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Spatial and Temporal Variability of TOC Concentrations in a Shallow and Eutrophicated Lake Ecosystem (Lake Jarosławieckie, Wielkopolski National Park, Western Poland)

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Abstract

The aim of this study was to characterize the spatial and temporal variability of total organic carbon concentrations in a shallow, eutrophic lake (Lake Jarosławieckie, the Wielkopolski National Park, mid-western Poland) against the background of lake habitat heterogeneity. The interrelations between TOC and chlorophyll *a* in different studied sites (in macrophyte communities as well as in open water sections) were also taken into account. In November 2000, March, May, June and July 2001, water samples were collected in two transects along and across the lake traversing macrophyte communities of the phytolittoral zonation (7 sites) and reaching the open water zone (mid-lake, 3 sites) and, additionally, in a site close to a beach attracting local inhabitants and tourists. Statistical analyses revealed significant temporal differentiation and reverse patterns of changes of both TOC and chlorophyll *a* concentrations in the studied lake, whereas the spatial one was not significant. No correlations between both parameters were found. The results of cluster analyses suggest macrophyte vegetation and its seasonal changes in development as the main factor to influence TOC concentrations.

Keywords: total organic carbon, chlorophyll *a*, lake, temporal and spatial distribution

Introduction

Natural organic matter – due to its chemical structure and character - plays a multifunctional role in the natural environment and in water treatment processes. In aquatic ecosystems its values range from 0.5 to 100 mg/L of organic carbon [1], whose concentrations are meant to reflect the water trophy and pollution by organic substances [2]. Among forms of organic carbon, dissolved organic carbon (DOC) is especially considered as related to the trophical status of water [3-6]. Since chemical oxygen demand determination gives no complete information on all organic compounds, total organic carbon (TOC) is regarded as the main indicator of the sum content of organic compounds, which not only enables an evaluation of the level of pollution but also expresses the degree of biodegradation and purification of surface and wastewater [7, 8]. The importance and necessity of determining TOC has been known for over 70 years [9]. Since DOC constitutes even 90 per cent of TOC, it is the major component of TOC [4]. Although particulate organic carbon (POC), an indicator of carbon contained in water organisms forming ecological groups of phytoplankton and zooplankton [8], reveals in waters much smaller amounts than the dis-

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solved one, it is more variable (especially temporarily) and results in TOC variability [2, 7, 8].

The determinations of organic carbon were performed in lakes of Wielkopolski National Park (mid-western Poland) and published by Barałkiewicz and Siepak [2, 7]. The diversity within the lake habitat of Lake Jarosławieckie, object of the present study, and two other lakes of WNP resulted in clear spatial distribution of the water and sediment properties [10]. Horizontal variability of phytoplankton, and zooplankton communities was also observed in Lake Jarosławieckie [11, 12].

The aims of the study were to characterize the spatial and temporal variability of total organic carbon concentrations in Lake Jarosławieckie against the background of the lake habitat heterogeneity. The interrelations between TOC and chlorophyll *a* in different studied sites (in macrophyte communities as well as in open water sections) were also taken into account.

Materials and Methods

Lake Jarosławieckie is located in Wielkopolski National Park in a part of the Rosnowsko-Jarosławiecka tunnel-valley. It is a post-glacial reservoir with no flows, maximum depth of 6.56 m and mean depth of 3.68 m [13].

The lake has an elongated shape and consists of two basins differentiated due to the surface area and depth. The two basins are separated by a wide belt of reeds and nymphaeids. Basin I occupies a smaller area but is deeper and more intensely used for recreational purposes whereas basin II takes a larger area but is shallower and less popular as a recreational site but enjoys more interest among anglers. The pressure from people taking a bath in the studied lake has increased since 1995 when nearby Lake Góreckie was taken under reserve protection and its use for recreation was forbidden. Lake Jarosławieckie is characterized by incomplete stratification with epilimnion and hardly developed thin metalimnion in summer. The lake was classified into the 3rd group of susceptibility to degradation, mainly because of a large area of the catchment of agricultural and forest type (953 ha) with respect to the area of the lake (11.2 ha) [13].

