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PRELIMINARY CHARACTERIZATION OF THE TROPHIC STATE OF MAŁY KOPIK LAKE NEAR OLSZTYN AND ITS DRAINAGE BASIN AS A SUPPLIER OF BIOGENIC SUBSTANCES

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Abstract

The study was carried out on a small (7.8 ha) and shallow (9.0 m) lake Mały Kopik, situated 9 km on south western from Olsztyn, drainage basin of Giłwa and Pasłęka rivers. The catchment area of the lake is 194.7 ha. Forests cover the most of the drainage basin area (64.2%), agriculture land comprises 28.7% (21% grass land and 7.7% arable land) and urban land – 7.1%. Lake Mały Kopik is not susceptible to degradation (III category), and drainage basin having a great potential for supplying matter to the reservoir, was included in basin category 4. The lake with its drainage basin belong to the 4th type of lake-drainage basin ecosystems. In such a system the natural eutrophication of the lake is expected to proceed at a fast rate.

As evidenced in the study, lake Mały Kopik is highly eutrophic reservoir. The lake waters were characterized by a high content of nutrients, up to 0.673 mg $P \cdot dm^{-3}$ and 10.61 mg $N \cdot dm^{-3}$. The high fertility of the lake was exhibited also by the values of BOD_5 reaching 7.5 mg $O_2 \cdot dm^{-3}$, chlorophyll *a* content – 50 $\mu g \cdot m^{-3}$, and low water transparency – 2 m.

Key words: lake, drainage basin, nutrients, external loading, eutrophication, susceptibility to degradation.

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WSTĘPNA CHARAKTERYSTYKA TROFICZNA JEZIORA MAŁY KOPIK K. OLSZTYNA ORAZ JEGO ZLEWNI JAKO DOSTAWCY ZWIĄZKÓW BIOGENICZNYCH

Abstrakt

Badaniami objęto małe (7,8 ha) i niezbyt głębokie (9 m) jezioro Mały Kopik, położone ok. 9 km na południowy zachód od Olsztyna, w dorzeczu Giłwy-Pasłęki. Zlewnia jeziora to obszar o powierzchni 194,7 ha. Największy udział (64,2%) mają w niej lasy, 28,7% zajmują tereny użytkowane rolniczo, w tym 21% stanowią użytki zielone, 7,7% grunty orne, pozostała część tego terenu (7,1%) to nieskanalizowane gospodarstwa rolne.

Jezioro Mały Kopik jest zbiornikiem nieodpornym na wpływy zewnętrzne, należy do III kategorii podatności na degradację. Jego zlewnia charakteryzuje się dużą możliwością uruchamiania obszarowego ładunku związków biogenicznych, należy do 4. typu zlewni. Kombinacja grupy podatności zlewni i odporności jeziora na degradację pozwala zaliczyć jezioro Mały Kopik i jego zlewnię do czwartego typu układów ekologicznych w systemie BAJKIEWICZ-GRABOWSKIEJ (2002), w którym następuje szybka eutrofizacja wód jeziornych. Przypuszczenie to potwierdziły badania chemiczne wód, które wykazały, iż jezioro Mały Kopik jest zbiornikiem silnie zeutrofizowanym. W wodach zbiornika stwierdzono bardzo wysoką zawartość związków biogenicznych, tj. 0,673 mg P dm^{-3} i 10,61 mg N dm^{-3}. O dużej żyzności jeziora świadczyły także wartości BZT_5, dochodzące do 7,5 mg O_2 dm^{-3}, ilość chlorofilu *a* (ok. 50 µg m^{-3}) i niska przezroczystość wody – 2 m.

Słowa kluczowe: jezioro, zlewnia, związki biogeniczne, obciążenie zewnętrzne, eutrofizacji, podatność na degradację.

