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Comparison of microbiological activity in bottom sediments of littoral and profundal zones of a submontane dam reservoir

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Abstract – In the surface layer (0.5 cm) of bottom sediments during the period April–October 1995 the amount of organic carbon was 2956–3020 kJ m^{-2} in the littoral (0.5 and 5 m) and 985–2045 kJ m^{-2} in the profundal (10 and 20 m). The energy value of the heterotrophic bacterial biomass and its respiration showed a decreasing tendency from the littoral to the deep profundal (4.64–2.0 and 19–12 kJ m^{-2} day^{-1}, respectively). Energy expenditure per bacteria biomass unit increased from the littoral (4.0) to profundal (6.1) which suggested that the organic matter present in the latter zone was more refractory to bacterial decomposition. The biomass of algae (348 kJ m^{-2}) and their photosynthesis (65 kJ m^{-2} day^{-1}) were 3 times higher in the shallow than in the deep littoral. The total respiration of bottom communities ranged from 264 to 960 kJ m^{-2} day^{-1} and was lowest in the deep zone of the reservoir.

Key words: bacteria, algae, biomass, production, respiration, sediments, dam reservoir.

1. Introduction

The littoral zone of reservoirs plays an important role in controlling the transfer of nutrients and various particles from the surrounding area. During the decomposition of organic matter in the littoral zone the particulate components are released to the water. Both the chemical and structural components of detritus and also accompanying microorganisms allow the inclusion of decomposed material in different mode in the cycle of elements both in the littoral zone and in the water of a reservoir as a whole (Webster and Benfield 1986, Pieczyńska 1993).

The bottom sediments in the profundal zone, besides inorganic substances, mainly originate from the remains of planktonic organisms, which after their death settle on the bottom. In this zone there are no primary producers. An oxygen deficit can appear there and the mineralization of organic matter is considerable owing to bacteria and fungi. The animals living there feed on detrital material together with attached bacteria, or follow a predatory mode of life (Starmach 1976).

The early investigations carried out in the Dobczyce Reservoir (southern Poland) concerned its littoral zone, the River Raba, and some streams flowing into the reservoir. An increasing share of anaerobic processes in the metabolism of

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epibenthic communities in the section from the stream to the littoral zone was shown (Bednarz and Starzecka 1993, Starzecka and Bednarz 1993, 1994, 1997). Also demonstrated was an increasing tendency of production, respiration, standing crop, and net deposit of organic mater along the longitudinal axis from the River Raba to the dam. This meant that organic matter transported by the River Raba was mainly deposited in the reservoir, but the processes taking place there distinctly reduced the amount of energy stored in the bottom sediments of the river below the reservoir (Bednarz and Starzecka 1997, