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DOES INFLOW OF WATER RIVER SHAPE THE NUTRIENT CONTENT OF LAKE SEDIMENTS?

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Abstract

This study evaluated the influence of the Symsarna River on the spatial distribution of organic matter, Kjeldahl nitrogen (N_K) and total phosphorus in the surface layer of bottom sediments. The analyzed site was Symsar Lake in the Olsztyn Lakeland (north-eastern Poland) and the inflows. The results of this study indicate that the lake's morphology and inflowing streams were largely responsible for the variations in the nutrient content of bottom deposits in the flow-through Symsar Lake. The N_K content was significantly correlated with the lake's depth, whereas TOC levels were determined mainly by the location in the lake. The surface layers of bottom sediments in Lake Symsar were characterized by an average organic matter content of 171.2 g kg^{-1} and near-neutral pH (6.78-7.77). The average contents of components in the analyzed sediments were determined at 62.01 g TOC kg^{-1} d.m., 6.08 g N_K kg^{-1} d.m. and 2.18 g TP kg^{-1} d.m. Converted to fresh mass, the above contents expressed per square meter of the lake's sediment reached 3.95 kg TOC m^{-2} f.m., 0.42 kg N_K m^{-2} f.m. and 0.18 kg TP m^{-2} f.m. In turn, the average concentrations of components in sediments from the streams, likewise per square meter, equalled 12.4 g TOC m^{-2} d.m., 0.93 g N_K m^{-2} d.m. and 0.9 g TP m^{-2} d.m. The highest contents of the analyzed components were observed in bottom sediments near the outflow of a river from the lake and in the lake's region intersected by the river. The Symsarna River was responsible for the transport of and variability in the deposition of mineral fractions, and for the nutrient accumulation in the surface layer of bottom sediments. A flow-through water body in a river-lake system can contribute to retention in periods when it exerts a negative impact on the trophic status of a lake. From a broader, ecological viewpoint, it can inhibit the transport of pollutants outside the catchment.

Keywords: lake, bottom sediment, river-lake system, nutrient.

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INTRODUCTION

River-lake systems comprise chains of lakes connected by rivers and streams that flow through them. Rivers play two major roles in nature by facilitating the transport and accumulation of organic matter and nutrients. Sediments can be lifted from the bottom of water bodies by a passing stream or river, and they can be recirculated into the system. Matter can also be accumulated at the bottom, thus contributing to the silting of water bodies. The accumulation of nutrients in bottom sediments of lakes is determined by their supply, the flow rate of the intersecting river and the lake's depth. Compounds released from bottom sediments during the growing season are also removed from the lake by a passing river or stream (HILLBRICHT-ILKOWSKA 1999). The composition of matter carried by flowing water is modified by human activity (responsible for surface runoff and point source pollution) and by natural factors such as climate change (LOZBA-ŞTIRBYLEAC et al. 2011).

Bottom sediments are an important element of lacustrine ecosystems because they participate in the circulation of nutrients and pollutants in water (KOWALCZEWSKA-MADURA, GOŁDYN 2010). The interaction between bottom sediments and the water column, and the resulting internal nutrient cycling can considerably influence the trophic state of a water body (SKWIERAWSKI, SIDORUK 2014). The assimilation of nutrients by macrophytes eliminates them temporarily from the circulation, which affects the ecological status of water bodies (LYCHE-SOLHEIM et al. 2013).

The aim of this study was to analyze variations in nutrient concentrations in the bottom sediments of Symsar Lake. Attempts were made to evaluate: a) the impact of the Symsarna River on changes in nutrient accumulation in bottom sediments, and b) the role of Symsar Lake in limiting the dispersal of organic carbon, Kjeldahl nitrogen and total phospohorus outside the catchment area. It was expected that Symsar Lake acted like a filter inhibiting the dispersion of pollutants outside the catchment area.

MATERIAL AND METHODS

The spatial distribution of Kjeldahl nitrogen, total phosphorus and organic carbon in the surface layer of bottom sediments was evaluated in Symsar Lake (SL) in the Olsztyn Lakeland, north-eastern Poland. The study was carried out between November 2012 and October 2014. The lake is situated approximately 60 km north-east of the town Olsztyn. Its catchment has an area of 2.2 km^2, and is occupied by forests and arable land. Symsar is a flow-through lake with a total area of 135.5 ha (Table 1). It is the last water body in a chain of lakes intersected by the Symsarna River (SR), which enters the lake in the south-east and exits it in the north, towards the Łyna and Pregola rivers. The Symsarna River has a largely agricultural catchment covering an

Table 1

Morphometry of Symsar Lake

Parameter		Unit	Value
Area		(km²)	1.35
Volume		10^3 (m³)	6 626.7
Length of shoreline		(m)	2750
Maximum length			2 750
Maximum width			1 150
Maximum depth			9.6
Average depth			4.9
Area of direct catchment		(km²)	2.2
Land use	arable land	(%)	45.8
	forests		46.5
	buildings		5.1
	wetlands		2.6
Area of indirect catchment		(km²)	229.1
Land use	arable land	(%)	70.0
	forests		15.0
	buildings		5.0
	wetlands		10.0

area of 276.6 km². In the hydrological years of 2013-2014, the average river flow rate was 0.946 $m^3 s^{-1}$, and the outflow per unit area of the catchment was estimated at 2.614 $m^3 s^{-1} km^{-2}$ (POTASZNIK, SZYMCZYK 2015).

Symsar Lake is also supplied by the drainage canal Tolknicka Struga (TS) and some smaller unnamed watercourses, whose catchment areas are dominated by forests (stream I) and arable land (stream II). Due to the low processing capacity of a local wastewater treatment plant, Tolknicka Struga receives untreated wastewater from a housing estate in the village of Klutajny (Figure 1), a former state-owned farm.

The indirect catchment, which has an area of 129.9 km² and is 100-times larger than the lake, is used mainly for agricultural purposes. Wetlands occupy 10% of its area. The direct catchment (2.2 km²) is dominated by forests, but it also features recreational grounds. Symsar Lake is a eutrophic body of water with an annual water exchange rate of 1243.6%. Based on its morphometric parameters, the lake was assigned to degradation vulnerability class III (SIDORUK, POTASZNIK 2011). Entirely homogenous bottom sediments were sampled from the lake using an Ekman grab with a sampling area of 225 cm². The surface layer of bottom sediments was sampled for analysis at the depth to 0.15 cm (18 sites). Samples were collected in several locations across the lake at different depths (presented in Figure 1), and in inflows to and outflows from the lake (once, in the same year).

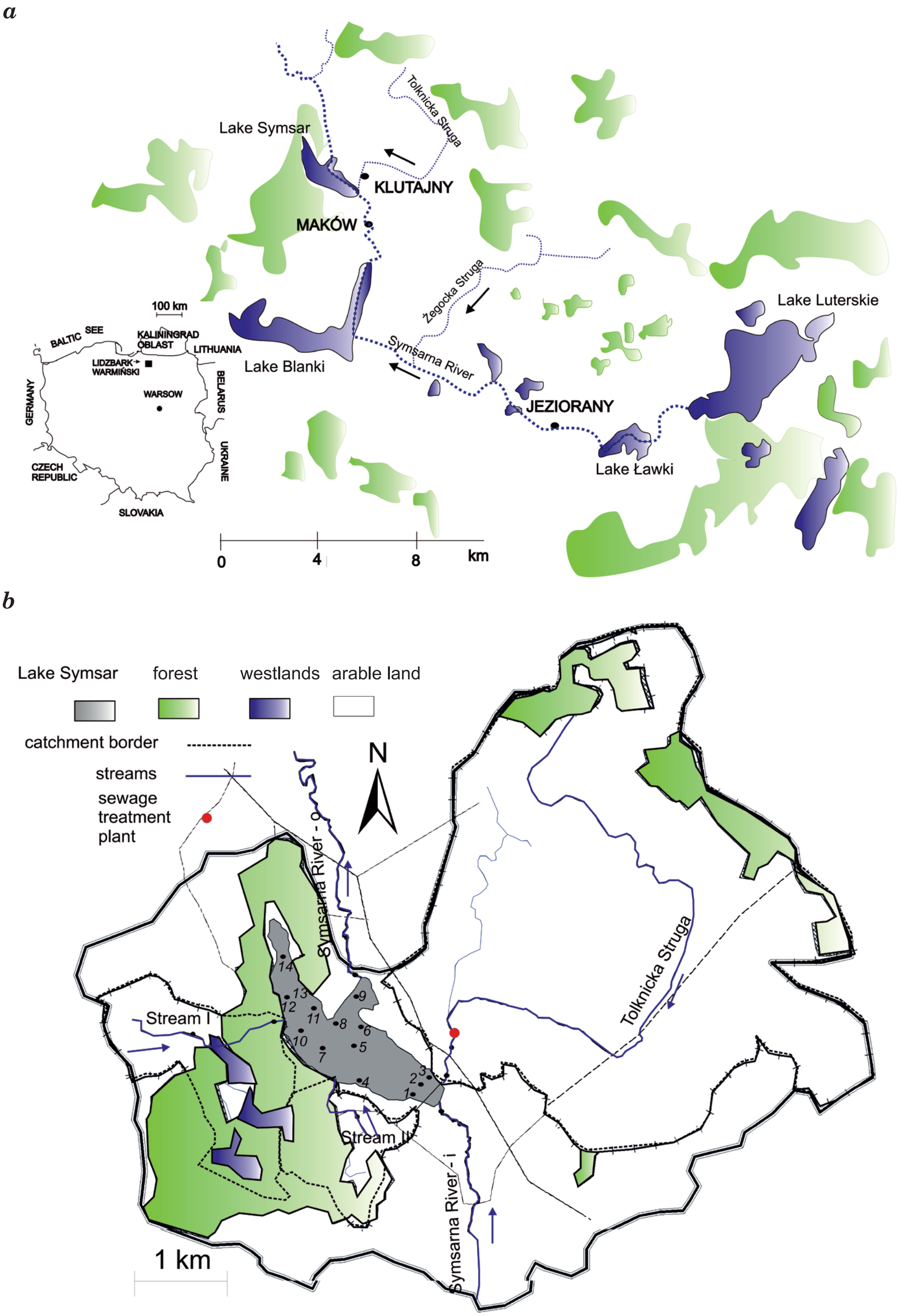


Fig. 1. Location of Symsar Lake in the river - lake system and in Poland (*a*), including the direct catchment of Symsar Lake together with the catchments of the lake's inflows (*b*)

The samples were transported to the laboratory of the Chair of Water Resources, Climatology and Environmental Management, at the University of Warmia and Mazury in Olsztyn. Air-dried sediments were ground in a mortar and analyzed to determine the following physicochemical parameters:

- organic matter content (OM, g kg^{-1}), by the gravimetric method, after drying at 105°C and incinerating in a muffle furnace at 550°C;
- pH, by the potentiometric method in KCl (actual and exchangeable acidity), 1:2.5 w/v ratio, according to PN-ISO 10390:1997.

Sediments were analyzed in triplicates to determine chemical parameters in the following way: samples of bottom sediments (2 g weight) were mineralized in Kjeldahl flasks placed in a heating block (open system, mineralization temperature about 120ºC). In order to mineralize the samples for total phosphorus determinations, a mixture (1:1, v:v) of nitric acid 65% p.a.(HNO_3) by CHEMPUR and perchloric acid 70% p.a. ($HClO_4$) by STANLAB was used. The post-digestion residue was passed through hard filter paper into beakers (500 cm^3) and replenished with distilled water. The total phosphorus (TP) content of sediments was determined colometrically with ammonium molybdate and tin(II) chloride at 650 nm wavelength using a spectrophotometer.

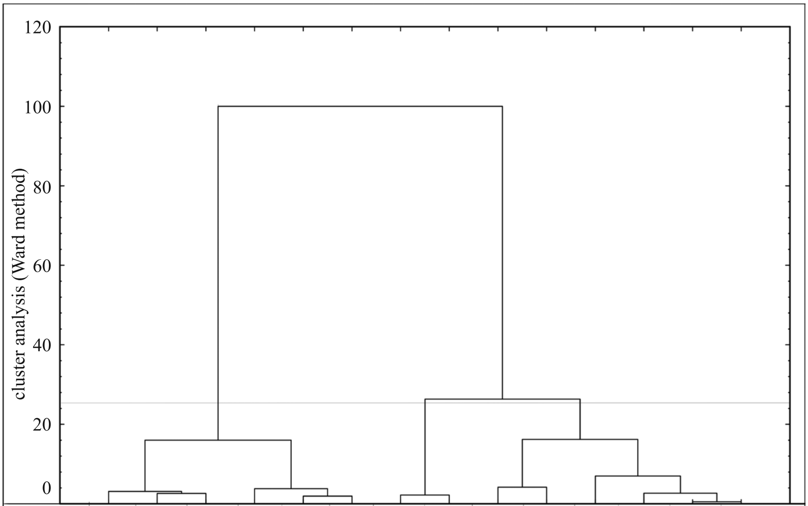
The mineralization procedure for Kjeldahl nitrogen (N_K) determinations was completed in a mixture of sulfuric acid 95% p.a. (H_2SO_4) by CHEMPUR and hydrogen peroxide 30% p.a. (H_2O_2) by Standard. The resulting sediment was distilled in 0.1 mol dm^{-3} HCl in a distillation apparatus by BŰCHI, and the distillate was titrated with 0.1 mol dm^{-3} NaOH.

The organic carbon content (TOC) was determined by the Tiurin method, heating the added 0.068 M $K_2Cr_2O_7$ (based on H_2SO_4) to 140°C and titrating with 0.1 mol dm^{-3} Mohr's salt solution. The analyzed parameters were expressed as TOC/N_K (determining the ability of nitrogen assimilation by plants), N_K/TP (determining the biomass production) and TOC/TP (determining the availability of phosphorus) ratios. Bottom sediments were divided into three groups based on the lake's depth and distance from the inflow of the Symsarna River. The classification was performed based on the results of a cluster analysis performed according to the Ward's method (Figure 2):

1) sediments in the lake's region intersected by the Symsarna River (SR),
2) sediments in the central part of the lake outside the reach of the river (C),
3) sediments located in the lake's bay, in the northern part of Symsar Lake (SL_b).

All subsequent statistical analyses are based on this division.

The distribution of components in bottom sediments (interpolation) was visualized using the Surfer 8.0 Software. The results were processed in the Statistica 10 PL application (StatSoft 2014). The normality of distribution was analysed with the Shapiro-Wilk test, and then a nonparametric test, a one-way Anova (Kruskal-Wallis test, $p \leq 0.05$), and a multiple comparison



sample	13	14	12	10	11	9	8	7	6	5	4	3	2	1
depth	2.5	2.0	2.0	3.0	3.5	3.7	4.8	5.2	7.5	8.3	6.0	6.5	6.9	6.9
distance	2.3	2.7	2.7	1.9	1.9	1.6	1.5	1.6	1.2	1.2	1.9	0.2	0.3	0.4
	SL b						*C*		*SR*					

Fig. 2. The division of bottom sediments in Symsar Lake (based on results of cluster analysis): depth – depth of lake, distance – distance from theinflow of the Symsarna River zone, *SLb* – bay of the lake, *C* – central part (beyond the reach of the Symsarna), *SR* – reach of the Symsarna

test were used to verify the significance of differences between the means of the analyzed parameters in various parts of the lake.

The correlations between environmental factors and the nutrient content of bottom sediments were determined by principal component analysis (PCA) with multiple scaling, after data transformation to logarithms log $\sqrt{n+1}$, centered by species. PCA was preceded by detrended component analysis (DCA), based on which the lengths of recovered composition gradients were checked (the gradients were short).

Data analysis was performed with Canoco 4.5 software (TER BRAAK, ŠMILAUER 2002).

RESULTS AND DISSCUSION

Active acidity arises mainly from the presence of organic acids and carbonic acid in a solution. It also depends on the chemical composition of mineral sediment fractions, in particular carbonates, and a lake's depth. The pH of the evaluated sediments was neutral or slightly alkaline, ranging from 6.92 to 7.26 (the median 7.03). When acidity is high, exchangeable acidity is more likely to be determined by Al^{3+} ions, which can be toxic to living organisms. Variations in the pH of water and sediments result from different processes in water ecosystems, including the accumulation and release of phosphorus (KOWALCZEWSKA-MADURA, GOŁDYN 2010).

With the lake's mean depth of 4.9 m, the average organic matter content of the bottom sediments of Symsar Lake was determined at 172 g kg^{-1}. Outside the littoral zone, the OM content was 15.1% higher than the average OM content for the entire lake. At a depth of approximately 4.25 m, in the central part of the lake (sample No. 8), the OM content reached 191 g kg^{-1}. In the bay, the OM content was 9.3% lower than the lake's average (Figure 3, Table 2). In the deepest part of the lake, which is intersected by the Tertiary