INTRODUCTION

Lakes are the least permanent element of the hydrosphere as they readily collect energy and matter from the watershed, which gradually changes their limnological properties (LANGE 1986). Many authors (HILLBRICHT-ILKOWSKA 1999, BAJKIEWICZ-GRABOWSKA 2002, GROCHOWSKA, TEODOROWICZ 2006) share the opinion that the course of evolutionary changes in lakes is comparable but the rate and character of such changes differ, depending on the morphometry of the bowl of a lake as well as the hydrology and influence of its watershed, which vary according to the geological structure and land use. The physical and geographic features of a watershed may stimulate or limit surface run-off, although the natural features of a lake may sustain its waters in a certain trophic condition (BAJKIEWICZ-GRABOWSKA 1999).

Increased productivity of lake waters has many adverse effects (deoxygenation of near-bottom waters and occurrence of hydrogen sulphide, internal loading with nutrients stored in bottom sediments, phytoplankton blooms, shortage of species on all trophic levels), indicating the need to seek methods to reverse, remove or at least slow down the process (KUBIAK, TÓRZ 2005).

Regarding multiple functions of lakes and the ensuing necessity to protect them, the aim of the study was defined as determination of the trophic condition of Mały Kopik Lake, previously not studied, and its natural vulnerability to degradation. Another objective was to evaluate the watershed as a supplier of matter to the reservoir. Such analysis should allow us to determine the eutrophication rate of the lake.

MATERIAL AND METHODS

Mały Kopik Lake (20°24'4"E and 53°41'3"N) lies approximately 9 km south-west of Olsztyn, at 119.3 m above sea level, in a drainage basin of the Giłwa-Pasłęka Rivers (Topographical Map of Poland 1999) – Figure 1. Its surface area is 7.8 ha, maximal depth 9.0 m, mean depth 3.2 m and the volume 248.1 thousand m^3 (IRŚ 1964). The shoreline is poorly developed

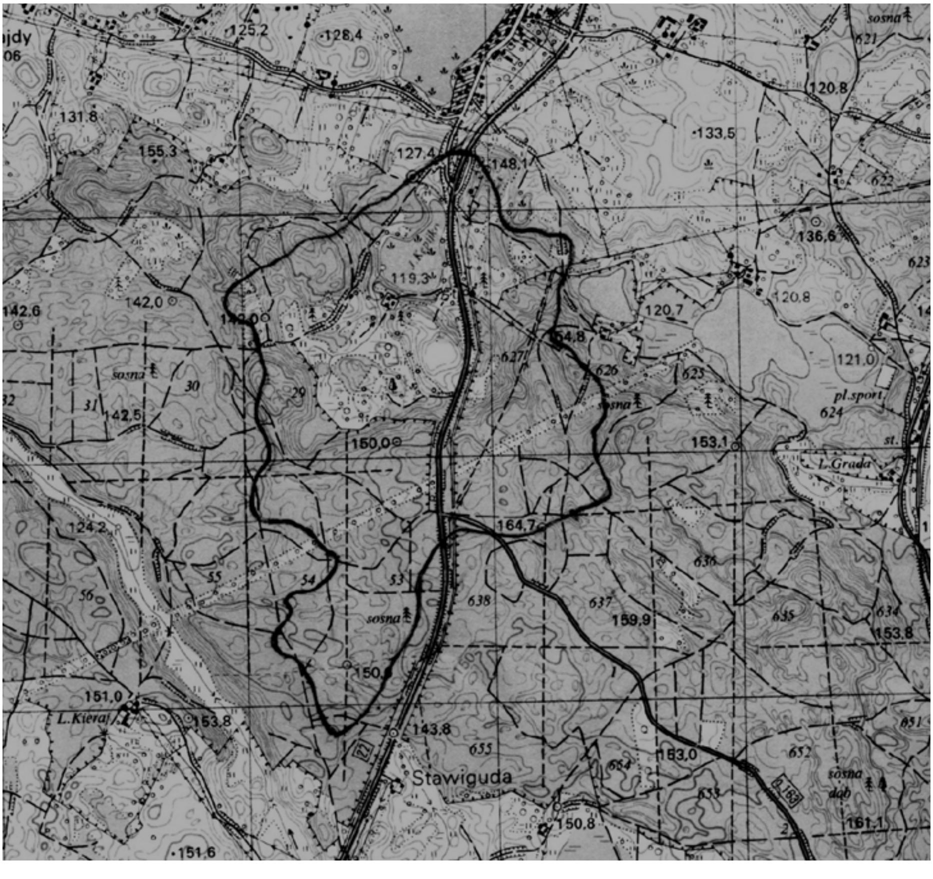


Fig. 1. Catchment's area of Mały Kopik Lake
Rys. 1. Zlewnia jeziora Mały Kopik

(K-1.26) but the depth indicator of 0.36 and the relative depth of 0.032 indicate a relatively big depression (Table 1). Kopik Mały Lake has no outflows.

