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Seasonal Distribution of Dissolved and Particulate Organic Carbon in the Water Column of a Meromictic Lake

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Abstract

This study investigated concentration changes of dissolved and particulate organic carbon in a meromictic lake to determine the lake's productivity. It was revealed that the dominant form of organic carbon was the dissolved form (DOC). Maximum production activity was observed in summer (with the peak in June). At the same time, the factors restricting that process were determined, such as: strong pressure of the bacteria competing with the phytoplankton for mineral nutrients, and simultaneous precipitation of phosphates on HS-Fe complexes. The generated organic matter was settling intensively, and one of the transport methods of the dissolved organic matter was adsorption on calcium carbonate and bacterial transformation of the part of DOC into POC.

Keywords: dissolved organic carbon (DOC), particulate organic carbon (POC), productivity, meromixis

Introduction

Organic matter comprises a common constituent of surface waters. It penetrates particular areas in an ecosystem from natural sources (autochtonous and allochtonous) and artificial sources (anthropogenic). The measure of its amount in the aquatic ecosystems can be the content of organic carbon. It constitutes about 50% of dry weight of organic matter [28] and its chemical determination is quick, precise and environmentally friendly.

Total organic carbon (TOC) occurs in the form of dissolved organic carbon (DOC), particulate organic carbon (POC), and volatile organic carbon (VOC). The dominant form of organic carbon in the inland waters is the dissolved form whose content is determined by the balance between import and production, and export and consumption [29].

Considerably smaller part of TOC in waters comprises POC. Transformations in the POC stock occur due to physiological mortality of organisms and mortality related to consumption and paratising. Bacteria that incorporate POC into the biomass [4, 19] and grinding and filtrating organisms also play an important role.

Organic carbon content changes water pH, creates complexes of phosphorus compounds [8], metal cations and toxic substances [5, 21], and humic DOC through water colour modification influences the photic zone range [7]. Content of the individual forms of organic carbon makes it possible to assess the rate of organic matter migration in water reservoirs and to determine their trophic condition.

The aim of the study was to investigate the changes of POC and DOC in the water of Lake Zapadłe and determine the reservoir's productivity.

Materials and Methods

Lake Zapadłe is situated in the western part of the Warmińsko-Mazurskie Voivodeship, approximately 2 km east of the Łukta. The main morphometric properties (Teodorowicz – non published) are as follows: surface

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area – 4.6 ha, direct run-off watershed – 9.4 ha, max. depth – 18.0 mean depth – 10.7 m, relative depth – 0.083, depth indicator – 0.59, total watershed – 119.6 ha, volume – 49,400 m^3.

Lake Isąg is about 600m, with the surface area of 377.5 ha and max. depth 54.5 m [3]. The level difference between the water tables of these reservoirs is about 5 m, which causes intense seepage of the ground waters from Lake Isąg to Lake Zapadłe. Owing to that, with only a small and periodical surface inflow to Zapadłe, the lake has a permanent outflow of about 20 l/s.

The shores of Lake Zapadłe on the northern, western and southern side are elevated more than 20 m above the water table and make steep and high slopes grown with forest. Special morphometric features of the lake and its direct surroundings favour meromixis in the reservoir.

Examinations of the lake were carried out in April 2001 through January 2002. Water for the analyses was collected from the deepest site (18 m) of Lake Zapadłe at the following depths: 0.5 m, 4 m, 10 m, 12 m, 13 m, 15 m, 16 m and 0.5 m above the bottom.

TOC content was marked in unfiltered samples, and DOC after filtration on 0.45 µm Millipore filter. POC was calculated as the difference between TOC and DOC concentrations. Determinations were done on organic carbon analyser Schimadzu TOC-5000, after prior acidification of the samples with 2N HCl to about 2 pH in order to remove CO_2.

Additionally determined were:

- total count of bacterial plankton (TBC) and biomass of bacterial plankton (BB) by the direct analysis method of bacteria stained by acridine orange on polycarbonate black membrane filters (0.2 µm) [13]. Bacteria were analysed under epifluorescent microscope Axioskop (OPTON) with automatic display analysis by MultiScan (CSS) [27],
- transparency, temperature, oxygen content, individual forms of nitrogen (ammonium, nitrite, nitrate, organic), total phosphorus and ortophosphates, iron, manganese, chlorides, total and calcium hardness, chlorophyll a and feophytin. Analyses were conducted in accordance with the Standard Methods [26].