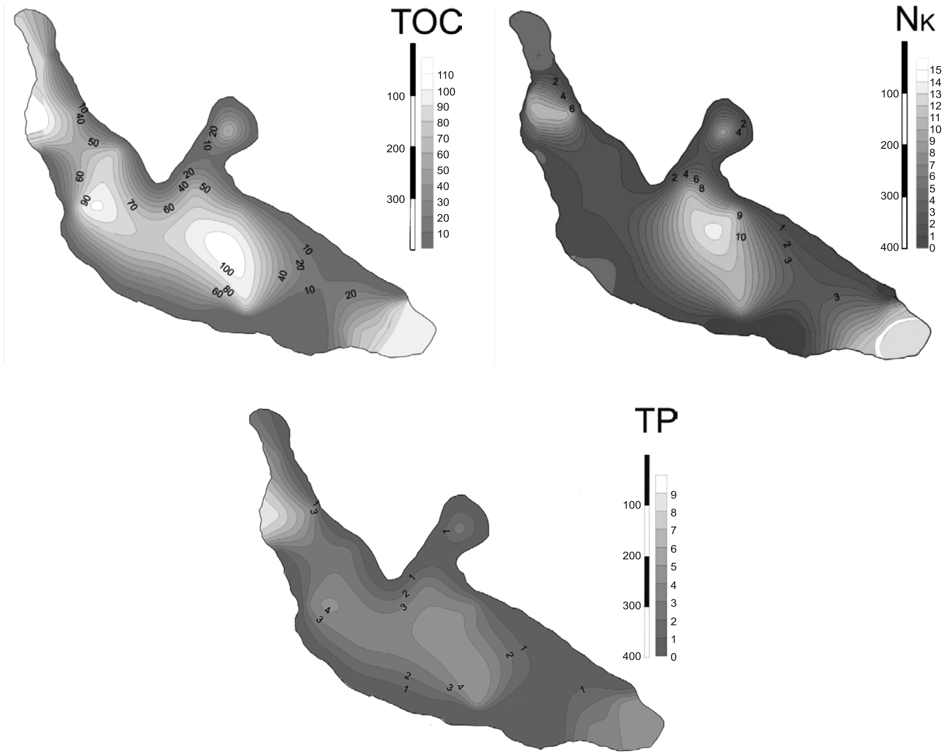


Fig. 3. Variability in the content of organic carbon (TOC, g kg^{-1}d.m.), Kjeldahl nitrogen (N_K, g kg^{-1}d.m.) and total phosphorus (TP, g kg^{-1}d.m.) in bottom sediments of Symsar Lake and streams (inflow of the Symsarna River into the lake, the Tolknicka Struga, outflow of the Symsarna River from the lake, stream I)

river channel, bottom sediments contained 175-185 g kg^{-1} organic matter. In other studies, organic matter was most abundant in bottom sediments sampled from the deepest points of water bodies (TROJANOWSKI, ANTONOWICZ 2005). The organic matter content of bottom sediments in the central part of the lake at a depth of approximately 5 m was estimated at 184-198 g kg^{-1}, which

Table 2

Selected physicochemical properties of bottom sediments in Symsar Lake

Specification	*N*	*SR*		*C*		*SLb*		*p*
		average	±SD	average	±SD	average	±SD	
OM (g kg^{-1})	18	17.9	0.6	18.2	2.4	15.6	1.7	0.024*
pH°		6.99	-	7.05	-	7.14	-	0.723
N_K(g kg^{-1})		7.87	3.34	9.32	0.59	2.29	3.44	0.073
TOC (g kg^{-1})		65.9	9.20	60.75	1.44	57.05	14.43	0.431
TP (g kg^{-1})		3.16	0.35	2.63	0.31	2.77	0.59	0.189
TOC/N_K		9.37	1.29	8.62	0.15	8.05	2.03	0.375
N_K/TP		2.40	1.18	3.56	0.19	0.78	1.01	0.020*
TOC/TP		21.18	3.55	23.30	3.26	22.07	9.36	0.835

SR – Symsarna River, *C* – central part; *SLb* – Symsar Lake's bay, *p* – significance of differences in the average values of variables (one-way ANOVA, Kruskal-Wallis test); * results are statistically significant at $p < 0.05$, ±SD – standard deviation, ° pH values were expressed by medians

indicates that substantial quantities of matter are deposited at the bottom of the lake. In shallow sites of a lobelia lake (Lake Dołgie Wielkie) with minor vegetation zones (reed and rushes), dispersed distribution of emergent plants contributes to the accumulation of organic matter (TROJANOWSKI, ANTONOWICZ 2005), especially plants preferring eutrophic reservoirs. A reverse trend was noted in shallow sites of the Symsar Lake bay due to temperature/oxygen induced mineralization of sediments, which contributed to a high content of the mineral fraction. Anaerobic conditions were observed at shallow depths in an oxbow of the Słupia River, and they were often a selection factor for macrozoobenthos (OBOLEWSKI 2005).