In November 2000, March, May, June and July 2001, water samples were collected in two transects (Fig. 1) along and across the lake traversing macrophyte communities of the phytolittoral zonation (7 sites) and reaching the open water zone (mid-lake, 3 sites). Transect along the lake traversed the following sampling sites (sites numbers: 2-5 and 8-11 on the map, Fig.1):

Basin I (smaller and deeper): *Phragmites australis* (Cav.) Trin ex Steud. stand - *Nuphar lutea* (L.) Sibth. et Sm. bed - *Nymphaea alba* L. bed - mid-lake 1 and in basin II (larger but shallower): mid-lake 2 - mid-lake 3 - *Nymphaea alba* bed – *Phragmites australis* stand. Transect across the lake (in plant communities separating both basins of the lake under study, site numbers: 6-7, Fig.1) consisted of two sites: *Typha angustifolia* L. stand and *Nymphaea alba* bed.

Additionally, samples were collected in a site close to a beach attracting local inhabitants and tourists (site number: 1, Fig. 1).

Chlorophyll *a* concentrations (corrected for phaeopigments) were determined spectrophotometrically after acetone extraction according to the procedures described in the Polish Norms. The samples of water for TOC analysis were homogenized and stabilized with phosphoric acid to pH<2. The organic carbon content was then determined on an organic carbon analyzer.

Statistical analyses of the data sets based on non-parametrical Kruskal-Wallis H-test and Man-Whitney U-test as well as Spearman correlation by rank as the empirical distribution of frequency was inconsistent with the normal one. Cluster analysis based on Ward's method and Euclidean distance was used and the results were presented in the form of a dendrogram.

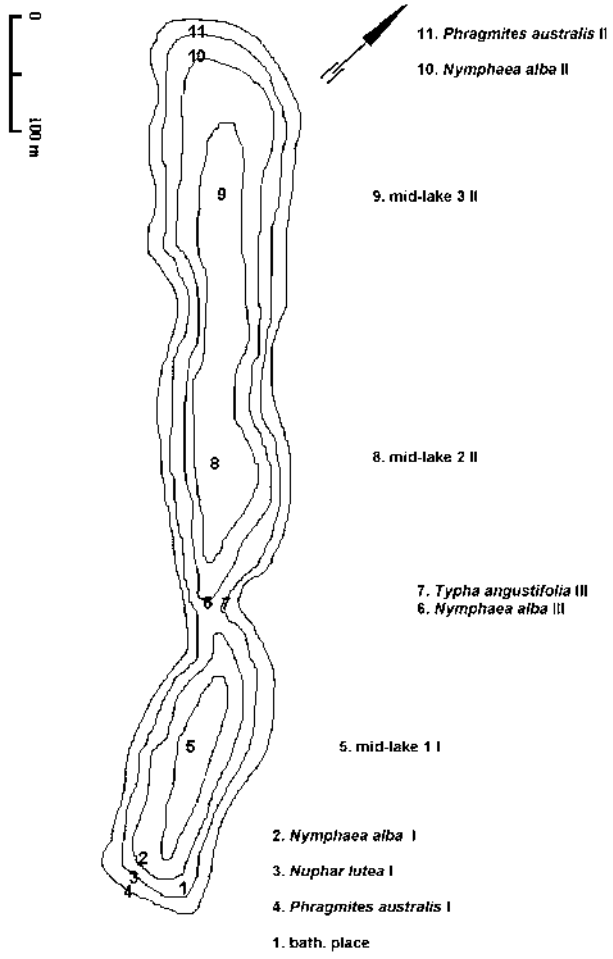

Fig. 1. Map of Lake Jarosławieckie with the distribution of the studied sites.

Results

Spatial Variability of TOC and Chlorophyll *a* Concentrations

During the investigation carried out in Lake Jarosławieckie TOC concentrations (regarding all the sampling sites) ranged between 5.0 mg C/L and 38.0 mg C/L, with the arithmetic mean of 12.30 mg C/L (SD = 6.1, lower quartile = 8.5, upper quartile = 15.0). The range of chlorophyll *a* concentrations was between 0.9 µg/L and 44.9 µg/L, with the arithmetic mean of 13.23 µg/L (SD = 12.5, lower quartile = 5.9, upper quartile = 13.1).