The lake is not resistant to the impact of external factors. In accordance with the guidelines given by KUDELSKA et al. (1994), it can be classified as representing degradation vulnerability class III (Table 2).

The lake drains an area of 194.7 ha. Most of the watershed is forested (64.2%) and the remaining area is used by agriculture (28.7%, including 21% grassland and 7.7% cultivated land) or occupied by non-sewered farmsteads (7.1%) – Figure 1. An average watershed slope is 25‰. The substratum is built mainly of clay and glacial-fluvial sand (PANFIL 1978).

Table 1
Tabela 1

Detailed morphometric data and lake parameters (after the Institute of Inland Fisheries, Olsztyn, 1964)
Szczegółowe dane morfometryczne i współczynniki charakteryzujące jezioro Mały Kopik (wg IRŚ w Olsztynie, 1964)

Parameter Parametr	Values Wartości
Water table surface area Powierzchnia zwierciadła wody (ha)	7.8
Maximum depth Głębokość maksymalna (m)	9.0
Mean depth Głębokość średnia (m)	3.2
Relative depth Głębokość względna	0.032
Depth index Wskaźnik głębokościowy	0.36
Volume (thousand m^3) Objętość (tys. m^3)	248.1
Maximum length Długość maksymalna (km)	0.420
Maximum width Szerokość maksymalna (km)	0.300
Elongation Wydłużenie	1.4
Shoreline length of the lake bowl Linia brzegowa misy jeziora (km)	1.240
Shoreline development Rozwój linii brzegowej	1.26

Table 2
Tabela 2

Degradation vulnerability of Mały Kopik Lake
Podatność na degradację jeziora Mały Kopik

Index Wskaźnik	Value Wartość	Score Punkty
Mean depth Głębokość średnia (m)	3.2	3
Volume (thousand m^3) / Shoreline length (m) Objętość jeziora (tys. m^3) / Długość linii brzegowej (m)	0.20	4
Stratification (%) % stratyfikacji	0.00	4
Active bottom area (m^2) / Epilimnion volume (m^3) P dna czynnego(m^2) / V epilimnionu (m^3)	0.27	3
% of water exchange % wymiany wody w roku	0.00	1
Schindler's factor Współczynnik Schindlera	8.16	2
Direct drainage area management Zagospodarowanie zlewni bezpośredniej (%)	> 60% forest – lasów	1
Average score Wartość średnia punktacji	2.57	
Susceptibility category Kategoria podatności	III	

The watershed belongs to group 4 in the classification designed by BAJKIEWICZ-GRABOWSKA (2002) – Table 3, which means that it supplies large quantities of matter to the lake.

The lake was surveyed 3 times: in the spring (11 May), summer (11 September) and autumn (24 November) of 2006. Samples of water were taken for complete chemical examinations from the sub-surface (1 m) and near-bottom (8 m) water layers at the deepest site of the lake determined with the help of a bathymetric chart and the global positioning system. Water temperature and dissolved oxygen readings were taken from surface to bottom at 1-m intervals, each time the water was sampled for analyses. The samples were taken using 3.5-l Ruttner apparatus with an in-built mercury thermometer (0.2°C accuracy). Chemical analyses of the water were done in accordance with the methods of HERMANOWICZ et al. (1999).