In water bodies, organic matter can be supplied with surface runoffs from the catchment, and it can undergo various changes directly at the bottom of a lake (KOSZELNIK et al. 2008). The composition and quality of organic matter is an important attribute of bottom sediments that reflects the physicochemical conditions in the benthic zone. Organic matter content can influence changes in the element composition of bottom sediments, including Ca, Mg, TP and TN (TROJANOWSKI, ANTONOWICZ 2005).

The Kruskal-Wallis test revealed significant differences between the OM content of bottom sediments in various parts of the lake (p = 0.024, H = 7.482), mainly in the zone intersected by the Symsarna River and in the lake's bay (based on the results of the multiple comparison test at p = 0.025, H = 7.482).

Mineral particles were the predominant fraction of bottom sediments that were sampled from the river and reclamation ditches supplying the lake. The organic matter content of bottom sediments in the river and streams ranged from 11 g kg^{-1} (Tolknicka Struga – TS) to 39 g kg^{-1} (in the upstream section of the Symsarna River – SR_i).

Bottom sediments contained 50 to 200 g kg^{-1} organic matter (Trojanowski, Antonowicz 2005), which can be classified as mineral-organic matter. Organic matter can have both an autogenic and allogenic origin. It is generally a product of biological processes in a lake, and its presence in bottom sediments is correlated with water fertility, depth, oxygen content and rate of matter circulation in a water body. Carbon is the major component of organic matter (Trojanowski, Antonowicz 2005). There are interactions in the water column among solute transport, metabolism and nutrient processing. Metabolism (primary production and respiration) accounts for the fluxes of O_2 and C (González-Pinzón et al. 2014). Carbon is the major component of organic matter (Trojanowski, Antonowicz 2005).

The content of organic carbon (TOC) in the bottom sediments of Symsar Lake was estimated at 61.2 g kg^{-1} d.m. Higher accumulation (by about 7.8%) was observed in parts of the lake intersected by the Symsarna River (Figure 3). According to the literature, the TOC content of bottom sediments can range from 29 g kg^{-1} d.m. to 460 g kg^{-1} d.m. (Cieślewicz 2005). According a Hylang et. al. (2005) the low range of TOC is formed < 10 g kg^{-1} d.m., and high range is formed about > 35 g kg^{-1} d.m. In this study, variations in the organic carbon content of bottom sediments in the analyzed watercourses were also noted, particularly in the upstream section (11.58 g kg^{-1} d.m.) and the downstream section of the Symsarna River (higher by approximately 70%) and in stream I, whose catchment is occupied by forests and farmland (higher by approximately 32% in comparison with smaller inflows) – Figure 3. Lower contents are characteristic for mineral sediments of riverbeds. Nitrogen and phosphorus concentrations in surface waters are determined by the nutrient load supplied from catchments (Skwierawski et al. 2008) and by the amount of nutrients removed from a water body by a passing watercourse. The elements are partially carried away from a water body and partially accumulated in its bottom sediments (Kowalczewska-Madura, Gołdyn 2010). The nitrogen content in Laurentian Great Lakes is affected by external and loading rates. Transformations of nitrogen and phosphorus in sediments-water interface are very important, as they depend on redox gradients and anaerobic conditions (Small et al. 2014).

Microorganisms inhabiting aquatic ecosystems transform nitrogen by fixing molecular nitrogen and participating in ammonification, nitrification or denitrification. Environmental processes can also affect the direction and rate of nitrogen transformations. The Kjeldahl nitrogen (N_K) content of the bottom sediments of Symsar Lake (Figure 3) reached 6.09±4.2 g kg^{-1} d.m. (Table 2). Smaller nitrogen contents (approximately 65%) were noted in sediments deposited in the bay, outside the direct influence of the Symsarna River. Higher N_K contents in the northern part of the lake (8.37 g kg^{-1}d.m.) could be attributed to wind-generated waves on the surface of the lake, which influenced the accumulation of nutrients in bottom sediments in the littoral zone. The Kjeldahl nitrogen content of bottom sediments in stream I was determined at 0.13 g kg^{-1} d.m. The catchment of stream I is occupied by forests and farmland, and in the area where it feeds into the lake, the stream intersects recreational grounds in the vicinity of bungalows. In comparison with the downstream section of the river, nitrogen contents were approximately 16-fold higher (Figure 3) in bottom sediments located upstream from the point where the river feeds into the lake. The observed difference could be attributed to runoffs from farm fields, the accumulation of fertilizer nutrients and a smaller flow rate in the vicinity of a hydraulic power plant. The decreased river's flow rate could lead to a negative water balance in the lake for most of the year

