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Original Research

The Effects of Two Shallow Reservoirs on the Phyto- and Bacterioplankton of Lowland River

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Abstract

The effect of two different reservoirs on some parameters of river water quality has been studied. The Antoninek Reservoir (wetland-type, mean depth 0.4 m, area 7.2 ha, mean residence time 0.5 day) and the Maltański Reservoir (also not stratified but plankton-type, mean depth 3.1 m, area 64 ha, mean residence time 34 days) are situated on the same river (mean discharge 0.67 $m^3 s^{-1}$). Water of this river, which leaves the hypertrophic Swarzędzkie Lake upstream from the reservoirs, is rich in nutrients and plankton. As it flows through the Antoninek Reservoir it loses most of the phytoplanktonic organisms, measured as chlorophyll-a (70%), mostly due to the shading effect of emergent vegetation. The fraction autotrophic picoplankton (APP) also decreased considerably, both in numbers and biomass (about 68% and 54% on average, respectively). A similar reduction was recorded for the numbers of bacterioplankton (39% on average) and suspended solids (66%). Phytoplankton growth was observed again in the Maltański Reservoir, due to the longer residence time of water and lack of macrophytes. Chlorophyll-a increased by 37%, APP numbers by 120%, their biomass by 154%, while the numbers of bacterioplankton only by 31%. Changes in plankton abundance and biomass as a result of retention of water in a shallow reservoir influenced the quality of outflowing water. Their range strongly depended on the presence of macrophytes within the reservoir.

Keywords: phytoplankton, picoplankton, chlorophyll-a, pre-reservoir water quality

Introduction

The quality of river water tends to improve in small reservoirs. Thus, building such reservoirs on tributaries of larger water bodies, to protect against excessive eutrophication, is recommended by many authors [1, 2, 3]. In the created models describing the decrease of concentrations of nutrients in the course of water flow through reservoirs, a major role is ascribed to phytoplankton that take up nitrogen and phosphorus from the water and after termination deposit them in bottom sediments. The factors affecting phytoplankton growth in reservoirs include residence time of water, concentration of nutrients, temperature and solar radiation [4, 1, 5, 6, 7].

Phytoplankton growth, however, does not have to start in the reservoir. Many lowland rivers feeding man-made reservoirs often carry large amounts of phytoplankton, washed out from lakes or other water bodies. After flowing into a reservoir the phytoplankton may become more abundant or decline [8, 9, 10, 11]. Hydromacrophytes, which compete with phytoplankton, play a very important role in this process, although unappreciated in the models mentioned above. The major objective of this study was to trace the changes in the phytoplankton and heterotrophic bacterioplankton of the same river as a result of flow of its water through two reservoirs, very different with regard to the area covered by macrophytes.

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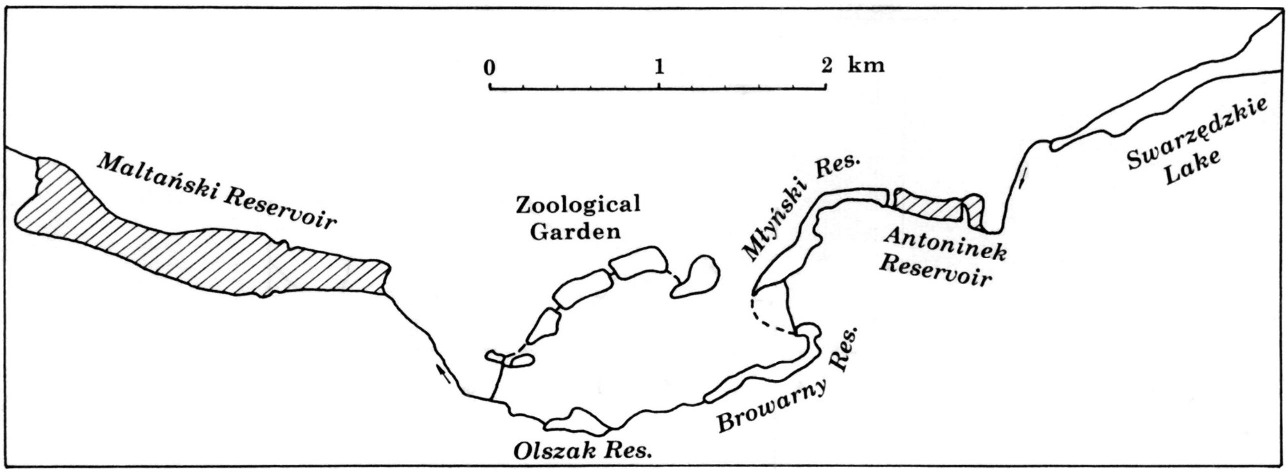

Fig. 1. Lower course of the Cybina River with the cascade of reservoirs.

