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A comparison between the water quality of the main tributaries to three submontane dam reservoirs and the sediment quality in those reservoirs

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Key words: rivers, dam reservoirs, sediment, nutrients, organic matter

Abstract

Nutrients, pH, and organic matter were determined in water samples collected from the Raba River above Dobczyce Reservoir (meso-eutrophic), from the Dunajec River above Czorsztyn Reservoir (mesotrophic), and Rożnów Reservoir (eutrophic), and in the bottom sediments of the reservoirs. The river waters were alkaline (pH 7.2–9.2). In the Raba River and Dunajec River, the ranges of nutrients and organic matter contents were similar (without significant differences) (in mg dm^{-3}; $N\text{-}NO_3$ 0.5–2.5, $N\text{-}NH_4$ 0.2–2.0, $N\text{-}NO_2$ 0.004–0.040, N-tot 1.1–5.6, PO_4 0.02–0.58, P-tot 0.03–1.9, while BOD_5 1.6–9.9 mg dm^{-3} O_2, COD 2.1–30.4 mg dm^{-3} O_2). The pH of reservoir sediments was from neutral to slightly alkaline (6.9–7.6). The sediments were mineral and were characterized by a low amount of nutrients (N-tot 0.04–0.36%, P-tot 0.007–0.185%) and organic matter (expressed as LOI 3.0–10.6%, TOC 0.9–3.3%). Nutrient (except P-tot) and organic matter contents in the sediments of three reservoirs were similar (without significant differences) and did not reflect the trophic state of the reservoirs.

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INTRODUCTION

Eutrophication is a major water pollution problem. Eutrophication is mostly due to overloading from external sources, which are mostly derived from insufficiently treated sewage effluents and agricultural runoff (Uhlmann et al. 1994, Scharf 1999, Mazurkiewicz-Boroń 2002), as well as from internal nutrient loads (Wróbel 2002). Organic matter and nutrient contents in lake sediments depend on the load of nutrients entering the reservoir, authogenic processes like primary productivity intensity, resuspension, as well as complex mechanisms including diagenesis, redox processes, biological assimilation, and enzymatic and non-enzymatic hydrolysis reactions that favor N or P-release from the sediments (Baldwin 1996, Ulrich 1997, Watts 2000). They amounts in lake sediment usually follow the trophic state of the lake (Sobczyński et al. 1997; Kleeberg et al. 1999; Trojanowski, Bruski 2003).

The results of long-term studies (physicochemical and biological) indicated the different trophic state of three sub-Carpathian dam reservoirs, i.e. Dobczyce Reservoir (meso-eutrophic, limnetic) on the Raba River, and Czorsztyn Reservoir (mesotrophic, limnetic) and Rożnów Reservoir (eutrophic, rheolimnetic) on the Dunajec River (southern Poland) (Mazurkiewicz-Boroń 2002; Pociecha, Wilk-Woźniak 2005).

The aim of the studies was to estimate the quality (nutrient and organic matter contents) of the water of the main tributaries to those reservoirs, and of the reservoir sediments. Because hydrological conditions and the catchment area mostly influence the processes that take place in submontane dam reservoirs, it was hypothesized that a relation between the trophic state of the submontane reservoir and the content of nutrient and organic matter in its bottom sediment is impossible.

STUDY AREA

Dobczyce Reservoir on the Raba River, and Czorsztyn Reservoir and Rożnów Reservoir on the Dunajec River are situated in one geographical unit, and their river catchment basins have similar natural conditions. However, many factors like the size of catchment basin, anthropogenic land use, morphometric features, age, water residence time, and trophic state make the reservoirs different from each other (Tables 1 and 2). The catchments of the reservoirs are not densely populated and are mainly used for agriculture. The main geological and climatic features of the region, as well as the hydrological and hydro-chemical characteristics of the Dunajec River and the Raba River, were reported by Pasternak and Gliński (1972), Łajczak (1995), and Mazurkiewicz-Boroń (2002). In a considerable area of the catchment basin of

Table 1

Characteristic features of dam reservoirs (according to Mazurkiewicz – Boroń 2002).