The influence of various land use types in the catchment area on nitrogen concentrations in the surface waters of Symsar Lake was analyzed in 2012. The highest concentrations of organic nitrogen were noted in the watercourse which receives wastewater. At the point where Symsarna River feeds into the lake, organic nitrogen accounted for 85% of Kjeldahl nitrogen. At the river outflow, the content of organic nitrogen decreased to 79%, and the share of mineral nitrogen increased by around 6.1%, which suggests that nitrogen is accumulated in bottom sediments and used up by plankton (Potasznik et al. 2013) or macrozoobentos. This observation also explains the decreased nitrogen content of surface waters in the downstream section of the Symsarna River.

The biological transformation of total phosphorus (TP) is largely dependent on biochemical changes involving carbon and nitrogen. Changes in the total phosphorus content of bottom sediments can run counter to the changes in carbon and nitrogen contents, like in the case of the lobelia lake in Słowinski National Park (Trojanowski, Antonowicz 2005), where the content of phosphorus is natural. Phosphorus can be released when sediments come in contact with water. Due to internal loading, the amount of phosphorus that is released in the water column can exceed the amount that is deposited in sediments. In summer, the release of phosphorus from sediments can be the main source of this element in water. Phosphorus release is enhanced by temperature, pH, oxygen concentrations in water that comes into contact with the surface layer of bottom sediments, iron and manganese concentrations, and the activity of macroinvertebrates (Kowalczewska-Madura, Gołdyn 2010, Niemistö et al. 2011). In Jamno Lake, the lake's poor ecological status, caused by elevated levels of nutrients, resulted in the presence of Chironomidae and Oligochaeta in bottom sediments (Obolewski 2009).

The total phosphorus content in the bottom sediments of Symsar Lake was determined at 2.85 g kg^{-1} d.m. (Figure 3). In the central part of the lake, TP in bottom sediments was nearly 7.7% lower, whereas in the zone intersected by the Symsarna River it was 10.9% higher than the lake's average total phosphorus content.

Another study investigating changes in concentrations of various forms of phosphorus in Symsar Lake revealed lower levels of TP in the downstream section of the Symsarna River, which indicates that phosphorus was accumulated in the lake (Potasznik et al. 2014). In a study by Obolewski and Glińska-Lewczuk (2013), the Słupia River contributed to erosion and the accumulation of trace elements in bottom sediments by slowing down sediment transport, as a result the flow of River Słupia by Lake Krzynia (river-lake system).

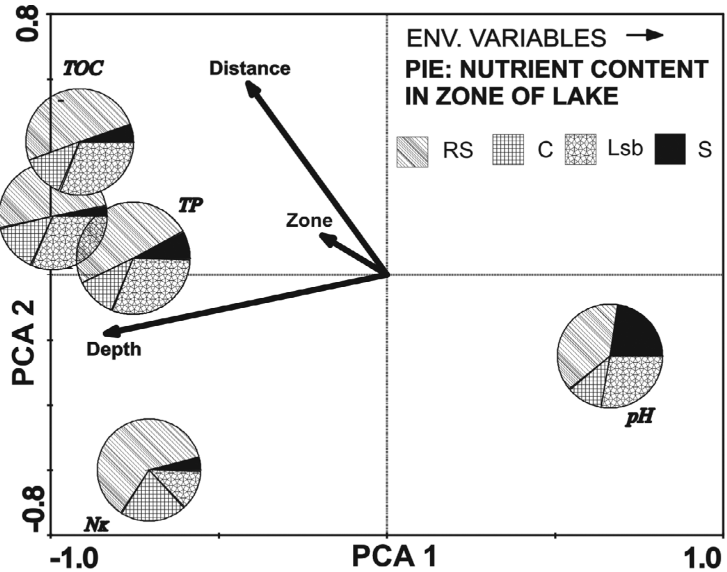
The bottom sediments of Tolknicka Struga were characterized by a 0.53 g kg^{-1} d.m. TP content, which could be attributed to the accumulation of phosphorus compounds supplied with wastewater from a malfunctioning treatment plant. Phosphorus concentrations were nearly 4-fold higher in the upstream section of the Symsarna River (before lake inflow), whereas TP levels were significantly reduced (35-fold) in the downstream section of the river.

