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Carbon and nitrogen and their elemental and isotopic ratios in the bottom sediment of the Solina-Myczkowce complex of reservoirs

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Abstract

The studies concerned the ecosystem of the Solina-Myczkowce cascade of reservoirs. While the elemental C:N ratio was higher in the Solina Reservoir branches and in the Myczkowce Reservoir (>10), the values for stations located near the Solina Dam were low (<10). Markedly, the lowest values for $\delta^{13}C$ were noted in the Myczkowce Reservoir (-28.5‰), and these contrasted with the higher values found in the Solina Reservoir (ca. -27‰). $\delta^{15}N$ varied from 2‰ in the upper Solina to above 3.5-4‰ downstream. While the data obtained indicate the autochthonous origin of sedimentary matter, primary production influences the properties of the bottom sediments in the lower part of the Solina reservoirs.

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INTRODUCTION

It is usual for reservoirs to be more loaded with nutrient and organic pollutants than lakes, above all due to the size of their catchment areas (Straškraba 1998). This ensures more rapid processes of eutrophication and degradation, as does the fact that reservoirs are efficient traps for nutrients and organic matter intensively produced in catchments, as well as via internal production. The identification of the contribution that auto- and allochthonous matter makes to bottom sediment and suspended matter is important to an understanding of the biogeochemical cycling of nutrients and to consequent decision making as regards the protection and restoration of water bodies (Lehmann et al. 2004). Carbon-to-nitrogen elemental ratios (C:N) and isotopic compositions are often used to monitor sources and fates of organic matter in estuarine, lake, and reservoirs environments (Murase and Sakamoto 2000, Graham et al. 2001, Lehmann et al. 2004, Strand 2005).

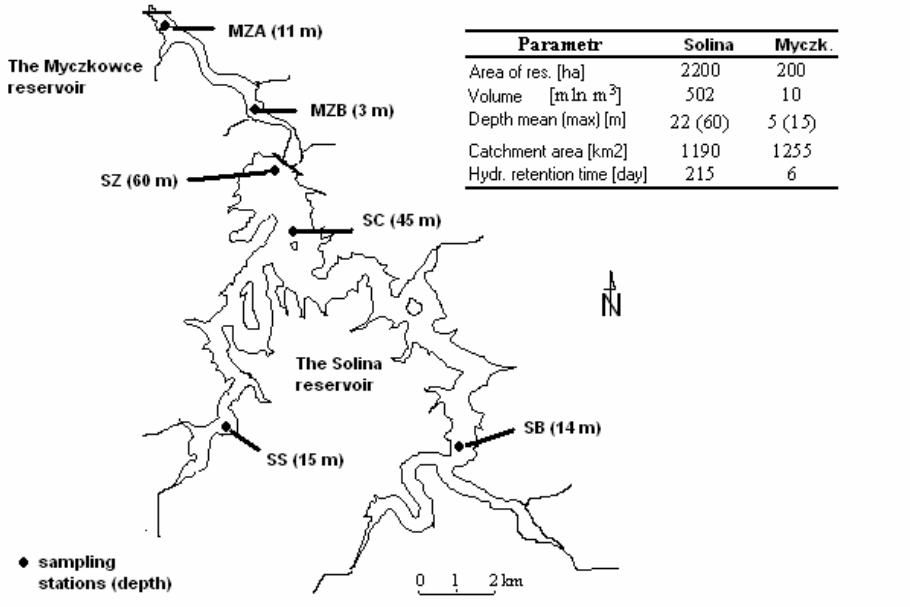
The aim of this study was to investigate the source and fate of the bottom sediment matter of the Solina–Myczkowce complex of reservoirs through observation and the analysis of the spatial distributions of C, N contents, and C:N and stable isotope ratios.