Study Area and Methods

This study regards two reservoirs situated on the Cybina River in Poznań (in western Poland). The first and last reservoir of the cascade of five reservoirs have been selected because they are markedly different in terms of morphometric parameters and area covered by hydromacrophytes. The first is the Antoninek Reservoir (Fig. 1), with an area of 7.2 ha, volume of 30 thousand m^3, mean depth of 0.4 m and a theoretical mean water residence time of 0.5 days. This is a wetland-type, because 97% of its area is covered by macrophytes, mainly by common reed (*Phragmites australis* (Cav.) Trin. ex Steud.) (64.1%) and cattails (*Typha angustifolia* L., *T. latifolia* L.) (14.8%) [12]. The other is the Maltański Reservoir, with an area of 64 ha, volume of 2 million m^3, mean depth of 3.1 m and a mean residence time of water of 34 days. In this reservoir the same species of macrophytes develop only along the banks, forming small patches that cover only 0.2% of the total area of the reservoir. The Antoninek Reservoir is a part of the cascade of four preliminary reservoirs, which was created to improve the water quality of the Cybina River before its discharge into Maltański Reservoir [13, 12]. Maltański Reservoir is used mostly for water sports (rowing and canoeing competitions). In the past decade some biomanipulation experiments have been carried out there [14, 15, 16].

This study was carried out in 1995. Samples were taken monthly from midstream of the Cybina River at the inlet and outlet of each reservoir, in which chlorophyll-a, suspended solids, autotrophic picoplankton (APP) and bacterioplankton were analyzed. Chlorophyll-a was assessed with the Lorenzen method after extraction in acetone [42], while suspended solids were weighted after filtration through a Whatman glass fibre filter GF/C and desiccation at 105°C (expressed as dry weight). APP and bacterioplankton numbers were counted using epifluorescence microscopy [17, 18]. Subsamples of 1-5 ml were filtered on black Nuclepore filters of 0.2 μm pore size at a low vacuum pressure, and then stained with the fluorochrome DAPI. Twenty to sixty fields were examined, or at least 1000 cells were counted at a magnification of 1500x under an Olympus BX-60 microscope. An HBO 100 W lamp and standard filter sets for green and blue light excitation for APP and ultra-violet for bacteria analyses were used. APP was classified as prokaryotic or eukaryotic on a basis of autofluorescence colour, shape and size of cells [18]. Both APP and bacteria biomass (expressed as wet weight) was estimated by multiplication of numbers by the mean volume of cells, calculated separately in 2 size and shape classes for APP and 8 for bacteria. Volume was estimated by comparing shape of the cells to geometric figures. Phytoplankton biomass was mostly expressed as chlorophyll-a contents, but for comparison with APP and bacterioplankton as well for the evaluation of their share in mass of suspended solids, the phytoplankton biomass was also expressed in milligrams of fresh weight. It was estimated from the relationship between chlorophyll-a and biomass, using the equation of Desortová [19]:

$$y = 1.58 + 4.97\,x \quad (r = 0.785,\ p < 0.001,\ n = 197)$$

where:
y — chlorophyll-a in $\mu g\ l^{-1}$,
x — biomass in mg f. w. l^{-1}.

Biomass of organisms was converted to carbon following the conversion factors used by Amblard et al. [20]: for bacteria — 200 $fgC\ \mu m^{-3}$, for APP — 121 $fgC\ \mu m^{-3}$ and for phytoplankton larger than 2 μm — 12% of wet weight biomass.

Single values for each sampling time were used to analyze temporal variability of each criterion (Figs. 2-7). To assess the statistical significance of the changes of analyzed criteria as a result of water flow through the reservoir, the Wilcoxon matched pairs test and Mann-Whitney U-test from nonparametric statistics were applied, using STATISTICA 5.1 software. Changes in water quality were evaluated on the basis of concentration of the studied criteria, not their loads, because the discharge of water at the inlet and outlet of each reservoir did not differ significantly. The studied reservoirs do not have any additional tributaries and the water overflows the weir in an uncontrolled way.