	Czorsztyn Reservoir	Rożnów Reservoir	Dobczyce Reservoir
Start exploitation	1997	1942	1987
NPP- standard damming ordinate (m)	529.0	264.0*	269.9
Surface area – NPP (ha)	1051	950	950
Capacity – NPP (mln m^3)	181.2	79.2	99.2
Mean depth (m)	19.0	10.0	11.7
Max depth (m)	46	25	28
Reservoirs length (km)	11	22	10
Water exchange (times $year^{-1}$)	3.3	11.1	3.4
Reservoir silting (t $year^{-1}$)	197 000**	591 000**	100 000**
Trophy	mesotrophic***	eutrophic***	meso-eutrophic***

* weir ordinate, ** Łajczak (1995), *** according to Pociecha, Wilk-Woźniak (2005)

Table 2

Characteristic of the catchment area of the reservoirs (according to Mazurkiewicz–Boroń 2002).

	Czorsztyn Reservoir	Rożnów Reservoir	Dobczyce Reservoir
River length (km)	Dunajec (247)	Dunajec (247)	Raba (137)
Dam abutment (km)	173.3	80.0	60.1
Catchment area (km^2)	1147	4864	768
Forest (%)	52.2 and 37.2*	44.5**	41.1 and 35.8***
Arable land (%)	37.2 and 54.6*	46.9**	52.0 and 51.5***
Among them:			
Arable field	34.8 and 38.9*	50.6**	60.1 and 73.4***
Grassland (meadows & pastures)	65.2 and 61.1*	49.4**	39.9 and 26.6***
Population (person km^{-2})	122 and 140*	125**	125 and 169***

*Tatrzański and Nowotarski District, ** Nowosądecki District, *** Limanowski and Myślenicki District (Rocznik Statystyczny 2001)

the reservoirs, sandstone-shale rocks of fairly great or medium calcium and magnesium content predominated (Pasternak, Gliński 1972). Loamy soils with a medium content of skeleton grain predominated in most of the mountain part of the basin. The direct catchment basin of Dobczyce Reservoir is covered by fine sandy soils originating from the Carpathian Flysch. Nutrient loading into the reservoirs is rather high due to soil erosion, insufficient municipal wastewater treatment, and village wastewaters (there are no sewage systems in most cases) in the vicinity of the reservoirs (Mazurkiewicz-Boroń 2002). The water of the

Dunajec and Raba rivers had an alkaline character. Hydrocarbonate, Ca, and Mg dominated among ions. The amounts of sulphate ranged from 7–50 mg dm^{-3} and chlorides from 2.5–10 mg dm^{-3}. A detailed description of the physico-chemical characteristics of the water of Dobczyce Reservoir, Czorsztyn Reservoir, and Rożnów Reservoir was given by Mazurkiewicz-Boroń (2002).

MATERIALS AND METHODS

Water samples were collected monthly (from April to October) from the stations located near the inlet of the Dunajec River and the Raba River to the reservoirs studied. Sediment samples were collected from the stations located along the long axis of Dobczyce Reservoir (Stations 1-5; the depths of 5, 10, 15, 20, and 25 m), Czorsztyn Reservoir (Stations 1-6; the depths of 5, 10, 15, 20, 30, and 40 m), and Rożnów Reservoir (Stations 1-4; the depths of 5, 10, 15, and 20 m) on 17 May, 8 September, and 8 November 2005 (Fig. 1). An upper layer (0-3 cm) of the sediment was taken using a polyethylene corer with an area of 12.56 cm^2. One sediment sample contained several subsamples.

Water temperature was measured *in situ* to the nearest 0.1°C. The pH and conductivity was measured with an Orion pH meter (Expandable ion Analyser EA 940). Dissolved oxygen and BOD_5 (biochemical oxygen demand) were determined according to the Winkler method (APHA, 1985) Nitrates were analyzed with the hydrazine reduction method, ammonia with the nesslerization method, phosphates and total P (after mineralization) with the molybdenum blue method, while COD (chemical oxygen demand) was established with the titrimetric method (APHA 1992). Total nitrogen is presented as the sum of the Kjeldahl nitrogen forms plus $N\text{-}NO_3$ and $N\text{-}NO_2$. Nitrates, ammonia, and phosphates were determined in the water samples filtered through GF/F fiberglass filters.

