accelerates the eutrophication of surface waters [HAHN *et al*. 2012]. Many attempts are being undertaken to limit the amount of phosphorus from agricultural sources. This study showed that the highest concentrations of PO_4-P were recorded in waters of the Tolknicka Struga reclamation ditch (Fig. 1), fed permanently by primary treated domestic sewage effluents. Mean concentration of PO_4-P in water was 0.203±0.25 $mg \cdot dm^{-3}$ in the vegetation season and 0.054±0.06 $mg \cdot dm^{-3}$ out of the vegetation season (Tab. 1). This was by 73.1% (vegetation) and 26.1% (non-vegetation) higher than the mean concentration in waters of other streams inflowing to Lake Symsar. PO_4-P concentrations in the ditch largely depended on the constant input of mechanically treated domestic sewage from residential settlement. They showed the lowest variability coefficient (66.5%) among all measured concentrations.

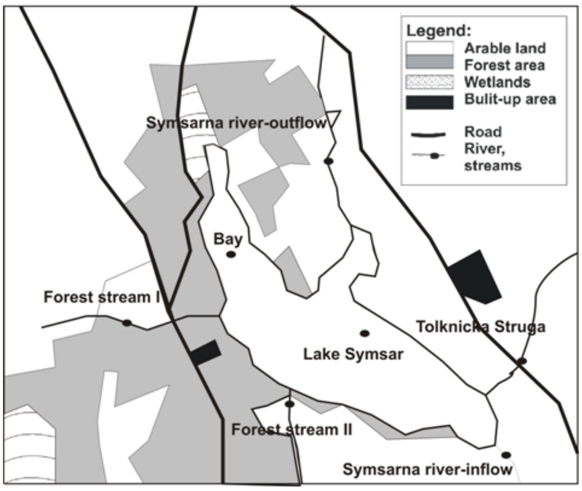

Fig. 1. Location of sampling sites; source: own elaboration

The highest concentrations of TP (0.439±0.24 $mg \cdot dm^{-3}$) were found in the vegetation period in waters of forest stream II draining agricultural lands and (as in the case of PO_4-P) in waters of the Tolknicka Struga (0.258±0.24 $mg \cdot dm^{-3}$). TP concentrations in both streams were by 68.6% (forest stream II) and by 46.5% (Tolknicka Struga) higher than the averaged concentrations of TP in the Symsarna River and forest stream I.

In the non-vegetation period the lowest TP concentrations were noted in forest stream I of agricultural-forest catchment (mean 0.118±0,07 $mg \cdot dm^{-3}$) i.e. by 44.7% smaller than in other streams.

In waters of the Symsarna River – the main inflow to Lake Symsar – mean concentrations of PO_4-P were 0.072±0.08 $mg \cdot dm^{-3}$ in the summer and 0.074±0.05 $mg \cdot dm^{-3}$ in the winter half year (Tab. 1). This, according to the Decree of the Minister of Environment [Rozporządzenie MŚ 2011], ascribes these waters to the 1st class of water quality. PO_4-P concentrations in the outflow from lake were smaller by 55% compared with those in the inflowing waters during the vegetation season (Fig. 2). Considering smaller

Table 1. Concentrations of PO_4-P and TP in surface waters of the Lake Symsar catchment basin