MATERIALS AND METHODS

The Solina-Myczkowce complex of reservoirs is Poland's largest man-made lake system, situated on the upper San River, southeast Poland. The morphometric parameters for these reservoirs are shown in Fig. 1. The mean depth (22 m) and high value for the upper Solina Reservoir (SRES) volume to length of shoreline ratio (157) ensure its immunity to degradation. The lower, Myczkowce Reservoir (MRES) is supplied mainly by cold hypolimnetic water from the upper one. The catchment area of the reservoirs is characterized by a steep slope, and in combination with the geological structure of the bed-rock, shape the reservoirs' low capacity to retain precipitation. The greater part of the catchment area is forested, to a lesser extent also used as meadows and pastures. Populations in the drainage basin are small, the built-up areas mainly concentrating in valleys near the mouths of rivers and streams. Industrial facilities are entirely absent, while most of the resorts present are of a recreational character, with leisure centers and bungalows. The reservoir tributaries differ in length (from 6.5 to 92.4 km), basin areas (16.7-604 km^2), and mean flow (0.06-10.4 $m^3 s^{-1}$).

Bottom sediment cores were collected using a gravity sampler during the ice-free season (on nine occasions from May to November 2005), at four stations in SRES and two in MRES. The stations were located along the

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Parametr	Solina	Myczk.
Area of res. [ha]	2200	200
Volume [mln m^3]	502	10
Depth mean (max) [m]	22 (60)	5 (15)
Catchment area [km2]	1190	1255
Hydr. retention time [day]	215	6

Fig. 1. Locations of sampling stations and some of the physical features of the Solina-Myczkowce complex of reservoirs.

longitudinal axes of the reservoirs (Fig. 1). A thin (2 cm) upper layer of sediment was analyzed each sampling day. Samples were dried at 60°C, milled, and subjected to the removal of the carbonate fraction following 72-hour contact with a vapor of 30% HCl in a desiccator (Zimmermann et al. 1997). The contents of total organic carbon (TOC) and nitrogen (TN) were measured using an elemental analyzer (Flask 1112, ThermoQuest). The C and N isotopic compositions were detected using a DELTA^{Plus} isotopic ratio mass spectrometer (Finnigan Mat) coupled with the elemental analyzer. Values for isotope ^{15}N:^{14}N and ^{13}C:^{12}C ratios showed as $\delta^{15}N$ and $\delta^{13}C$ were evaluated versus Air and PDB standards, respectively. Organic matter (OM) was analyzed using the loss ignition method at 550°C for 4 hours.

RESULTS AND DISCUSSION

Mean contents of OM, TN, and TOC were lower in the Solina Reservoir (SRES) than in the Myczkowce Reservoir (MRES). The results showed that two sampling stations in upper branches of SRES, two in the central section of

SRES and two in MRES (Fig. 1) were statistically indistinguishable from one another (Fig. 2). Comparison of the parameters obtained, therefore, allows identifying three kinds of bottom sediment matter in the studied reservoirs. The content of organic matter ranged from 9.3 to 10.2% in the inlet parts of SRES to the 12.5% near the MRES dam (Fig. 2a). These are concentrations slightly lower than those noted for other similarly-aged reservoirs in Polish lowlands