The TOC/NK ratio in bottom sediments of Symsar Lake was determined at 8.65 due to relatively high contents of organic carbon which contributed to the release of nitrogen. Narrow TOC/N_K ratios (4-10) are noted in protein -rich organic matter, whereas broader TOC/N_K ratios (> 20) are found in organic matter formed by macrophytes and bigger plants abundant in cellulose. A narrow TOC/N_K ratio (< 10) could indicate that phytoplankton is the main source of organic matter (Mayers, Ishiwatai 1995). In the bottom sediments of Symsar Lake, the TOC/TP ratio was determined at 2.18, and the N_K/TP ratio – at 2.25.

The principal component analysis was carried out based on pH, OM, TOC, N_K and TP values in bottom sediments and three environmental variables (depth, zone and distance from SR) – Figure 4.

Both axes explain 95.1% of the variation of nutrients in relation to environmental factors (Figure 4). The first axis (PCA 1) is very well correlated with the environmental data (r = 0.743, 74.3%). The analogous correlation of the second axes is considerably lower (20.8%). The NK content of lake sediments was correlated mainly with the lake's depth. Nitrogen levels were 3-fold higher in the littoral zone than in deeper parts of the lake. The contents of TOC depended on the location (zone) of sampling sites, and the highest TOC amounts were noted in the zone intersected by the Symsarna River (7.6% higher than the average TOC for the entire lake). The content of TP was nearly 4.4% higher in the zone outside the littoral than in the littoral zone. In a study by Zhou et al. (2007) on the Yangtze River flowing into the East China Sea, the highest contents of TOC, N and TP were observed in the estuary zone, explaining the important role of the river in the spatial distribution of this component in bottom sediments. A similar dependence was observed in the tested river-lake system of the Symsarna River and Lake Symsar. The highest values of the analyzed components were observed in sediments located in the reach of the Symsarna River and in the estuary zone (the littoral).

The results of our study, which investigated a river-lake system, show that the Symsarna River is responsible for the variations in nutrient accu-



Axes	1	2	Total variance
Eigenvalues:	0.743	0.209	
Species environment correlations	0.922	0.646	
Cumulative percentage variance			1.000
of species data:	74.3	95.1	
of species environment relation:	86.4	98.3	
Sum of all eigenvalues			1.000
Sum of all canonical eigenvalues			0.730

Fig. 4. The results of PCA investigating the impact of environmental variables (mostly the lake zones) on the evaluated parameters (p = 0.942)

mulation levels in bottom sediments. The accumulation of selected elements, including TP, in the zone beyond the littoral suggests that the nutrient content of sediments was also influenced by the shape of the lake basin and its depth. Bottom sediments in the littoral zone accumulated mineral nutrients which were transported to the lake by inflowing streams and surface runoffs (GLIŃSKA-LEWCZUK et al. 2009, POTASZNIK, SZYMCZYK 2015). The highest NK concentrations were observed in the littoral zone, and the NK content was negatively correlated with the lake's depth. Higher accumulation of the analyzed components was noted in bottom sediments situated in the vicinity of inflows, which is confirmed by higher nutrient concentrations in the parts of the lake situated less than 1 km from SR.

CONCLUSIONS

The results of this study indicate that the lake's morphology and inflowing streams were largely responsible for the variations in the nutrient content of bottom deposits in the flow-through Symsar Lake. The N_K content was significantly correlated with the lake's depth. The highest concentrations of the analyzed components were observed in bottom sediments near the outflow of the river from the lake and in the part of the lake intersected by the river.

The surface layers of bottom sediments in Symsar Lake were characterized by an average organic matter content of 171.2 g kg^{-1} and near-neutral pH (6.78-7.77). The average concentrations of components in the analyzed sediments were determined at 62.01 g TOC kg^{-1} d.m., 6.08 g N_K kg^{-1} d.m. and 2.18 g TP kg^{-1} d.m. Expressed in fresh mass per square meter of the lake's sediment, the above content reached 3.95 kg TOC m^{-2} f.m., 0.42 kg N_K m^{-2} f.m. and 0.18 kg TP m^{-2} f.m. In turn, the average content of the components in the streams' sediments, likwise calculated per square meter, equalled 12.4 g TOC m^{-2} d.m., 0.93 g N_K m^{-2} d.m. and 0.9 g TP m^{-2} d.m.

The Symsarna River was responsible for the transport of and variability in the deposition of mineral fractions, and for nutrient accumulation in the surface layer of bottom sediments. A flow-through water body in a river-lake system can contribute to retention in periods when it exerts a negative impact on the trophic status of a lake. From a broader, ecological viewpoint, it can inhibit the transport of pollutants outside the catchment.

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