Water	Concentration, mg·dm^{-3}				
	vegetation season, mean	non-vegetation season, mean	range	median	coefficient of variation, %
Phosphate phosphorus (PO_4-P)					
Lake Symsar	0.040±0.04	0.070±0.05	0.006–0.165 (0.055±0.04)	0.040	124.4
Bay of Lake Symsar	0.031±0.03	0.063±0.05	0.001–0.132 (0.046±0.04)	0.049	112.9
Symsarna River – inflow	0.072±0.08	0.074±0.05	0.004–0.276 (0.073±0.06)	0.064	113.8
Tolknicka Struga	0.203±0.25	0.054±0.06	0.007–0.771 (0.132±0.20)	0.061	66.5
Forest stream I	0.058±0.03	0.044±0.03	0.010–0.113 (0.051±0.03)	0.044	163.5
Forest stream II	0.034±0.005	0.0003±0.005	0.0003–0.040 (0.029±0.014)	0.032	193.3
Symsarna River – outflow	0.032±0.04	0.074±0.06	0.002–0.200 (0.053±0.05)	0.034	102.2
Total phosphorus (TP)					
Lake Symsar	0.124±0.08	0.183±0.08	0.007–0.290 (0.152±0.08)	0.130	182.9
Bay of Lake Symsar	0.134±0.09	0.191±0.09	0.033–0.310 (0.160±0.09)	0.186	170.5
Symsarna River – inflow	0.168±0.10	0.130±0.05	0.011–0.360 (0.149±0.08)	0.126	182.2
Tolknicka Struga	0.356±0.30	0.149±0.10	0.044–0.938 (0.258±0.25)	0.183	103.1
Forest stream I	0.134±0.06	0.118±0.07	0.021–0.271 (0.126±0.06)	0.125	197.2
Forest stream II	0.469±0.26	0.288±0.25	0.181–0.801 (0.439±0.24)	0.415	178.9
Symsarna River – outflow	0.122±0.09	0.136±0.07	0.047–0.286 (0.128±0.08)	0.101	160.7

Source: own study.

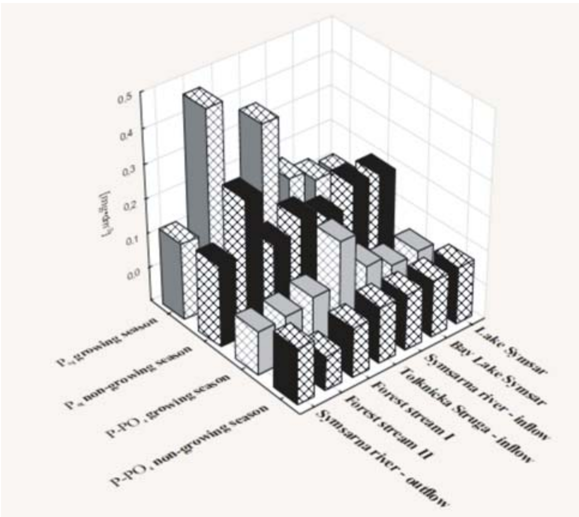

Fig. 2. Mean concentrations of PO_4-P and TP in vegetation and non-vegetation periods in waters of Lake Symsar and in its inflows and outflow; source: own study

volume of inflowing water (and hence smaller PO_4-P input) this comparison indicates significant reduction of concentrations during water flow through the lake. During the non-vegetation season PO_4-P concentrations were similar in the inflow and outflow from the lake with no practical reduction. Concentrations of TP at river inflow were by 27.8% higher (0.149±0.08 mg·dm^{-3}) than in the river outflow. TP concentrations classified river waters to the 1st class of water quality. The same classification was applied by WIOŚ in 2010 [WIOŚ 2011]. In the non-vegetation season outflow waters contained by 3.6% more TP than those delivered by the Symsarna River. The source of increased TP concentrations in this period could be the loads introduced with smaller inflows.

The Symsarna River inflowing from the south-east and flowing out to the north of Lake Symsar conventionally divides the lake into main basin and a bay. The latter being a north-eastern part of the lake is outside the river course. Comparative analysis of phosphorus forms in both parts allowed for the assessment of river impact. Water sampled from the main basin was by 23.4% richer in PO_4-P (0.040±0.04 mg·dm^{-3}) during the vegetation season and by 10.6% richer (0.070±0.05 mg·dm^{-3}) in the non-vegetation season than bay waters. The Symsarna River upstream the lake drains mainly agricultural lands. The main source of phosphates may thus be nutrients not taken up by plants and delivered to waters during surface runoff. This way, the river becomes the main source of phosphates to lake waters. Also studies by BERLEĆ *et al.* [2013] showed the highest concentration of phosphates in a lake delivered in waters draining agricultural lands and discharging to the lake. HAHN *et al.* [2012] underlined the importance of rainfall intensity which affected phosphorus runoff from lands, mainly from arable fields. They observed that phosphorus was more susceptible to washing out at medium rainfall intensity than during a downpour. Similarly, DURKOWSKI *et al*. [2006] observed that the concentration of phosphorus and nitrogen in water inflows to Lake Miedwie was higher in wet years which was caused by more intensive nutrient outwash. These studies lead, however, to general conclusions that a lack or deficit of precipitation results in the cessation of surface runoff which consequently eliminates nutrient transport in a catchment. This confirms the thesis that rainfalls markedly stimulate surface erosion in a catchment. In the Lake Symsar catchment basin, mean sum of precipitation in the years 2011–2013 was 410 mm in the vegetation season and almost half that (215 mm) in the non-vegetation season.