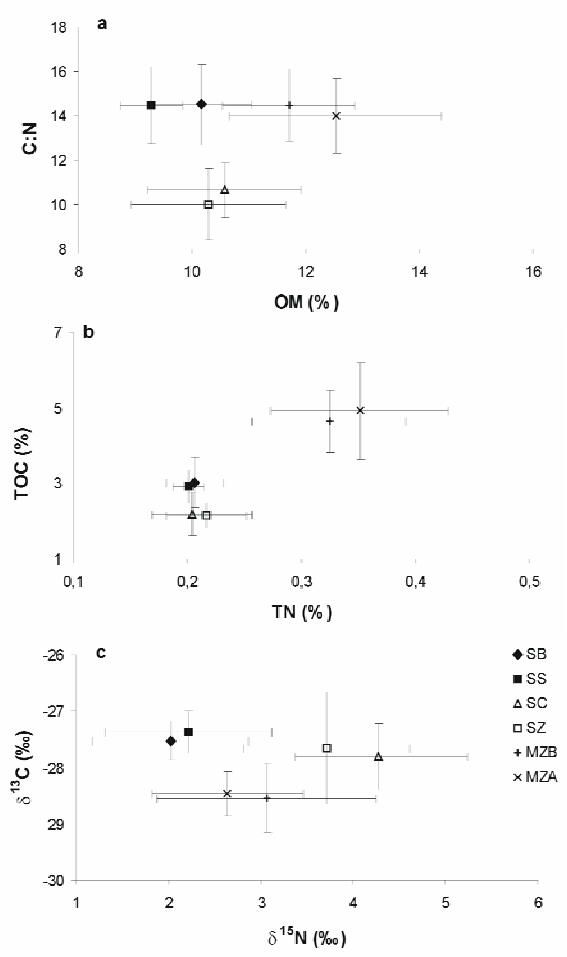


Fig. 2. Comparison of data obtained from the six analyzed sampling stations, (a) organic matter in sediment (OM) vs. C:N ratio, (b) total nitrogen (NT) vs. total organic carbon (TOC), and (c) stable isotopic data. Standard deviations are marked.

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(Kajak 1990, Wiśniewski 1994, Bednarek et al. 2004). Nevertheless, the younger submontane Dobczyce Reservoir had a content of OM in the thin layer of sediment only half as high (Gołaś et. al 2005). While values for total N content were almost constant throughout the bottom sediments in SRES (at 0.20 – 0.22%), they were higher in MRES, reaching 0.32 and 0.35% by the dam (Fig. 2b). Compared to those in the literature, these were low values, especially in the case of SRES (Kajak 1990, Bednarek et al. 2002). In contrast with stable TN, the content of TOC declined markedly along the axis of SRES from 3.02% in the inlet branch to 2.14% lower down. TOC content was highest in MRES at 4.6 – 4.9% (Fig. 2b). The fact that the percentages of TN and TOC were almost twice as high in the bottom sediment of the Myczkowce Reservoir as in the Solina Reservoir may be connected with its supply with hypolimnetic water from the upper reservoir. In deep reservoirs, most of the organic matter is carried through the reservoir and in the enriched hypolimnion in the deepest section near the dam (Wang et al. 2005). The significant correlations between TN and TOC noted for three sections of the sediment matter (Table 1) denote the prevalence of organic over inorganic nitrogen in all of stations analyzed.

Table 1

Significant correlations expressed as the Pearson coefficient (r) and significance level (P) between TOC, TON, isotope and elemental ratios (n = 18) for three kinds of study sites.

Sites		TN - TOC	$\delta^{15}N$ - TN	$\delta^{13}C$ - TOC	$\delta^{15}N$ - C:N
SS & SB	r	0.8077	-	-	0.5164
	P	0.00005			0.0282
SC & SZ	r	0.7943	-	-0.4170	0.6002
	P	0.0001		0.093	0.0108
MZA & MZB	r	0.8787	-0.72856	-0.4078	0.4236
	P	0.000002	0.0006	0.0599	0.0257

C:N ratios were slightly higher than the Redfield ratio of 6.6:1. Land-derived organic matter generally has a higher C:N ratio (>20) than its lacustrine counterpart (<10) (Murase and Sakamoto 2000). Sediments from the upper parts of SRES and from MRES were characterized by a higher ratio above 14, suggesting a dominant contribution made by external organic matter. The station nearest to the Solina Reservoir dam reported the lowest C:N values of about 10:1 (Fig 2a). Organic matter from the catchment is thus subject to decomposition during transport from the upper branch, while the participation of planktonic (autochthonous) carbon in bottom sediments is greatest.

Nevertheless, the upper SRES and MRES stations in particular reported increased C:N ratios across the spring-fall period (Fig. 3). This was not connected with the supply of land-derived matter, because most of it loaded the reservoirs in spring during snow melt. It may, however, result from the inflow of sewage (C:N >12, Graham et al. 2001) from households that mostly lack sewers, as well as from motels and camp sites during the tourist season.