Results

Antoninek Reservoir

The waters of the Cybina River flowing into the Antoninek Reservoir carried large amounts of suspended solids and chlorophyll-a (Table 1) originating from rich-in-nutrients Swarzędzkie Lake located upstream (Fig. 1). APP accounted for a small proportion of total phytoplankton biomass (below 1%), while the biomass of bacterioplankton was relatively high, accounting for 20% of phytoplankton biomass on average.

In the course of water flow through the Antoninek Reservoir, values of all the measured criteria were markedly reduced, the differences between the inlet and outlet being statistically significant. The greatest reduction was detected for chlorophyll-a, especially in June and September (82%), when maximum values were recorded at the inlet (Fig. 2a). Suspended solids decreased all year, parallel to the changes in chlorophyll-a (Fig. 2b). APP numbers were variously reduced during the year. A maximum reduction (by about 92,000 cells ml^{-1}) was recorded in May, when numbers were the highest at the inlet, but the biggest relative reduction (93.5%) was observed in July, when the numbers were low in the Cybina River (Fig. 3). It was only in September and October that APP numbers were higher at the outlet than at the inlet. The proportion of eukaryotic cells in APP was usually lower than that of prokaryotic cells. The decrease in the numbers of prokaryotic cells that took place in the course of water flow through the Antoninek Reservoir was considerable (by 73%), while the numbers of eukaryotic cells slightly increased, although the difference was not statistically significant. Among the studied criteria, the numbers of bacterioplankton were least reduced (by 39% on average). Only in April and June was a slight increase detected at the outlet as compared with the inlet (Fig. 4). Similar changes were observed in bacterioplankton biomass (Table 1).

Maltański Reservoir

The Cybina River, downstream of the Antoninek Reservoir, flows through three other small reservoirs (Młyński, Browarny and Olszak) and receives a right-bank tributary from ponds located in the area of the Zoological Garden (Fig. 1). As a result, phytoplankton, measured as chlorophyll-a, increased in this river section (Figs. 2, 5). It increased even further as the water flowed through Maltański Reservoir (by 37.4% on average), although the changes were not significant from the statistical point of view (Table 2). An analysis of the seasonal variation shows that an increase of chlorophyll-a between the inlet and the outlet was observed mostly in late summer, autumn and winter. In spring phytoplankton were more abundant at the inlet than at the outlet (Fig. 5a). Similar seasonal changes were recorded for the concentration of suspended solids, although in autumn and early winter decrease of its values were also observed (Fig. 5b). APP numbers increased considerably as the water was flowing through the reservoir. Only in late summer and autumn, when their numbers were very low, was

Table 1. The differences between the values of investigated criteria at the inlet and outlet of Antoninek Reservoir (n = 12).

Criteria			Mean value		Difference	% of changes	Significance level
			Inlet	Outlet			
Suspended solids		($mg\ l^{-1}$)	11.80	3.97	7.83	66.4	0.002
Chlorophyll-a		($\mu g\ l^{-1}$)	38.48	11.62	26.86	69.8	0.002
Total phytoplankton biomass		($mg\ ww\ l^{-1}$)	7.42	2.02	5.40	72.8	0.002
		($\mu g\ C\ l^{-1}$)	891	242	648	72.8	0.002
APP	Numbers	(10^3 cells l^{-1})	13630	4303	9327	68.4	0.023
	Biomass	($mg\ ww\ l^{-1}$)	0.0099	0.0046	0.0053	53.5	0.099
		($\mu g\ C\ l^{-1}$)	1.20	0.56	0.64	53.5	0.099
Bacteria	Numbers	(10^6 cells l^{-1})	10865	6651	4214	38.8	0.019
	Biomass	($mg\ ww\ l^{-1}$)	1.49	0.83	0.66	44.3	0.010
		($\mu g\ C\ l^{-1}$)	299	166	133	44.5	0.10

