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Chemical properties of bottom sediments in throughflow lakes located in Drawieński National Park

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Abstract

This study presents and discusses the result of research on the chemical composition of bottom sediments of throughflow lakes located in Drawieński National Park. Basic hydrochemical indicators of the studied sediments are discussed: total organic carbon (C_{org}), total nitrogen (N_{tot}), and the C_{org}/N_{tot} ratio, which shows the rate of organic matter mineralization. The research and the analysis of the results show that the quality of the studied sediments changed with their distribution in the lake basin. The highest C_{org} and N_{tot} values were noted in sediments

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accumulated in the maximum depth of each lake, and at the inflow and outflow from the first lake in the whole cascade of throughflow lakes. Low C_{org}/N_{tot} ratios indicate that most of the sedimentary organic matter in the throughflow lakes comes from aquatic organism production, but the small participation of land-plant organic matter delivered to the lakes is also shown.

INTRODUCTION

Drawieński National Park (DNP) was established to protect the landscape of the young glacial outwash plain, which is covered with forests, lakes and the valleys of two rivers, the Drawa and Płociczna, both of which are close to a pristine natural state. The area of the park (established in 1990) is 113.42 km^2. Due to its importance for Poland and Europe, the DNP, as a habitat of rich flora and fauna formed in the sub-Atlantic climate, was included in the European Habitat Directive. The post-glacial lakes, which are significantly distinguished by their sizes and trophic states, as well as the original flora and fauna inhabiting the lakes, are valuable features of the park's landscape.

Bottom sediments are an important element of lakes. The sediments are products of the processes occurring in the aquatic environment, as well as in the whole catchment area. They are traps for a substantial part of the matter delivered to lake sediments, and, therefore, they provide information that is important for the interpretation of global climate changes in the natural environment. These sediments are considered to be a valuable and unique record of processes occurring in the aquatic environment (Meyers and Lallier-Vergès 1999). The process of lake sediment formation is an inseparable element of the overall change and general cycle of matter in a given environment. The quality of organic matter is an important feature with respect to the physicochemical conditions on the lake bottom. The approximate value of the amount and quality of the organic matter, as well as its decomposition, can be determined by the organic carbon to total nitrogen ratio C_{org}/N_{tot} (Kamaleldin et al. 1997, Meyers 1997, Meyers 2003, Twichell et al. 2002, Mielnik 2005). The C_{org}/N_{tot} ratio in lake sediments is often used as an indicator of time changes in the organic matter cycles in aquatic ecosystems (Kamaleldin et al. 1997; Meyers, Lallier-Vergès 1999).

In this paper, research on bottom sediments delivered and deposited in the throughflow lakes Sitno, Płociczno, and Ostrowiec, located in the Drawieński National Park, are presented and discussed.

MATERIALS AND METHODS

Three lakes Sitno, Płociczno, and the northern part of Lake Ostrowiec form a cascade of lakes connected by the Płociczna River in the eastern arm of the DNP (Fig. 1). The sediments of these lakes were the research material. Lake

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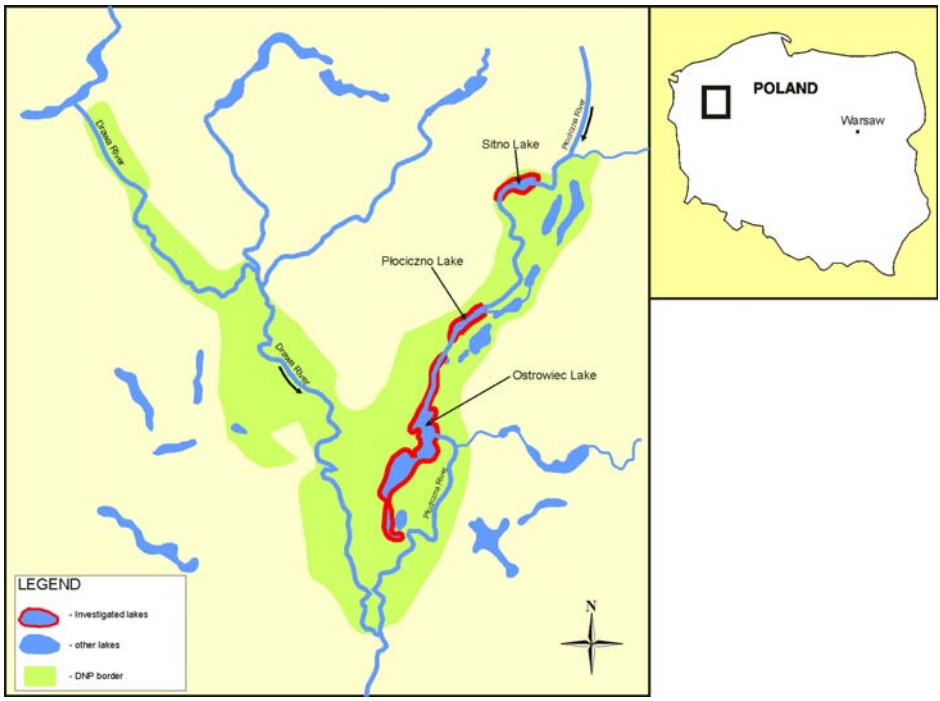


Fig. 1. Location of investigated lakes in the DNP.