Spatial and temporal variability of TOC and chlorophyll *a* concentrations in Lake Jarosławieckie are presented in Figures 2 and 3, where all the sampling sites are shown separately. In the case of TOC, cluster analysis based on the whole set of data generally produced two

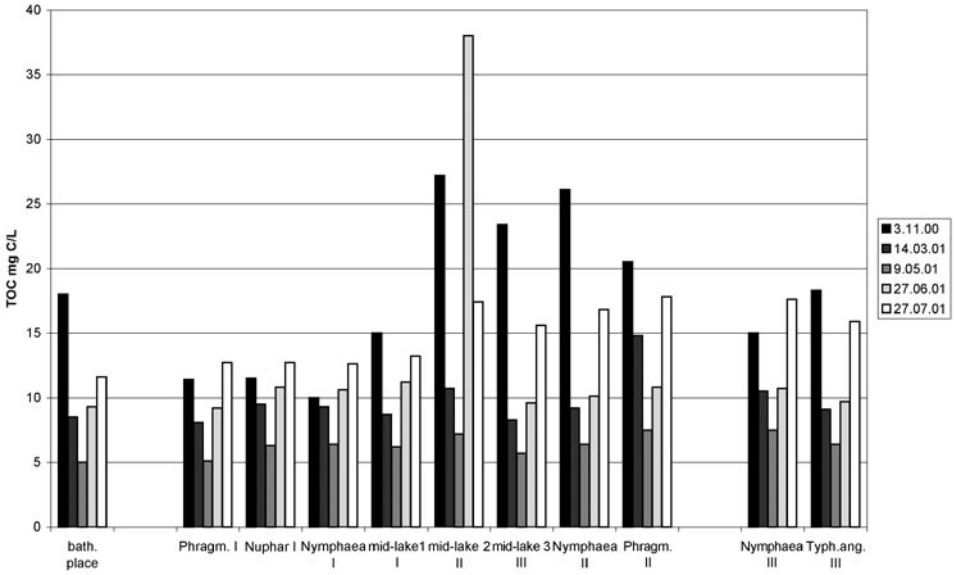

Fig. 2. Spatial and temporal variability of TOC concentrations in particular sampling sites studied in Lake Jarosławieckie.
Explanations: bath. place - bathing place, Phragm. I - *Phragmites australis* stand in basin I, Nuphar I - *Nuphar lutea* bed in basin I, Nymphaea I - *Nymphaea alba* bed in basin I, mid-lake 1 I - central part of basin I (the deepest part of Lake Jarosławieckie), mid-lake 2 II and mid-lake 3 II - two sampling points in central part of elongated basin II, Nymphaea II - *Nymphaea alba* bed in basin II, Phragm. II - *Phragmites australis* stand in basin II, Nymphaea III and Typh. ang. III - *Nymphaea alba* bed and *Typha angustifolia* stand separating both basins of Lake Jarosławieckie.