ww — wet weight

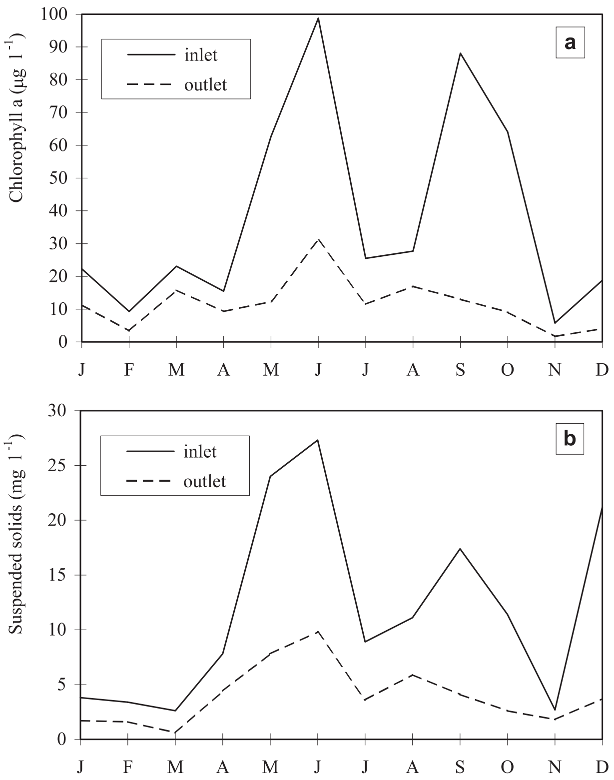

Fig. 2. Chlorophyll-a (a) and suspended solids (b) concentration at the inlet and outlet of Antoninek Reservoir.

a slight decrease detected at the outlet (Fig. 6). A clear increase in numbers of eukaryotic picoplankton was observed, particularly in winter and spring (up to 720% in March). This increase was statistically significant. Similar changes in APP biomass were detected (Table 2). Bacterioplankton numbers and biomass increased in the course of water flow through the reservoir nearly all year round (Fig. 7, Table 2). Although this rise was lower than in the case of phytoplankton (in biomass 24.5% and 40.3% respectively), it was more significant from the statistical point of view (Table 2).

Discussion

The studied reservoirs, in the classification by Straškraba et al. [21] fall into the category of shallow dam reservoirs, because they do not have thermal stratification in summer. Changes in the concentration of suspended solids in the course of river water flow through them were typical of reservoirs differing in residence time of water. Thus, a decrease was recorded where residence time was short (0.5 day on average), and an increase was observed where it was longer (34 days). A similar relationship was observed by Wiśniewski et al. [22]. They found that in small lowland reservoirs with the average residence time not exceeding 0.5 day, the concentration of suspended solids decreased by up to 40%. In reservoirs with a longer residence time, these authors recorded an increase in suspended solids, which was linked with phytoplankton growth in the reservoir and its washout with flowing water. Ryding and Rast [3] suggested that excessive phytoplankton growth is observed when residence time is longer than three days. Mander and Järvet [23] found that the concentration of suspended solids in all studied small reservoirs decreased considerably (by 25-70%). The decrease was most serious in smallest reservoirs. Nevertheless, the marked reduction of the amount of suspended solids in the studied Antoninek Reservoir is not caused only by the short residence time of water, which limits phytoplankton growth. Simm [10] reports that even in a reservoir with an average residence time of 0.5 day (in the summer usually prolonged to 2-7 days), a 20-40-fold

Table 2. The differences between the values of investigated criteria at the inlet and outlet of Maltański Reservoir (n = 12).

Criteria			Mean value		Difference	% of changes	Significance level
			Inlet	Outlet			
Suspended solids		(mg l^{-1})	11.43	11.28	0.15	1.3	0.8139
Chlorophyll-a		(μg l^{-1})	23.82	32.72	-8.90	-37.4	0.0844
Total phytoplankton biomass		(mg ww l^{-1})	4.47	6.26	-1.79	-40.0	0.0844
		(μg C l^{-1})	537	752	-0.215	-40.0	0.0844
APP	Numbers	(10^3cells l^{-1})	9467	20846	-11378	-120.2	0.0229
	Biomass	(mg ww l^{-1})	0.0061	0.0155	-0.0094	-154.1	0.0186
		(μg C l^{-1})	0.75	1.88	-1.14	-154.1	0.0186
Bacteria	Numbers	(10^6 cells l^{-1})	8276	10856	-2580	-31.2	0.0281
	Biomass	(mg ww l^{-1})	1.053	1.311	-0.258	-24.5	0.0342
		(μg C l^{-1})	211	262	-51.0	-24.5	0.0340