Concentrations of TP in waters of the main basin of Lake Symsar varied widely in the range from 0.007 to 0.290 $mg \cdot dm^{-3}$ (mean 0.152±0.08 $mg \cdot dm^{-3}$, median 0.130 $mg \cdot dm^{-3}$) at a high variability coefficient (182.9%) (Tab. 1). In the bay, TP concentrations varied between 0.033 and 0.310 $mg \cdot dm^{-3}$ at the coefficient of variability equal 170.5%. TP concentrations showed reverse relationships than phosphates since TP concentrations were by 5.9% higher in bay than in the main basin.

Studies by GRABIŃSKA *et al*. [2004] demonstrated that in summer the concentrations of TP were higher by 36% and those of phosphates – by 32% than in the spring time which was caused by agricultural land use and unfavourable weather conditions resulting in water temperature and the intensity of water flow and aeration. Similar relationships were revealed in a study of a eutrophic Lake Jagiełek performed by SZYMCZYK and GLIŃSKA-LEWCZUK [2007]. Phosphate-phosphorus concentrations were on average 0.26 $mg \cdot dm^{-3}$ in spring and 0.70 $mg \cdot dm^{-3}$ in the period of summer low waters. These values represented an excess of phosphorus that remained unused in water when all plant demands for this nutrient were covered at highly eutrophic conditions and phosphorus was not a limiting factor any more.

High temperatures and water waves (particularly important at low water levels) are responsible for bottom sediments resuspension and phosphate presence in water. The effect of temperature on mineralization of phosphorus deposited in sediments was shown in studies by SKWIERAWSKI and CYMES [2004] in a shallow reservoir Nowe Wółki.

Oxygen conditions largely contributed to phosphorus transformations which can be seen in Fig. 3. During vegetation period the bay of Lake Symsar was dominated by total phosphorus whose main part was organic P (plankton) due to water circulation and sediment resuspension in shallow part of the water body. During this period oxygen concentration in bay water was by 13.5% lower (Fig. 3) than in the main basin which was probably caused by algal blooms and decomposition of organic matter. Reverse relationship was observed in lake water close to the river inlet, where oxygen concentration was higher (9.1 mg $O_2 \cdot dm^{-3}$) and phosphates were the dominating P form because of mineralization, abundance of river waters with phosphates and aeration of through-flowing river waters. KIM *et al*. [2011] observed the effect of water aeration but also of season on sediment resuspension. The share of available phosphorus in sediments was much higher in the dry than in the rainy season probably because of a lack of resuspension.

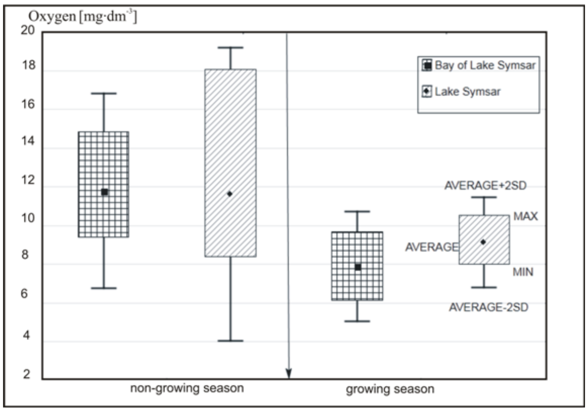

Fig. 3. The variability of oxygen concentrations in Lake Symsar and in its bay; source: own study

Studies performed by SMOROŃ *et al*. [2011] in submountain region, where surface runoff is especially intensive, showed that a high percent of grasslands on lands of steep slopes decreased nutrient concentrations in surface waters.