The vulnerability to degradation of Lake Mały Kopik was assessed using the criteria given by KUDELSKA et al. (1994). The role of the watershed in supplying matter to the lake and the rate of its eutrophication

Table 3
Tabela 3

Assessment of Mały Kopik Lake drainage basin as nutrient supplier
Ocena zlewni jeziora Mały Kopik jako dostawcy materii do zbiornika

Indicator Wskaźnik	Value Wartość	Score Punkty
Ohle's coefficient Współczynnik Ohlego	24.96	1
Water budget type of the lake Typ bilansowy	no run-off bezodpływowe	2
Density of the river network Gęstość sieci rzecznej (km · km^{-2})	0.1	0
Mean sloping of the drainage basin Średni spadek zlewni (‰)	25	3
No run-off areas Obszary bezodpływowe (%)	< 20	3
Geological construction of the drainage basin Budowa geologiczna zlewni	clay and sand gliniasto-piaszczysta	2
Soil use in the drainage basin Użytkowanie ziemi	forests, agriculture and residential leśno-rolnicza z zabudową	3
Mean score Wartość średnia punktacji	2.0	
Susceptibility category of the drainage basin Kategoria podatności zlewni	group 4 4 grupa	

were determined in accordance with the guidelines given by BAJKIEWICZ--GRABOWSKA (2002).

The size of the watershed and land use types in the watershed were determined by *in situ* surveys and demarcation of the watershed borderlines as well as by analysing the planimetry of its surface on a topographic map 1:10,000.

The surface run-off of nutrients was calculated using the coefficients given by GIERCUSZKIEWICZ-BAJTLIK (1990). In order to calculate the allowable and dangerous loadings of phosphorus and nitrogen we used the statistical model of VOLLENWEIDER (1968).

The analyses of the trophic state of the lake were conducted on the grounds of the classifications given by the following authors: PATALAS (1960b), ZDANOWSKI (1983), HILLBRICHT-ILKOWSKA and WIŚNIEWSKI (1993), and FARAŚ-OSTROWSKA and LANGE (1998).

Table 4
Tabela 4

Annual loadings of N and P to Mały Kopik Lake
Całkowite roczne obciążenie jeziora Mały Kopik ładunkiem N i P

Sources Źródła	Loadings Ładunki	
	phosphorus (kg P·year^{-1}) fosfor (kg P·rok^{-1})	nitrogen (kg N·year^{-1}) azot (kg N·rok^{-1})
1. Spatial sources – Źródła przestrzenne	80.8	1886.8
a) forests – lasy	37.5	1125.0
b) build up land – teren zabudowany	12.4	82.8
c) grass land – użytki zielone	20.4	409.0
d) arable land – grunty orne	10.5	270.0
2. Scattered sources – Źródła rozproszone	17.5	43.8
3. Atmospheric sources – Źródła atmosferyczne	4.5	93.6
3. Total – Razem	102.8	2024.2

RESULTS AND DISCUSSION

Lakes are dynamic ecosystems, changing over time and aiming to enrich and intensify the biological productivity. It is well known (PATALAS 1960a, GROCHOWSKA, TANDYRAK 2006, GROCHOWSKA et al. 2006) that in lakes with lower water dynamics eutrophication runs more slowly and that such lakes are less vulnerable to man-made pressure.

Mały Kopik Lake is a small reservoir situated in a land hollow, whose southern and western shores are strongly elevated and covered by a mixed forest. Wind access to the lake is considerably limited, which is reflected by poor water dynamics. The theoretical depth of mixing (2.64) calculated after PATALAS (1960a) indicates degree IV of the lake stability. This assumption was confirmed by the results of the study conducted in 2006: as early as in the first days of May, the difference in temperatures across the water column was considerable and lasted throughout the summer. At the peak of the summer stagnation (early September) the epilimnion was 4 m thick (the temperature oscillated around 18°C) with a thermocline beneath with the max. gradient of 4.8°C·m^{-1}.

Other parameters, such as morphometric characteristics (especially the low mean depth 3.2 m), the ratio between volume and shoreline length, incomplete thermal stratification in the summer (no hypolimnia) and a high volume of the epilimnion compared to the active bottom area, indicated that the lake belonged to category III of vulnerability to degradation.

(KUDELSKA et al. 1994). Category III can be attributed to lakes which are not vulnerable to degradation. The values of the above parameters reflect intensive exchange of nutrients from the lake sediments to the trophogenic layer, which may augment the primary production.