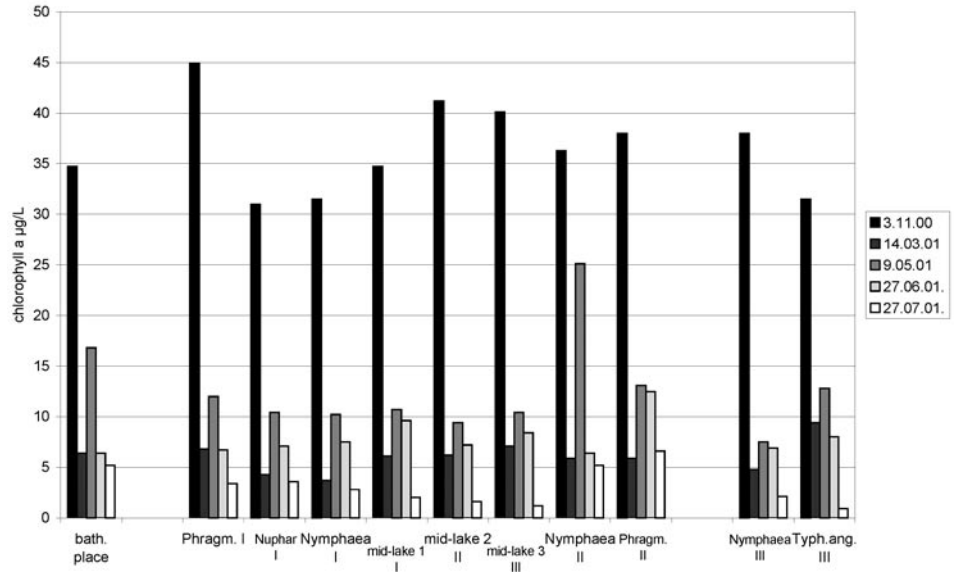

Fig. 3. Spatial and temporal variability of chlorophyll *a* concentrations in particular sampling sites studied in Lake Jarosławieckie. For explanations see Fig. 2.

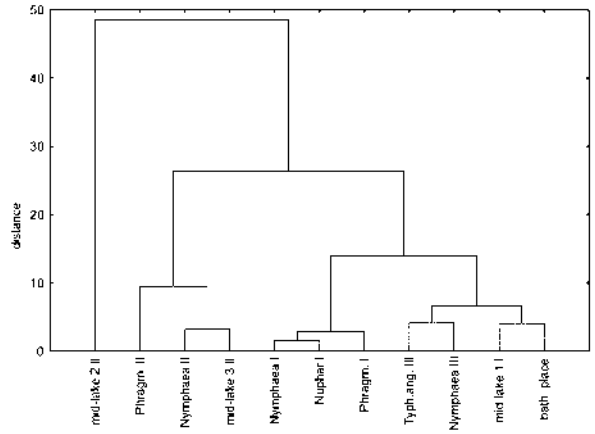

Fig. 4. Result of cluster analysis based on TOC concentrations in particular sampling sites during the study in Lake Jarosławieckie. For explanations see Fig. 2.

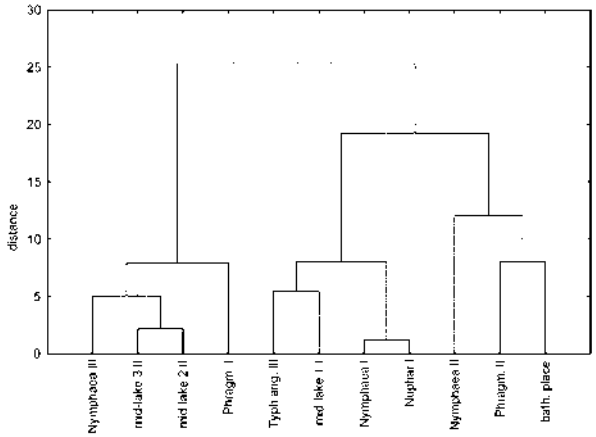

Fig. 5. Result of cluster analysis based on chlorophyll *a* concentrations in particular sampling sites during the study in Lake Jarosławieckie. For explanations see Fig. 2.

groups of sites representing both basins constituting the studied lake (Fig. 4). It is noteworthy that sampling sites localized closely in the lake (especially macrophyte communities) were joined together. The only exception was mid-lake II, separated from the rest of sites. Cluster analysis of chlorophyll *a* concentrations also produced two groups of sites (Fig. 5). However, the dendrogram obtained was inconsistent with the result obtained for TOC.

Although cluster analysis produced groups of sampling sites, neither in the case of TOC nor in the case of chlorophyll *a* Kruskal-Wallis ANOVA by rank (H-test), based on all the values obtained during the study, revealed any statistically significant differences of concentrations among studied sites. Mann-Whitney U-test did not reveal any significant differences between both basins.

Temporal Variability of TOC and Chlorophyll *a* Concentrations

As far as all the sampling sites in Lake Jarosławieckie are considered altogether, Kruskal-Wallis ANOVA by rank revealed statistically significant temporal differentiation of both TOC [H test (4, N = 55) = 42.16743, p = 0.0000] and chlorophyll *a* [H test (4, N = 55) = 47.77589, p = 0.0000] concentrations, this being shown by Figures 6 and 7 (temporal variability in particular sampling sites was presented also in Figures 2 and 3). Both parameters revealed maximum concentrations in November 2000 that were especially expressed by chlorophyll *a* (Fig. 7). The smallest amounts and the narrowest range of values of TOC were observed in May 2001 (Fig. 6). Since that time TOC concentrations increased. Between March and July 2001 chlorophyll *a* concentrations followed quite the opposite pattern of changes to the TOC ones and reached minimum values in July 2001. Although any relationships between both parameters might have been expected, no significant correlations were found (Spearman correlation by rank R = -0.0524, p = 0.7, N = 55) which is in accordance with the results reflected by Figures 4 and 5.