In a sediment sample pH, P-tot, N-tot, LOI, and TOC content were determined. The pH of wet sediments was measured immediately after sampling. Sediment samples were air dried and homogenized using a Planetary Mill "Pulverisette 5". Total nitrogen was determined with the Kjeldahl method, total phosphorus with the spectrophotometeric method with ammonium molybdate and ascorbic acid as the reducing agent, while TOC was determined with the Tiurin method (APHA 1992). In the samples collected in July, the grain fractions were determined using Bonyoncosa-Casagrande's method modified by Prószyński (Lityński et al. 1976).

To determine the seasonal differences in the contents of organic matter (expressed as LOI and TOC) and nutrients in the bottom reservoir sediments, the Wald-Wolfowitz runs test was used, while those differences among reservoirs were determined by the Mann-Whitney *U* test.

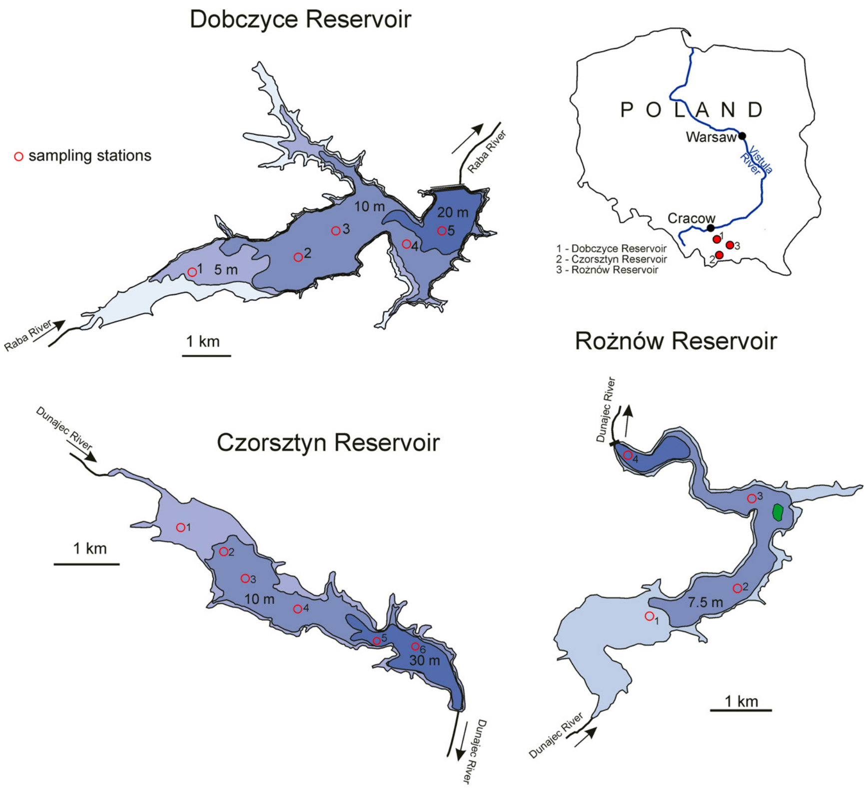

Fig. 1. Location of sampling sites in the Dobczyce Reservoir, Czorsztyn Reservoir, and Rożnów Reservoir.

RESULTS AND DISCUSSION

Water

The water quality of the main tributaries of the reservoirs reflected the natural regional background and the management of the catchment area. The river waters had an alkaline character pH (7.2–9.2) (Table 3). Dunajec River water was slightly more alkaline in comparison with that of the Raba River. In the river waters, dissolved inorganic nitrogen and phosphorous species ranges were as follows: N-NO_3 0.5–2.5 mg dm^{-3}, N-NH_4 0.2–2.0 mg dm^{-3}, N-NO_2 0.004–0.04 mg dm^{-3}, and PO_4 0.02–0.58 mg dm^{-3}. The above contents are high and characteristic for submontane rivers (Kasza 1993, Wróbel 1995). Among nitrogen species, N-NO_3 dominated. The contents of dissolved inorganic nitrogen species were slightly higher in the water of the Raba River, in

Table 3

Ranges, mean ±SD content of chosen physicochemical parameters in the water of the main tributaries near the inlet to the reservoirs.