The statistically significant relationships were computed between the concentration of organic carbon and the hydro-chemical parameters and bacterial parameters, assuming the level of significance at p=0.05.

Results and Discussion

Results of the examinations have revealed a clear vertical differentiation of DOC and POC in the waters of Lake Zapadłe. The dominant form of organic carbon was DOC. Its mean content was 3.4 mg C/l which made about 60% of the total content of organic carbon. The highest DOC concentrations were detected in spring. In April, both in the surface waters and near the bottom the max. values were marked (6.4 mg C/l and 7.2 mg C/l, respectively) (Tab. 1). The high DOC concentrations in that period were related to the increased transport of organic matter from the allochtonous sources and photosynthesis in the reservoir. The spring phytoplankton bloom was displayed by chlorophyll present (4.3 µg/l) in the surface water layer, high content of oxygen (16.7 mg O_2/l, 143 % saturation) and low transparency (1 m). The decrease of transparency in the lake overlapped with the rise of DOC and POC concentrations (r = -0.53 and r = -0.43). The optical properties of dissolved and particulate organic matter can influence light penetration and thus reduce the range of the trophogenic layer [2, 14, 20].

The highest activity of the primary production was observed in summer, with the peak in June when chlorophyll a concentrations reached the value of 18.7 µg/l at 4 m, and 12 µg/l under the surface. The high chlorophyll a concentrations overlapped with the increase of TOC (6.4 mg C/l), oxygen (15.4 mg O_2/l, 148 % saturation) in the surface water layer, low transparency (1 m) and total depletion of ammonium nitrogen and phosphates to a depth of 4 m. Much importance to the intensity of the primary production in Lake Zapadłe had also the pressure of the water bacteria. Increased concentrations of humic substances (HS) intensify the activity of heterotrophic bacterial plankton, as well as photo- and chemotrophic organisms capable of running photosynthesis in anaerobic conditions at light access [11]. Currie [6] and Azam & Cho [1] point out that bacteria can limit the growth of phytoplankton competing for mineral nutrients, especially phosphorus [25]. In Lake Zapadłe these rules seem to be confirmed by the high number and biomass of bacteria (TBC in summer – 5.4 million cells/ml and BB – 145.8 µg C/l) and the considerable contribution (to 30 %) in bacterial plankton of the phototrophic bacteria in summer and autumn on the interface of the aerobic and anaerobic layers, i.e. at a depth of 4 m.

Much influence on the production size in the lake had also the parallel precipitation of phosphates on HS. The latter can absorb phosphates on HS-Fe complexes [9, 16, 17] and thus limit the availability of this element to algae [15, 24]. From the studies of Gerke & Hermann [10] it is evident that the intensity of these processes rises together with increasing Ca^{2+} concentration. It was confirmed in Lake Zapadłe by the high concentration of calcium (72.3 mg Ca^{2+} on average) and the significant dependence between POC and Fe (r = 0.47).

The process of photosynthesis in summer in Lake Zapadłe effected in high production of organic matter in the reservoir. The increasing concentrations of DOC and POC towards the bottom (Tab. 1), as well as the occurrence of chlorophyll a (5.4 µg/l on average) and feophytin (3.5 µg/l on average) in the near-bottom layers were the evidence of intensive sedimentation of allochtonous organic matter. One of the ways of dissolved organic matter (DOM) transport towards the bottom may be adsorption on organic and inorganic (with $CaCO_3$) suspension [22, 23]. Despite the lack of significant statistical correlation between DOC and calcium content (r = 0.03), it can be

Table 1. Content of TOC, DOC and POC in Lake Zapadłe since April 2001 through January 2002.