ww — wet weight

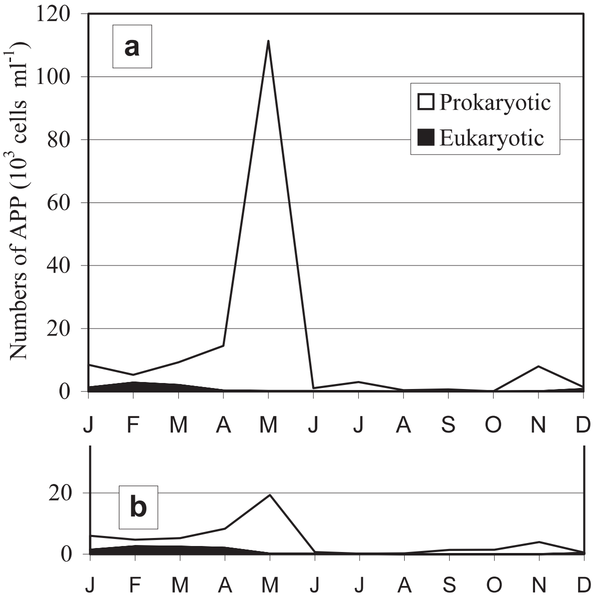

Fig. 3. Comparison of prokaryotic and eukaryotic APP numbers at the inlet (a) and the outlet (b) of Antoninek Reservoir.

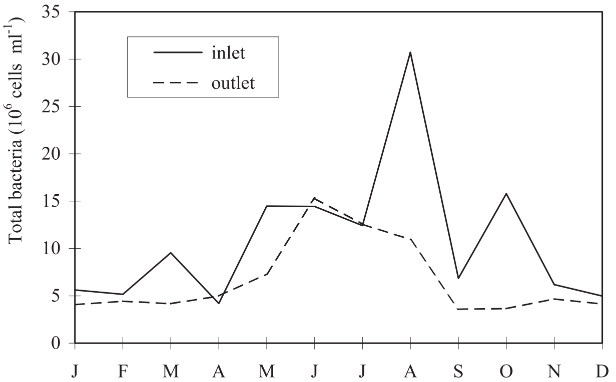

Fig. 4. Total numbers of bacteria at the inlet and outlet of Antoninek Reservoir.

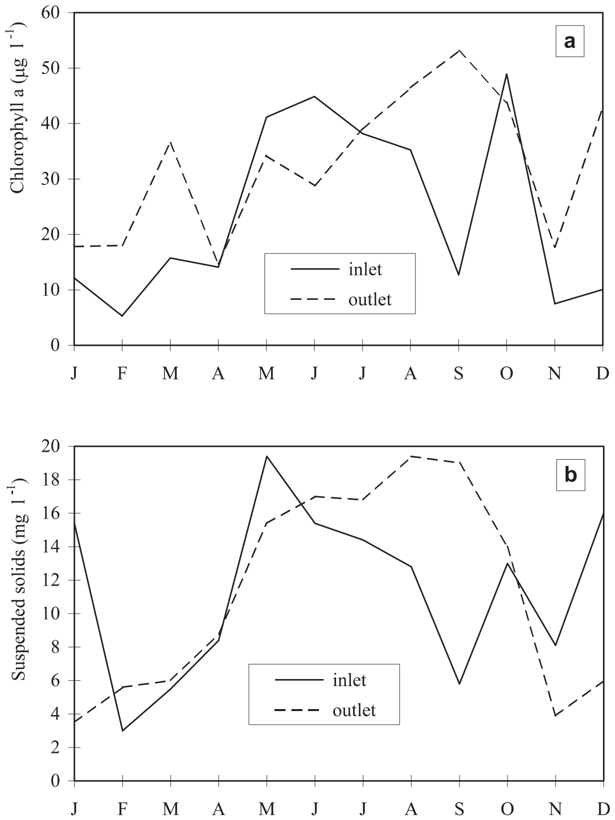

Fig. 5. Chlorophyll-a (a) and suspended solids (b) concentration at the inlet and outlet of Maltański Reservoir.