Parameter		Raba River (Dobczyce Reservoir)	Dunajec River (Czorsztyn Reservoir)	Dunajec River (Rożnów Reservoir)
pH	Range Mean ±SD	7.2-8.8 8.1 ±0.6	8.2-9.2 8.7 ±0.5	7.5-8.7 8.3 ±0.4
Conductivity	Range Mean ±SD	259-374 326 ±47	198-357 286 ±56	269-402 309 ±45
Nitrate ($N\text{-}NO_3$) (mg dm^{-3})	Range Mean ±SD	0.6-2.5 1.2 ±0.7	0.5-1.4 0.7 ±0.3	0.7-1.3 1.0 ±0.3
Ammonium ($N\text{-}NH_4$) (mg dm^{-3})	Range Mean ±SD	0.2-1.1 0.5 ±0.3	0.2-0.3 0.3 ±0.0	0.2-2.0 0.5 ±0.6
Nitrite ($N\text{-}NO_2$) (mg dm^{-3})	Range Mean ±SD	0.009-0.033 0.018 ±0.009	0.007-0.025 0.011 ±0.006	0.004-0.040 0.014 ±0.012
N-tot (mg dm^{-3})	Range Mean ±SD	1.1-3.4 2.3 ±0.7	1.6-5.6 2.8 ±1.4	1.9-5.4 3.3 ±1.2
Phosphate (PO_4) (mg dm^{-3})	Range Mean ±SD	0.02-0.47 0.1 ±0.16	0.10-0.21 0.1 ±0.05	0.06-0.58 0.16 ±0.19
P-tot (mg dm^{-3})	Range Mean ±SD	0.03-0.7 0.2 ±0.3	0.05-1.0 0.2 ±0.3	0.05-1.9 0.3 ±0.7
BOD_5 (mg dm^{-3})	Range Mean ±SD	1.6-8.3 3.0 ±2.4	1.6-6.0 3.5 ±1.8	1.7-9.9 3.8 ±3.3
COD (mg dm^{-3})	Range Mean ±SD	2.1-30.4 11.2 ±9.2	3.5-16.0 11.8 ±4.6	4.9-27.2 13.4 ±7.4

comparison with that of the Dunajec River, as well as in the water of the Dunajec River above Rożnów Reservoir in comparison with those waters above Czorsztyn Reservoir. The amount of PO_4 in the water of the Raba River was slightly lower than in the Dunajec River. However, those differences as well as those in the amount of N-tot and P-tot were not statistically significant.

Organic matter content (expressed as BOD_5 and COD) was similar at the studied stations (there was a lack of statistical differences) (Table 3). In general, their contents were slightly higher in the Dunajec River in comparison with the Raba River. Their content increased at the station on the Dunajec River above Rożnów Reservoir in comparison to those above Czorsztyn Reservoir. Those rivers are well oxygenated; therefore, organic matter contents (expressed as BOD_5 and COD) in the water are not very high.

Sediment

The bottom sediments along the long axis of the Dobczyce Reservoir, Czorsztyn Reservoir and Rożnów Reservoir were rich in clayey silty fractions (56-72%, 40-60%, and 60-74% of the total, respectively) and clay fractions (10-40%, 6-30%, and 17-38% of the total, respectively). They reflected the soil composition in the catchment basin of the Dunajec and Raba rivers (Pasternak 1969).

Ranges and mean contents of the studied parameters in the sediments of the meso-eutrophic Dobczyce Reservoir, the mesotrophic Czorsztyn Reservoir, and the eutrophic Rożnów Reservoir are given in the Table 4. In general, the sediments had a mineral character. They were characterized by a low amount of organic matter (LOI 3.0–10.6%, TOC 0.9–3.3%), N-tot 0.04–0.36%, P-tot 0.007–0.185%, and pH from neutral to slightly alkaline (6.9–7.6). Contrary to the result of the study by Ligęza and Smal (2002), there was no clear pattern of sediment pH changing along the long axis of the reservoir. The results obtained confirmed that the sediments of the submontane reservoirs created on the Carpathian Flysh have a low amount of organic matter and nutrients (Pasternak, Gliński 1972; Wójcik 1991). The percentage shares of TOC, LOI, and N-tot in the sediments of the studied reservoirs were lower in comparison with lowland Zemborzyce Reservoir (Misztal, Smal 1984; Ligęza, Smal 2005), and Otmuchów Reservoir on the Nysa Kłodzka River, which is polluted mainly by organic sewage from cellulose and the paper industry (Pasternak 1970). They were much lower in comparison to those found in the sediment of eutrophic lakes, for example, Petersdorf Lake (Germany) (LOI 27–36%, N-tot 1.3–2.1%, P-tot 0.16%) (Kleeberg et al. 1999), Lake Rzuno (LOI 7–36%, C_{org} 3–19%, N-tot 0.13–1.58%) (Trojanowski, Bruski 2003), and Lake Góreckie (Sobczyński et al. 1997).