Sitno is the first one in the cascade of throughflow lakes. Pine forest covers 89% of its basin (Szyper and Kraska 1999). The water flushing rate in the lake is 18.1 times a year. Analysis performed by Piotrowicz et al. (1998) allowed them to classify Lake Sitno waters as strongly eutrophic, on the brink of hyperthrophy. Lake Płociczno is the second throughflow water body of the Płociczna River. With regard to its morphometric parameters, it is very similar to the lake situated above it with 98% of its basin is covered with mixed forest. The water flushing rate is the highest here and occurs 46 times a year. The water of Lake Płociczno, like the waters of Lake Sitno, are classified as on the brink of strong eutrophy and hypertrophy. Lake Ostrowiec is the third lake in the cascade. It is the most distinct water body with respect of shoreline development and the surface features of the lake basin. Lake Ostrowiec is separated into four parts. The Płociczna River flows into the northern part of the lake to a maximum depth of 11.5 meters, and then it flows out from it. The throughflow part of the waters in Lake Ostrowiec are classified as mezotrophic, and 95% of its drainage basin is covered with mixed forest in which a pine

plantation is dominant. The annual water flushing rate of whole volume of the lake is 1.5 times a year.

The bottom sediments were sampled during summer stagnation in the surface layer. They were taken at a thickness of from approximately 0 to 20 cm. The samples were collected in the summer of 2006 in three replicates from each lake in three fields: (i) at the river inflow into the lake, (ii) at the maximum depth of the basin (in Lake Ostrowiec it was the depth of the part through which the Płociczna River flows), and (iii) at the river outflow from a lake. The content of organic carbon (C_{org}), determined with the method by Orłow and Grindel, and the content of total nitrogen (N_{tot}), with that by Kjeldahl, were measured dry, and the sampled sediments were sieved through 1 mm mesh. The C_{org}/N_{tot} values were determined based on the results obtained.

RESULTS AND DISCUSSION

Elemental analysis

Organic carbon (C_{org}) content is an important parameter indicating substantial changes in organic matter deposited in bottom sediments. In the bottom sediments of the investigated lakes the C_{org} content level was relatively low ranging from 0.6 to 12.7% (Table 1). This indicates there is a significant contribution of mineral substances to the examined sediments. The analysis of ash and silica content (69.5 – 99.2%) in the sediments confirms these observations. The highest C_{org} content was recorded in Lake Sitno, the first lake in the cascade. In the bottom sediment of Lake Płociczno, the C_{org} values were significantly lower than they were in the first lake. The lowest C_{org} content was observed in the third lake in the cascade of the throughflow lakes. The tendency of varied C_{org} content in the different fields of organic matter sedimentation was observed to be the same for the all three lakes. In each lake, the highest C_{org} content was in the sediments deposited in the field of the maximum depth (12.0 – 12.7%). Statistically considerable differences in the values determined were not found. The sediments collected on the river inflow into the lakes contained considerably less C_{org}.

Examining the total nitrogen (N_{tot}) content in sediments provides important information about the quality of sedimentary organic matter. The concentration of N_{tot} in the investigated sediments is significantly high and varies from 0.37 to 1.17% (Table 1). High nitrogen content in lake sediments results from high protein content in the organic matter. This is a product of the life activity of aquatic organisms, as well as the decomposition of plant and animal residues. The tendency of changes in N_{tot} content in the examined sediments is similar to the that observed for C_{org} content. The highest content of N_{tot} is observed in the

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sediments of Lake Sitno (1.0 – 1.2 %). In the sediments of lakes Płociczno and Ostrowiec, which are loaded on the river inflow and outflow from the lakes, the rapid decrease in N_{tot}, in relation to its content in the sediments cumulated at the outflow from Lake Sitno. As in the case of C_{org} content, the highest concentration of N_{tot} was observed in sediments in the fields of maximum depth.

Table 1

Elemental composition of the sediments of the studied lakes.

Lake		Area [ha]	Maximum depth [m]	C_{org} [%]	N_{tot} [%]	C_{org}/N_{tot}
Sitno	in	67.2	7.0	11.8	0.98	12.1
	m			12.7	1.17	10.9
	out			9.8	1.15	8.5
Płociczno	in	56.1	5.2	8.2	0.56	14.7
	m			12.0	1.17	10.3
	out			4.7	0.42	11.2
Ostrowiec	in	387.6/ ?	28.5/11.5	3.0	0.60	5.0
	m			12.0	1.13	11.2
	out			0.6	0.37	1.6