increase in phytoplankton biomass may be observed. He also found that in reservoirs with a residence time of less than 0.5 day, phytoplankton biomass was often higher at the outlet than at the inlet. In the Antoninek Reservoir such cases have never been recorded, even in summer, when residence time increases to 6 days. The so-called critical residence time, i. e. time below which loss by dilution exceeds growth of phytoplankton, is subject to variation even in one reservoir between seasons, as it depends on light, temperature and nutrient concentration [5]. The critical residence time in the Antoninek Reservoir is probably very long, especially in summer, when light conditions worsen dramatically. This is linked with the effect of macrophytes, which develop dense stands. Common reed and cattails strongly limit the access of solar irradiance to water [27]. Ondok [28] reports that PhAR irradiance in helophyte stands at the water surface did not exceed 5% during the peak of the growing season. As a result, algae originating from water bloom decompose when they are pushed into a reed-bed, e. g. by the wind [27]. The effect of macrophytes in this reservoir is probably not linked with competition for nutrients because this interaction is typical between phytoplankton and submerged vegetation [24, 25, 26]. Macrophyte beds reduce flow velocity and enhance the deposition of suspended solids [29]. An important role in detention and decomposition of suspended solids (including phytoseston) also is played by epiphytic organisms that form a biological film (composed of bacteria, protozoans and invertebrates) covering the submerged parts of plants and other substrates [30, 31].

Similar effects of dense reed-beds were observed in The Lower Kis-Balaton Reservoir, called Ignói cops. Large amounts of phytoplankton were flushed from the Upper Reservoir (mean annual concentration of chlorophyll-a 130-150 μg l^{-1}), but about 90% of them were retained in the lower reservoir [32]. Phytoplankton growth was not detected there, although the residence time of water was longer than ten days. A positive effect of macrophytes on water quality improvement in a small reservoir situated in an agricultural catchment area is also reported by Mander and Järvet [24].

Since macrophytes cover only 0.2% of the area of the Maltański Reservoir, their impact on phytoplankton is negligible. As a result, the amount of suspended solids and phytoplankton increased there significantly. Differences in intensity of this process were connected with

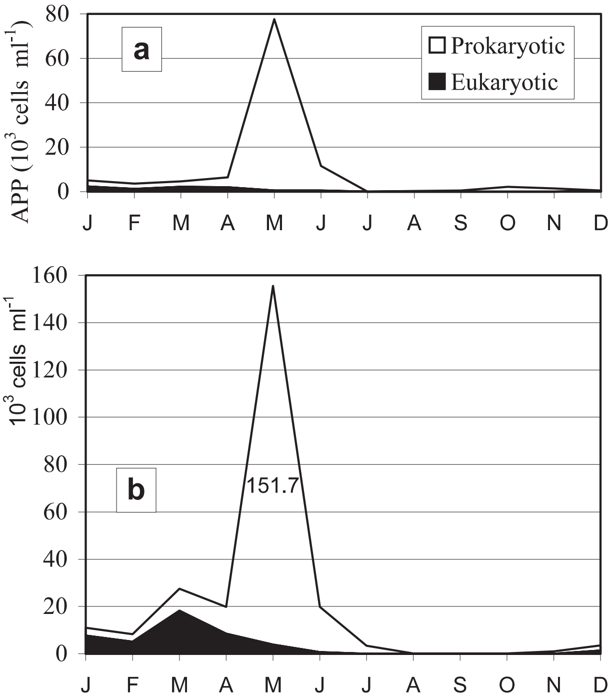

Fig 6. Comparison of prokaryotic and eukaryotic APP numbers at the inlet (a) and the outlet (b) of the Maltański Reservoir.