Table 4

Ranges, mean ±SD content of chosen physicochemical parameters in the sediments of the reservoirs studied in 2005.

Parameter		Dobczyce Reservoir	Czorsztyn Reservoir	Rożnów Reservoir
pH	Range	7.0-7.7	7.2-7.7	6.9-7.6
	Mean ±SD	7.3 ±0.2	7.4 ±0.2	7.3 ±0.2
LOI (%)	Range	4.3-8.0	3.0-12.6	4.9-10.4
	Mean ±SD	6.4 ±1.3	7.0 ±2.2	6.8 ±1.4
TOC (%)	Range	1.2-2.2	0.9-3.3	1.4-2.1
	Mean ±SD	1.8 ±0.28	1.9 ±0.52	1.8 ±0.2
N-tot (%)	Range	0.04-0.31	0.06-0.36	0.10-0.31
	Mean ±SD	0.17 ±0.06	0.16 ±0.08	0.18 ±0.06
P-tot (mg g^{-1})	Range	0.32-1.75	0.30-1.85	0.07-1.57
	Mean ±SD	1.01 ±0.38	0.74 ±0.41	0.58 ±0.45

In general, there were no seasonal differences in the content of organic matter (expressed as LOI, TOC) and of P-tot in the reservoirs studied. The only such difference was the significantly higher amount of N-tot (N_1=5, N_2=5, r=3, $p<0.05$) in the sediment of Dobczyce Reservoir in September in comparison with November. Misztal and Smal (1984) also did not find seasonal changes in C_{org}, N-tot, and P-tot contents in the sediment of Zemborzyce Reservoir. The authors related the changes in P-tot content with the hydrological condition in the catchment basin of the reservoir.

The amount of organic matter (expressed as LOI, TOC), N-tot, and P-tot were similar in the reservoirs studied (there was a lack of significant differences). Only the amount of P-tot in the sediment of Dobczyce Reservoir was significantly higher in comparison with that in the sediment of Rożnów Reservoir ($N_1=5$, $N_2=4$, $Z=-2.44$, $p<0.02$). Thus, the amount of organic matter and nutrients in the sediment did not follow the trophic state of the reservoirs: Czorsztyn (mesotrophic), Rożnów (eutrophic), and Dobczyce (meso-eutrophic) (Pociecha, Wilk-Woźniak 2005). The lack of differences in the amount of organic matter, as well as in nutrients (except P-tot) in the sediment of the eutrophic Rożnów Reservoir and the less eutrophicated Dobczyce and Czorsztyn Reservoirs, may be explained by (1) the rheolimnetic character of the Rożnów Reservoir, (2) the high amount of suspended matter transported with the Dunajec River to the Rożnów Reservoir (the most silted reservoir in the Upper Wisła catchment basin; Łajczak 1995), which may influence the "dilution" effect of the TOC, P-tot, and N- tot contents in the sediment. The elevated amount of P-tot in Dobczyce Reservoir in comparison to Różnów Reservoir may be explained by the limnetic character of the former i.e. there is a longer retention time which favors sedimentation and accumulation of organic and inorganic phosphorous compounds in the sediment.

CONCLUSIONS

The quality of the water (nutrients and organic matter contents) of the main tributaries near to the inlet to the reservoirs and the sediments of Dobczyce Reservoir (meso-eutrophic), Czorsztyn Reservoir (mesotrophic), and Rożnów Reservoir (eutrophic) were similar. Nutrient and organic matter contents in the reservoir sediment did not follow the trophic state of the reservoir.

There is no simple relation between the water quality of main tributaries and the sediment quality (organic matter and nutrients) of three dam reservoirs of different trophic states.

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