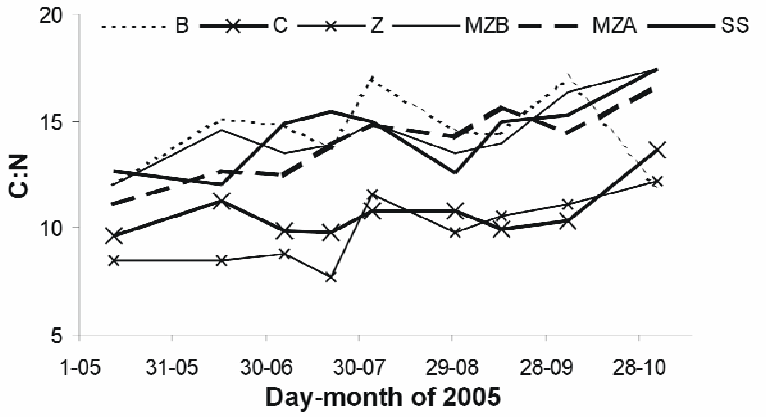


Fig. 3. Seasonal variations in C:N ratio at each sampling station.

In the Solina Reservoir, the mean values for TOC $\delta^{13}C$ in the top layer of the bottom sediment varied slightly across the range –27.37 to –27.81‰ (Fig. 2c), and these values indicate an external source of bottom sediment matter (Murase and Sakamoto 2000, Graham et al. 2001, Lehmann et al. 2004). No marked difference in $\delta^{13}C$ values was observed, though values rather closer to –27‰ were obtained at the upper stations in SRES. These results are correspond with the mainly wooded character of the catchment, because values of $\delta^{13}C$ near -27‰ are characteristic for C3 plants (Schidlowski 1995). In contrast, $\delta^{13}C$ values in MRES were lower, at about –28.5‰. This suggests less intensive mineralization of OM in MRES than SRES, which corresponds with the fact that the release of CO_2 leads to increased $\delta^{13}C$ in the decomposed material (Hellings et al. 1999). Lower $\delta^{13}C$ in MRES therefore account for the OM (and TOC, TN) peak in the reservoir. A low OM decomposition rate may result from the low temperature of MRES water (mainly derived from the SRES hypolimnion) all year round. A significant relationship between the $\delta^{13}C$ of the

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sedimentary OM and TOC was noted in the lower sections of the reservoir complex (Table 1).

Values for $\delta^{15}N$ nitrogen isotope ratios varied more than those for organic carbon, ranging in the case of the Solina sediment from about 2‰ in the upper branches to 4.39‰ in the central basin and 3.21‰ next to the dam (Fig. 2c). A similar, if less marked, distribution along the axes of bodies of water has been noted by others (Murase and Sakamoto 2000, Graham et al. 2001), suggesting that much land-derived nitrogen is consumed in biogeochemical cycling along the reservoirs axis (Lehmann et. al 2004, Strand 2005). No significant differences in the $\delta^{15}N$ values of about 3.5‰ were reported for the station located on MRES. It was noted in the current study that there were significant correlations in which high $\delta^{15}N$ values corresponded with high C:N ratios in the reservoirs (Table 1). In aquatic ecosystems, the ^{14}N isotope (as opposed to ^{15}N) is lost preferentially from the organic substrate during decomposition, thus producing higher $\delta^{15}N$, and these relationships suggest significant decomposition of external OM especially in SRES (Graham et. al 2001, Wu et. al 2003). This is observed in the lower sections of the reservoir complex and is confirmed by relationships between element isotope ratios and contents in the sediments (Table 1).

Runoff of nitrogen and organic carbon from the catchment is the main source of organic matter in sediment of the upper parts of SRES. Mineralization and the redistribution of sediment combined with primary production along the axes of reservoirs raise the contribution of autochthonous matter to the bottom sediments. The diversified character of the sediment matter at three different sites around the reservoir is mainly manifested in increases in OM, TOC, and TN content in MRES. Isotope fractionation of the elements suggests that more of the supplied matter was decomposed along the aquatic waterway from the tributaries to the lower dam.

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