in- inflow
m – maximal depth of lake/part of lake
out - outflow

The results obtained do not show any statistically significant differences. The values of C_{org} and N_{tot} were distinct and changed in terms of lake character, as well as in terms of the field where the sediments were collected in the lake basin (Table 1). Due to the distinct distribution of depth, sedimentation takes place in a different way in each lake in the shallow zone as well as in the deeper one. In the first two lakes, a substantial amount of the material transported by the river collects at the inflow into the lakes, where the river course speed continues. The least amount of sediment settles in the fields at some distance from the river course, that is at the outflow from the lake. From the research conducted by Szyper and Kraska (1999), it is clear that the load of nutrients (mainly nitrogen) is primarily influenced by their inflow with the Płociczna River (<90%). The largest amount of material transported by the river settles in the first lake. In this way, the water body located at the head of the cascade is supplied with the greatest loads of mineral and organic substances, whereas the other lakes, located at the end of the cascade, are supplied with significantly smaller loads of these substances. Moreover, the stratification of the third lake (Lake Ostrowiec), where the analyzed parameters were the lowest, had favorable effects on water quality. Stratification causes a decrease in lake water productivity, and, in this way, the loads of organic matter in the sediments are smaller. The variability of the examined sediments may be significantly influenced by the floral composition overgrowing the phytolittoral zones of the lake. Investigations

carried out by Piotrowicz et al. (2006) reported that the phytolittoral zone of lakes Sitno and Płociczno was dominated by nymphaeid communities from the alliance *Nymphaeion*. They mainly cover the area at the river inflows and outflows from the lakes. The other parts of the phytolittoral zone are covered with elodeids (communities from the alliance *Potamion)* and helophytes *(Phragmition + Magnocaricion)*. The flora in Lake Ostrowiec is dominated by elodeids, which occupy about 63% of the phytolittoral area, and helophytes, which cover about a quarter of the phytolittoral zone.

C_{org}/N_{tot} ratio

The changes in C_{org} and N_{tot} content that were noted in the examined sediments were conditioned also by the trophic state of the lakes. An increase in C_{org} and N_{tot} content was observed with increases in the trophic state of a given lake. The C_{org}/N_{tot} ratio ranged from 1.6 to 14.7 in the sediments examined (Table 1) In Lake Sitno the C_{org}/N_{tot} ratio was the highest at the river inflow into the lake, and it decreases as distance from the inflow increases. A similar distribution of the C_{org}/N_{tot} ratio was observed in Lake Płociczno sediments. However, the C_{org}/N_{tot} ratio at the river inflow and outflow from Lake Płociczno was significantly higher than it was in Lake Sitno. The situation is different in the sediments of the last lake in the cascade. The C_{org}/N_{tot} ratios in the sediments sampled at the inflow and outflow of Lake Ostrowiec were substantially lower than the other values at 3.0 and 1.6, respectively. These differences may have resulted from the different stratification of the Lake Ostrowiec basin in comparison to that of the lake basins of Sitno and Płociczno. It is assumed that in Lake Ostrowiec the sediments carried with the river inflow slide over the steep basin slope towards the deeper parts of the lake. The very low C_{org}/N_{tot} content, especially for the sediments in which $C_{org} < 1\%$, is explained by the high percent of non-organic nitrogen in relation to the rest of the nitrogen in sediments, which may falsely lower the C_{org}/N_{tot} ratio (Meyers 2003). A C_{org}/N_{tot} ratio between 13 and 14 is considered as a typical one for most lake sediments (Meyers and Lallier-Vergès 1999). This suggests the relatively equal contribution of phytoplankton elements, as well as vascular plants, to the organic matter. A C_{org}/N_{tot} ratio between 4 and 10 characterizes organic matter rich in protein but poor in lignin structures, the main sources of which are residues of algae, zooplankton, phytoplankton, and bacteria. The C/N >20 suggests that the organic matter was of land-plant origin; it contains macrophytes and higher plants rich in lignin and cellulose and poor in protein (Meyers and Ishiwatari 1993, Meyers 1997). The C_{org}/N_{tot} ratio for profundal sediments was practically the same for all the lakes at the range of 10.3 to 11.2. This indicates the predominant contribution of plankton to organic matter

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production, and the rather low contribution of higher plants containing lignin and cellulose. The C_{org}/N_{tot} analysis leads to the conclusion that the organic matter produced in the sediments collected at the river inflow and outflow from the lakes (excluding the inflow of Lake Sitno) is mainly of plankton origin. When analyzing the C_{org}/N_{tot} ratio, it should be taken into consideration that the selective decomposition of the organic matter by microorganisms during its slow diagenesis may be modified by its elemental composition as well as by the C_{org}/N_{tot} ratio of the organic matter in sediments (Kamaleldin et al. 1997; Meyers, Lallier-Vergès 1999; Routh et al. 1999).

CONCLUSIONS

The character of changes presented above in parameters such as the C_{org}, N_{tot}, and C_{org}/N_{tot} ratio in throughflow lake sediments reflects the natural migration of organic and mineral substances. Among other things, this is linked with different affinities with the decomposed organic matter accumulated in the sediments.

The diversity of the material transported by the river also results from its sedimentary differentiation along the water body, which is connected with different zone water flow velocity.

The differences in sediments in respect of their chemical properties result from the individual features of each lake, including the character of throughflow, morphometric differences, and the character of the drainage basin for which the lake is a sedimentation tank. The flora growing over the water body is a significant factor differentiating the chemistry of the sediments.

Material of plankton origin is the predominant source of the organic matter of the examined sediments.

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