The Symsarna River exerted an important impact on waters of Lake Symsar by feeding them with phosphates of agricultural origin. Parallel studies on nitrogen content in the same lake, its inflows and outflow [POTASZNIK *et al.* 2013] confirmed that streams flowing through agricultural lands and small streams flowing through villages devoid of sanitary infrastructure pose the greatest threat to lake water quality. However, one should not neglect a positive role of the river in the improvement of lake water aeration, particularly in periods when the water body is exposed to low oxygen concentrations (stagnation of water). One should also consider a positive role of Lake Symsar on river water quality similar to that observed by TARKOWSKA-KUKURYK [2013] in the Kraśnik dam reservoir which markedly reduced high phosphorus loads delivered in waters of the Wyżnica River.

CONCLUSIONS

1. Through-flow Lake Symsar improves the quality of waters (the Symsarna River and smaller

streams) draining agricultural catchment by the reduction of concentrations of phosphorus compounds.

2. Positive effect of Lake Symsar on the reduction of total phosphorus in outflowing water manifests itself in both vegetation (reduction by 27.8%) and non-vegetation period (reduction by 3.6%). Phosphate phosphorus was reduced (by 55%) only in the vegetation period.

3. With respect to PO_4-P and TP concentrations, the Symsarna River had waters of the 1st class of water quality.

4. The Symsarna River exerted a significant impact on lake water quality mainly by increased input of mineral forms of phosphorus. Bay of the lake, despite poorer aeration, had waters of better quality since phosphorus delivered in the river water did not accumulate there which protected the bay from phosphate input from the catchment.

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Rola jeziora Symsar w zmniejszaniu stężenia fosforu w wodach odpływających z terenów użytkowanych rolniczo

STRESZCZENIE

Słowa kluczowe: *fosfor ogólny, jezioro, kwas fosforanowy, wody powierzchniowe, zawartość fosforu, zlewnia rolnicza*

Celem badań była ocena roli jeziora Symsar w zmniejszaniu ilości fosforu, dopływającego do akwenu głównie rzeką, Symsarna. Badania nad wpływem jeziora Symsar w zmniejszaniu stężenia fosforu pochodzącego ze zlewni rolniczej były realizowane od marca 2011 do października 2013 r. w zlewni jeziora Symsar usytuowa-

nego w północno-wschodniej Polsce. Obejmowały comiesięczne pobieranie próbek wody powierzchniowej, reprezentatywnych dla badanej zlewni, w celu przeprowadzenia analizy oceny zawartości w nich fosforu fosforanowego (PO_4-P) oraz ogólnego (TP). Uzyskane wyniki poddano analizie z uwzględnieniem sezonu wegetacyjnego i pozawegetacyjnego. Jezioro jest ostatnim zbiornikiem w systemie rzeki Symsarna. Rzeka dzieli akwen na dwie części – akwen główny oraz część zatokową. W wodach głównego akwenu stężenie fosforu fosforanowego było o 17% większe niż w części zatokowej, z kolei zawartość fosforu ogólnego była mniejsza. Największą koncentrację odnotowano w wodzie cieku leśnego (TP) oraz Tolknickiej Strugi (PO_4-P). W wodzie rzeki Symsarna, poniżej wypływu z jeziora zaobserwowano zmniejszenie zawartości badanych form fosforu. Ze względu na zawartość fosforu fosforanowego oraz fosforu ogólnego wody rzeki Symsarna powyżej oraz poniżej jeziora kwalifikowały się do I klasy jakości.

Przepływowe jezioro Symsar – poprzez zmniejszenie zawartości form fosforu w wodach rzeki Symsarna – wpłynęło na poprawę jakości wód odpływających z akwenu.