The watershed of Mały Kopik Lake is classified as a group 4 watershed according to the classification of BAJKIEWICZ-GRABOWSKA (2002), i.e. it has a large ability to mobilize loadings from non-point sources. The unfavourable features of the lake's immediate surroundings are a low share of non-draining areas, steep sloping (25 ‰) and land use pattern. The evidence that the watershed enriches the lake with large loads of nutrients consists of the estimated annual loads of nitrogen (N) and phosphorus (P) as calculated with the coefficients of watershed use types and unit run-off given by GIERCUSZKIEWICZ-BAJTLIK (1990). It was determined that the total load of N was 2,024.2 kg and that of P – 102.8 kg (Table 4). The corresponding values calculated per unit surface area were 25.95 g $N \cdot m^{-2} \cdot year^{-1}$ and 1.32 g $P \cdot m^{-2} \cdot year^{-1}$.

The allowable and critical loadings in this lake, calculated using the statistical model by VOLLENWEIDER (1968), are 0.804 g $N \cdot m^{-2} \cdot year^{-1}$ and 1.608 g $N \cdot m^{-2} \cdot year^{-1}$, and 0.050 g $P \cdot m^{-2} \cdot year^{-1}$ and 0.100 g $P \cdot m^{-2} \cdot year^{-1}$, respectively.

Compared to the actual loadings of N and P to the lake, the values calculated after VOLLENWEIDER (1968) indicate that the actual loading exceeds more than ten-fold the critical values, being the reason for the lake's accelerated eutrophication.

The combination of the watershed vulnerability and the lake's resistance to degradation meant that Mały Kopik Lake and its watershed belonged to type IV of ecological systems (BAJKIEWICZ-GRABOWSKA 2002). In such a combination, the natural features of the watershed support surface run-off and the lake is largely vulnerable to external impacts, which was also confirmed by a comparison between the actual loading and the theoretical „Vollenweider" loadings (1968). As a result, eutrophication of the lake waters should proceed rapidly.

The influence of the watershed is reflected by the quality of the lake waters.

Oxygen profiles in Mały Kopik Lake are poor. In the surface water layers oxygen saturation oscillated around 90%, reaching 116% in May, which proved intensive primary production. Other concurrent parameters were: 8.42 pH, lack of free carbon dioxide and BOD_5–1.9 mg $O_2 \cdot dm^{-3}$. In the deeper layers, particularly near the bottom, oxygen depleted rapidly until total oxygen deficiency occurred. Such conditions, observed in May through September, were definitely caused by decay of the matter produced in the lake and deposited in the sediment. The oxygen curve in the lake was a clinograde (ABERG, RHODE 1942), typical for eutrophied lakes.

Eutrophication of a lake is demonstrated by concentrations of nutrients, particularly N and P (STAUFFER 1987, VAN DER MOLEN et al. 1998). Both elements occurred in large quantities in Mały Kopik Lake: up to 0.673 mg P·dm^{-3} and 10.61 mg N·dm^{-3} (Figures 2, 3).

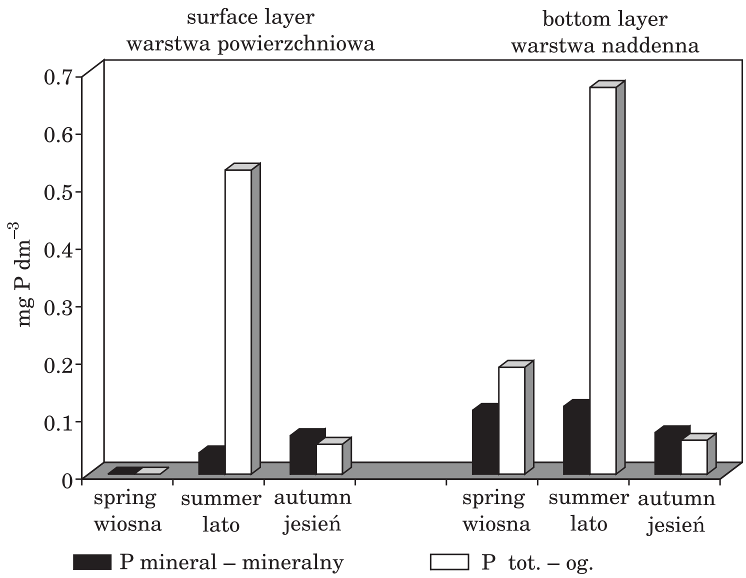


Fig. 2. Mineral and total phosphorus content in the waters of Mały Kopik Lake
Rys. 2. Zawartość fosforu mineralnego i ogólnego w wodach jeziora Mały Kopik