Discussion

A comparison of acquired results to literature data [7] allow us to conclude that the TOC concentrations observed in Lake Jarosławieckie emphasize its eutrophic character with abundant flora and fauna and wealth in nutritive substances. However, most values observed in the studied lake, especially in spring and early summer, were enclosed within the range found in 44 Polish lobelian lakes [4]. Mean value of TOC accounted in this study is similar to that given by Barałkiewicz & Siepak [7] and placed Lake Jarosławieckie in the group of lakes of the smallest amounts of TOC among the lakes investigated by the above-mentioned authors in Wielkopolski National Park.

Due to Polish standards, mean value of chlorophyll *a* corresponded with values typical for the second class of water purity and eutrophic status. Interestingly, most values of chlorophyll *a* observed in Lake Jarosławieckie were enclosed within the range found in the above-mentioned lobelian lakes [4]. Significantly higher chlorophyll *a* concentrations observed in November 2000 might have resulted from the water bloom caused predominantly by *Pseudanabaena catenata* Lauterborn (*Cyanoporokaryota*) [11].

Different patterns of clustering acquired in the present study suggest that both environmental variables, TOC and chlorophyll *a*, are to a significant extent independent. The lack of statistically significant correlations between them seems to confirm such a statement. However, as long as published data are concerned [4], such results as acquired in this study might be considered as rather unexpected. It might suggest that not phytoplankton, meant to force POC and hence TOC [8], is the factor modeling the spatial and temporal pattern of TOC changeability in Lake Jarosławieckie. Since sampling sites in closely located macrophyte patches were clustered together (which means the strongest linkage between them), macrophyte vegetation emerges to be the factor influencing TOC con-

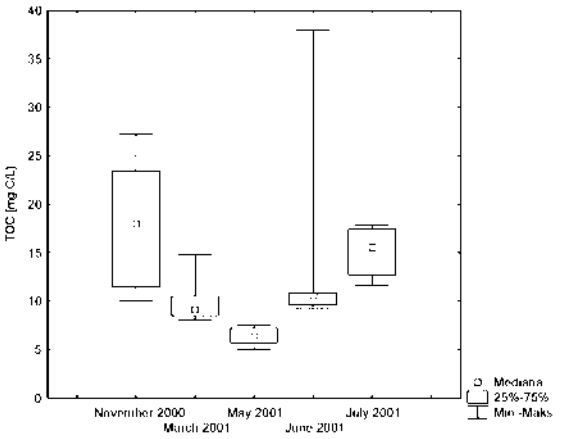

Fig. 6. Temporal changes of TOC concentrations in Lake Jarosławieckie.

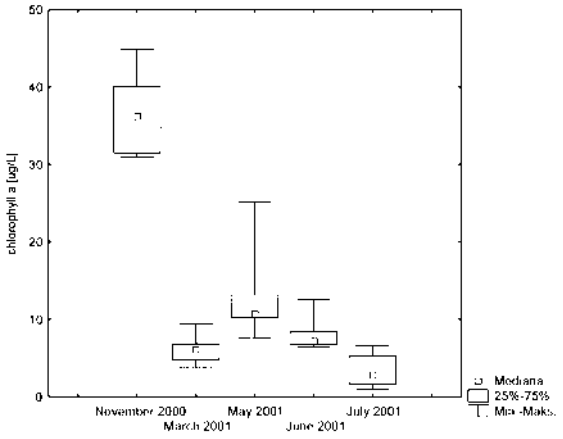

Fig. 7. Temporal changes of chlorophyll *a* concentrations in Lake Jarosławieckie.

centrations in Lake Jarosławieckie. In fact, macrophytes are listed among important autochthonous POC sources [14]. Therefore, seasonal changes in their development might result in changing POC concentrations. It is well documented that temporal changes of POC are responsible for TOC changeability as dissolved fraction of organic carbon reveals quite stable level of concentrations [2,7,8]. In the present study TOC concentrations decreased between November and May and then increased along the vegetative season. The highest TOC concentrations in November might also indicate the influence of macrophyte decay. In the authors' opinion, however, some differences between both lake basins, especially reflected in autumnal concentration of TOC, point to another, allochthonous (terrestrial), source of organic carbon as the concentrations were higher in the basin with the bigger share of forests in the catchment area.