Parameter	Unit	Month						
		IV	VI	VII	VIII	X	XI	I
		0.5 m under water table						
TOC	mgC/l	7.1	6.4	5.9	4.4	3.9	4.2	3.1
DOC	mgC/l	6.4	3.7	4.8	3.3	2.9	2.7	2.0
POC	mgC/l	0.7	2.7	1.1	1.1	1.0	1.5	1.1
		4 m						
TOC	mgC/l		6.3	4.6	5.1	3.2		
DOC	mgC/l		3.5	3.2	2.8	2.1		
POC	mgC/l		2.8	1.4	2.3	1.1		
		10 m						
TOC	mgC/l	7.0	5.7	5.1	4.3	5.3	3.6	3.7
DOC	mgC/l	4.8	3.8	2.6	2.7	2.4	2.5	2.0
POC	mgC/l	2.2	1.9	2.5	1.6	2.9	1.1	1.7
		12 m						
TOC	mgC/l	6.4	6.2	4.2	3.3	4.2	3.1	4.0
DOC	mgC/l	5.7	3.6	2.2	2.1	2.1	2.3	2.2
POC	mgC/l	0.7	2.6	2.0	1.2	2.1	0.8	1.8
		13 m						
TOC	mgC/l	7.1	5.7	3.6	3.6	5.1	3.5	3.8
DOC	mgC/l	5.8	3.4	2.1	2.1	2.1	2.2	2.2
POC	mgC/l	1.3	2.3	1.5	1.5	3.1	1.3	1.6
		15 m						
TOC	mgC/l	5.3	6.7	5.4	5.3	6.0	5.1	4.1
DOC	mgC/l	4.2	4.2	3.1	3.1	3.3	3.1	2.1
POC	mgC/l	1.1	2.5	2.3	2.2	2.7	2.0	2.0
		16 m						
TOC	mgC/l	6.7	8.3	7.6	7.8	9.6	6.2	4.7
DOC	mgC/l	4.2	5.0	3.3	4.1	4.2	3.3	2.4
POC	mgC/l	2.5	3.3	4.3	3.7	5.4	2.9	2.3
		0.5 m above bottom						
TOC	mgC/l	8.5	9.1	7.3	10.3	10.0	8.0	6.5
DOC	mgC/l	7.2	5.2	3.6	5.0	4.9	4.9	2.7
POC	mgC/l	1.3	3.9	3.7	5.3	5.1	3.1	3.8

assumed that calcium carbonate present in the lake may have been the factor responsible for parallel precipitation of organic matter, which was evidenced by the high concentrations of calcium (79.3 mg/l on average) and organic carbon near the bottom (Tab. 1).

Productivity of the surface water layers in Lake Zapadłe, as well as the resultant variable concentrations of DOC and POC in the water column (Tab. 1) confirms the obtained DOC:POC ratio. In eutrophic reservoirs such ratio equals between 6:1 and 10:1. Wetzel et al. [30] reports that the ratio can decrease to 5:1 in very productive lakes, or even to 1:1 in the layers where aggregated bacteria develop.

In Lake Zapadłe the DOC:POC ratio equalled from 9:1 to 2:1 in the surface layer and from 6:1 to 0.7:1 in the near-bottom layer. The visible decrease of the DOC:POC ratio towards the bottom speaks for the possibility that bacteria transform part of DOC into POC [1, 5, 18]. Organic carbon transformation in Lake Zapadłe is to a high degree determined by the microbiological loop i.e. the biological conversion of DOM by heterotrophic bacteria into particulate organic matter (POM) that makes their biomass [4, 12]. Organic matter broken down by enzymes is transformed into organic and mineral compounds, directly assimilated by bacteria. The biomass of these bacteria is the feed to protozoans and microzooplankton [8, 18]. The discussed dependence in Lake Zapadłe is confirmed by the statistically significant correlation between TBC and BB, and POC ($r = 0.70$ and $r = 0.66$, respectively). While the low correlation coefficient between TBC and BB, and DOC ($r = 0.39$ and $r = 0.27$, respectively) confirms the hypothesis that in the lake the bacterial plankton participates intensely in the functioning of the detritus-route of matter and energy turnover.

The increasing content of POC in the total pool of organic carbon (TOC) was visible not only in the vertical cross section of the lake but also in the individual seasons of the year. Between spring and winter the per cent contribution of POC, compared to TOC, increased from 20% to 48%.

Occurrence of a high amount of particulate organic matter in Lake Zapadłe during the autumn-winter period results from lake water productivity during the growing season, the import of allochtonous organic matter from the direct run-off watershed and the limited mineralisation due to low water temperature (7.2°C on average) and anaerobic conditions to a depth of 4 m. Organic matter, settled together with mineral suspension in the zones of discrete sedimentation, becomes a strong sorptive factor, thus eliminating pollutants from the water column.

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