Total P was dominated by the organic form, except for the summer stagnation peak, when the dominant form in the near-bottom water was phosphate-0.529 mg P·dm^{-3} (Figure 2). The latter was caused by the release of mineral P from the bottom sediments during a severe oxygen deficit. Taking into account the division of lakes by ZDANOWSKI (1983) and based on the spring concentration of total P in the water, Mały Kopik Lake can be described as polytrophic (degree IV of the productivity). The classification of HILLBRICHT-ILKOWSKA and WIŚNIEWSKI (1993), based on the water transparency, total P content and chlorophyll a (up to 50 mg·m^{-3}) – Figure 4, indicates that Mały Kopik Lake is a heavily eutrophied reservoir.

The overall amount of nitrogen compounds in the lake was dominated by the organic form. Mineral N occurred in the lake waters constantly and in high concentrations (Figure 3). Mineral forms of N were dominated by ammonium and nitrate. On the one hand, the mineral forms of N measurable in the water throughout the whole vegetative period suggest the abundance of nitrogen. On the other hand, they imply intensive mineralization and nitrification in the water. With regard to the richness in mineral N (PATALAS 1960c), Kopik Mały can be classified as 'poly'.

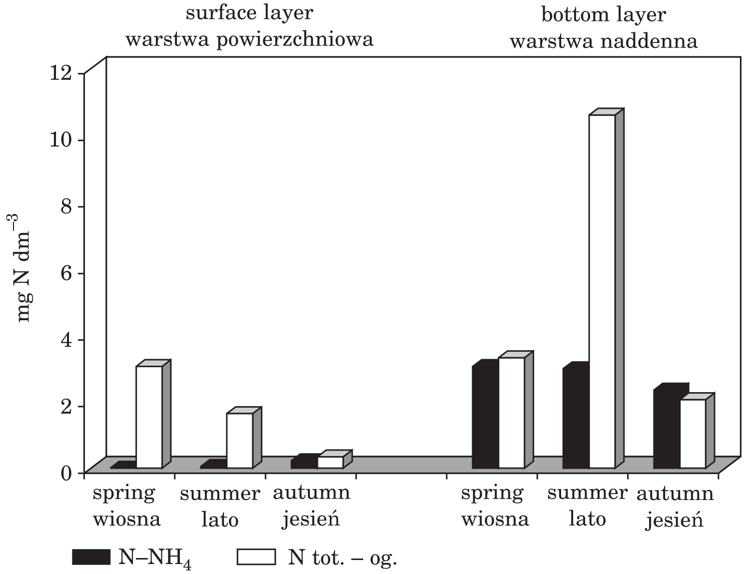
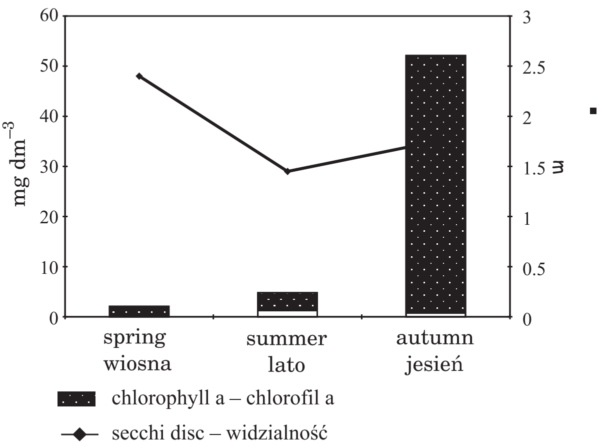