References

1. FRIMMEL F. H. Characterization of natural organic matter as major constituents in aquatic systems. Journal of Contaminant Hydrology **35**, (1-3), 201, **1998**.
2. BARAŁKIEWICZ D., SIEPAK J. Zawartość i sezonowe zmiany rozpuszczonego i znajdującego się w zawiesinie węgla organicznego w wodzie Jeziora Góreckiego. Morena **3**, 73 (in Polish), **1995**.
3. THURMAN E. M. Organic geochemistry of natural waters. Martinus Nijhoff/Dr. W. Junk, Boston, **1986**.
4. BARAŁKIEWICZ D., KRASKA M, SIEPAK J. The content of DOC, POC, and TOC in lobelian lakes. Pol. J. Environ. Stud., Vol. **5,** (6), 17, **1995**.
5. GÓRNIAK A., MISZTAL M. Dissolved organic matter in the waters of the basin of Lake Piaseczno, Łęczyńsko-Włodawskie Lake District, Poland. Acta Hydrobiologica **33,** (1-2), 17, **1991**.
6. GÓRNIAK A. Substancje humusowe i ich rola w funkcjonowaniu ekosystemów słodkowodnych. Dissertationes Universitatis Varsoviensis **448**, Białystok, pp.151 (in Polish), **1996**.
7. BARAŁKIEWICZ D., SIEPAK J. The contents and variability of TOC, POC and DOC concentration in natural waters. Polish Journal of Environmentals Studies, Vol. **32**, (15-1), **1994**.
8. SIEPAK J. Total organic carbon (TOC) as a sum parameter of water pollution in selected Polish rivers (Vistula, Odra, and Warta). Acta hydrochimica et hydrobiologica, **27** (5), 282, **1999**.
9. BORLISZ J. Instrumentelle TOC – Analytik vom Wasser. **46**, 35,**1976**.
10. PEŁECHATY M. Habitat diversity of the lake ecosystem. Brandt J., B.Tress and G. Tress [eds], Multifunctional landscapes. Interdisciplinary approaches to landscape research and management. Conference material for the international conference on "multifunctional landscapes". Centre for Landscape Research, Roskilde, October 18-21. 2000. -Published in September 2000, pp. 256, **2000**.
11. BURCHARDT L., PEŁECHATA A., PEŁECHATY M., SIEPAK J. Horizontal distribution of water and substratum properties and phytoplankton communities during autumnal mixing. 2nd Symposium for European Freshwater Sciences. SEFS-2. Abstract Book. University Paul Sabatier, Toulouse (France), 8-12 July 2001, pp. 25, **2001**.
12. PEŁECHATA A., WIEŚCICKA I. Relationships between phyto- and zooplankton in the phytolittoral and pelagial of a shallow, eutrophic lake. Glony rożnych ekosystemów, problemy ochrony, ekologii i taksonomii. XXI Międzynarodowa Konferencja Sekcji Fykologicznej Polskiego Towarzystwa Botanicznego, pp 128-129. **2002**.
13. SZYPER H., ROMANOWICZ W., GOŁDYN R. Zagrożenie Jezior Wielkopolskiego Parku Narodowego przez czynniki zewnętrzne. In: Burchardt L. (ed.), Ekosystemy wodne Wielkopolskiego Parku Narodowego. Uzupełnienie. Uniwersytet Adama Mickiewicza w Poznaniu, Seria Biologia, 66, Wydawnictwo Naukowe UAM, Poznań, pp 427-472, **2001**.
14. BIANCHI T. S., ARGYROU M. E. Temporal and Spatial Dynamics of Particulate Organic Carbon in the Lake Pontchartrain Estuary, Southeast Louisiana, U.S.A. Estuarine, Coastal and Shelf Science **45**, 557, **1997**.