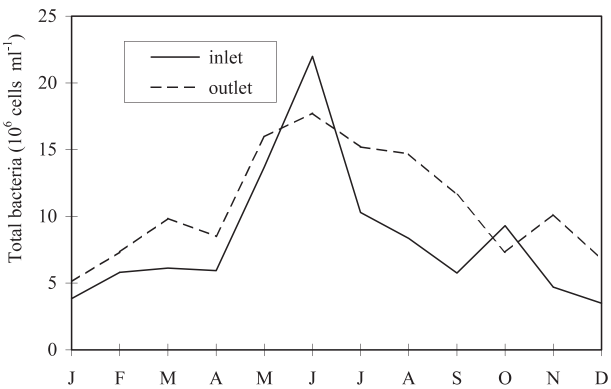

Fig. 7. Total numbers of bacteria at the inlet and outlet of the Maltański Reservoir.

seasonal changes in the taxonomic composition of phytoplankton in the discharging water. Within each reservoir, the qualitative and quantitative composition of phytoplankton is always modified, sometimes to a large extent [8, 9, 10, 11, 12]. In the Maltański Reservoir this was most evident in late spring and summer, when the algal community, dominated by diatoms and green algae in the discharging water, was transformed in the reservoir into a community dominated by cyanobacteria [33].

Simm [10] found that in small reservoirs with a very short residence time (less than 0.5 day) the composition of phytoplankton is transformed in the direction of nanoplanktonic forms. Because of this, it was supposed that in the Antoninek Reservoir similar changes would be observed for even smaller organisms, i. e. APP, especially that their small size slows their sedimentation, and a suitable pigment composition allows for their survival in bed light conditions [34]. Nonetheless, both the numbers and biomass of APP (prokaryotic in particular) were markedly reduced there, as was the whole phytoplankton community. By contrast, eukaryotic APP numbers were somewhat higher at the outlet, especially in spring, when shading by macrophytes was not so strong. This suggests that the effect of emergent vegetation on eukaryotic picoplankton is not as distinct as in the case of other phytoplankton fractions. Changes in APP of the Maltański Reservoir were usually parallel to those recorded for phytoplankton in general (a rise in numbers and biomass).

Changes in APP numbers and biomass detected between the first and second half of the year are also noteworthy. The reduction of eukaryotic picoplankton numbers in summer in comparison with winter and spring may be linked with changes in water temperature. Amblard et al. [20] found that there is a negative correlation between eukaryotic picoplankton and water temperature. From the other side, however, the decline in prokaryotic picoplankton numbers in summer coincided with a rise in the numbers of large filamentous cyanobacteria. This was probably associated with a marked reduction of the N: P ratio [14], which stimulates the growth of the N-fixing cyanobacteria. This agrees with the reports of Stockner and Shortreed [35], Vörös [36] and Takamura and Nojari [37], who found that picoplanktonic cyanobacteria prefer a high N:P ratio in water.

In the studied reservoirs APP had little effect on changes in water quality since, despite their high numbers they accounted for a very small proportion of total phytoplankton biomass. This phenomenon is often observed in eutrophic waters. For example, values of about 1% were recorded in eutrophic Mikołajskie Lake [38]. Similarly, Szeląg-Wasielewska [39] found that in a group of 12 shallow lakes of various trophic states, APP accounted for the smallest proportion of phytoplankton biomass in the lake where phytoplankton biomass was the highest. However, Vörös et al. [40] reported that also in eutrophic and even in hypertrophic waters APP may account for a large proportion of annual primary production, reaching up to 50-60%.

The range of bacterioplankton numbers recorded in this study agrees with the ranges recorded by a number of researchers in hypertrophic ecosystems [34]. The decrease in bacterioplankton numbers and biomass in the Antoninek Reservoir and the increase in the Maltański Reservoir were associated with parallel changes in suspended solids and phytoplankton. A statistically significant correlation between bacterioplankton numbers and chlorophyll-a concentrations was found (multiplicative function, $r = 0.68$). A review of the literature [34] suggests that such a relationship is commonly reported for water bodies of various trophic states. Chróst [41] regards the relationship between phytoplankton and bacteria as one of the most important relationships in aquatic ecosystems because up to 60% of the primary production of phytoplankton is not grazed by zooplankton but utilised by bacteria. Psychrophilic bacteria living in reservoirs are responsible for decomposition of phytoplankton organisms. A group of mesophilic bacteria (including pathogens) originating mainly from sewage, always considerably reduced its number in the course of water flow through the reservoirs [21], which was also observed in the Cybina River reservoirs [12, 13].

This study shows that changes in phytoplankton abundance and biomass under the influence of retention of river water in shallow reservoirs may have a significant effect on the quality of the effluent water. In the case of lowland reservoirs supplied with water rich in nutrients and containing large amounts of phytoplankton, an overgrowth of emergent macrophytes causes a considerable decrease in suspended solids, including live planktonic organisms.

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