Fig. 3. Ammonium and total nitrogen content in the waters of Mały Kopik Lake

Rys. 3. Zawartość azotu amonowego i ogólnego w wodach jeziora Mały Kopik



Rys. 4. Widzialność wód oraz ilość chlorofilu *a* w wodach jeziora Mały Kopik

Fig. 4. Visibility and chlorophyll *a* content in the waters of Mały Kopik Llake

The fairly advanced eutrophication and the resultant high productivity of Mały Kopik Lake can be further evidenced by the high BOD_5–up to 7.2 mg $O_2 \cdot dm^{-3}$ and permanganate value–up to 72 mg $O_2 \cdot dm^{-3}$ (Figure 5). Throughout the study, the ratio between permanganate value and BOD_5 was much higher than 1, which indicates widespread presence of allochthonous (coming from the watershed) organic matter in the lake waters.

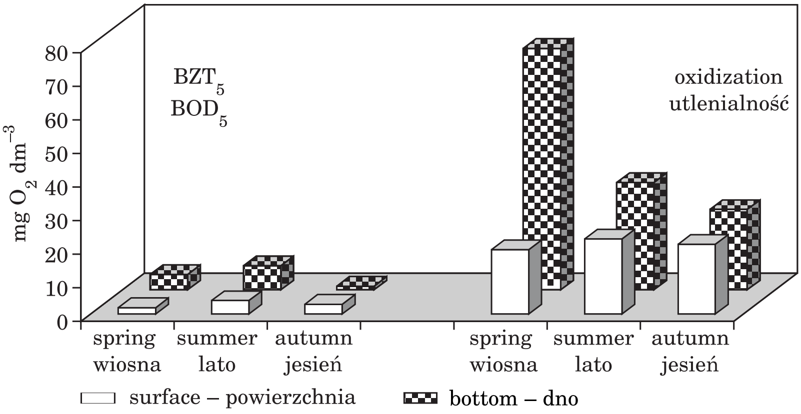


Fig. 5. Organic matter content in the waters of Mały Kopik Lake
Rys. 5. Zawartość materii organicznej w wodach jeziora Mały Kopik

Water transparency in the surveyed lake oscillated around 2 m. According to FARAŚ-OSTROWSKA and LANGE (1998), the value meets the criteria of a eutrophic lake.

At present, Mały Kopik Lake has low water quality, thus action in the watershed is critically needed to protect the lake and reduce the external loadings entering the lake. Further development in the watershed comprising expansion of residential areas or arable land may lead to total degradation of this reservoir.

CONCLUSIONS

1. Mały Kopik Lake is vulnerable to external impacts. It can be classified to category III of degradation vulnerability.

2. The lake's watershed has a high potential ability to mobilize non-point nutrient loadings.

3. The lake is subjected to high rate eutrophication.

4. According to ZDANOWSKI's criteria (1983), Mały Kopik Lake can be described as polytrophic – trophic condition degree IV.

5. According to the classification by HILLBRICHT-ILKOWSKA and WIŚNIEWSKI (1993), the lake can be classified as heavily eutrophied.

6. With regard to the richness in mineral N the lake is a 'poly' type (PATALAS 1960b).

7. Following the division of FARAŚ-OSTROWSKA and LANGE (1998), Mały Kopik can be qualified as eutrophic.

8. Prompt action should be undertaken in the lake's watershed in order to reduce the nutrient loadings running off to the lake. Further development in the watershed aimed such as expansion of built-up area or agricultural growth can result in total degradation of the reservoir.

REFERENCES

ABERG B., RHODE W. 1942. *Über die Milieufaktoren in Einigen Südschwedischen Seen.* Symp. Bot. Upsal., 5(3): 256.

BAJKIEWICZ-GRABOWSKA E., 1999. *Struktura fizyczno-geograficzna układu krajobrazowego zlewnia-jezioro i jej wpływ na tempo naturalnej eutrofizacji jezior*. Wyd. IRŚ w Olsztynie, 77-84.

BAJKIEWICZ-GRABOWSKA E. 2002. *Obieg materii w systemach rzeczno – jeziornych*. Wyd. UW, Wydz. Geografii i Studiów Regionalnych, 274.

FARAŚ-OSTROWSKA B., LANGE W. 1998. *Przezroczystość wody jako miara nasilenia eutrofizacji jezior. Zagrożenia degradacyjne a ochrona jezior*. Zakł. Limnologii UG, Bad. Limnol., 1: 181-191.

GIERCUSZKIEWICZ-BAJTLIK M. 1990. *Prognozowanie zmian jakości wód stojących*. Inst. Ochr. Środ., Warszawa.

GROCHOWSKA J., TANDYRAK R. 2006. *Temperature and dissolved oxygen profiles in Lake Plusze.* Limnol. Rev., 6(2006): 117-122.

GROCHOWSKA J., TEODOROWICZ M. 2006. *Ocena możliwości oddziaływania zlewni na jeziora górnej Pasłęki oraz podatności jezior na degradację.* Acta Scient. Polonorum ser. Formatio Circumiectus, 5: 99-111.

GROCHOWSKA J., TEODOROWICZ M., TANDYRAK R. 2006. *Temperature and dissolved oxygen characteristics of the lakes in the upper Pasłęka river catchment.* Pol. J Natur. Sci. 20(1): 291-305.

HERMANOWICZ W., DOŻAŃSKA W., DOJLIDO J., KOZIOROWSKI B., ZERBE J. 1999. *Fizyczno-chemiczne badanie wody i ścieków*. Arkady, Warszawa.

HILLBRICHT-ILKOWSKA A., WIŚNIEWSKI R. J. 1993. *Trophic differentiation of lakes the Suwałki Landscape Park (North-Eastern Poland) and its Buffer Zone – Present State, Changes Over Years. Position in trophic classification of lakes*. Ekol. Pol., 41(1-2): 195-219.

HILLBRICHT-ILKOWSKA A. 1999. *Jezioro a krajobraz: Związki ekologiczne, wnioski dla ochrony.* Wyd. IRŚ w Olsztynie, 19-40.

IRŚ, 1964. *Mapa batymetryczna i opracowanie danych morfometrycznych jeziora Mały Kopik.*

KUBIAK J., TÓRZ A., 2005. *Zmienność poziomu trofii bradymiktycznego jeziora Morzycko w latach 1974–2002.* Zesz. Probl. Post. Nauk Rol., 505: 199-209.

LANGE W. 1986. *Fizyczno-limnologiczne uwarunkowania tolerancji systemów jeziornych Pomorza.* Zesz. Nauk. UG, Rozpr. Monogr., 79.

Mapa Topograficzna Polski (skala 1:10 000), 1999. *Olsztyn, cz. Bartąg.* Główny Geodeta Kraju.

PANFIL J. 1978. *Pojezierze Mazurskie.* WP, Warszawa.

PATALAS K. 1960a. *Mieszanie wody jako czynnik określający intensywność krążenia materii w różnych morfologicznie jeziorach okolic Węgorzowa*. Rocz. Nauk Rol., 77(B-1): 223-242.

PATALAS K. 1960b. *Charakterystyka składu chemicznego wody 48 jezior okolic Węgorzowa.* Rocz. Nauk Rol., 77(B-1): 243-297.

STAUFFER R. E. 1987. *Vertical nutrient transport and its effects on epilimnetic phosphorus in four calcareous lakes*. Hydrobiologia, 154: 87-112.

VAN DER MOLEN D., PORTIELJE R., BOERS P. C. M., LIJKLEMA L 1998. *Changes in sediment phosphorus as a result of eutrophication in lake Veluwe, the Netherlands*. Wat. Res., 32(11): 3281-3288.

VOLLENWEIDER R. A. 1968. *Scientific fundamentals of the eutrophication of lakes and flowing water, with particular reference to nitrogen and phosphorus as factor in eutrophication*. Tech. report Organisation for Economic Cooperation and Development, Paris.

ZDANOWSKI B. 1983. *Variability of nitrogen and phosphorus contents and lake eutrophication*. Pol. Arch. Hydrob., 29(3-4): 541-597.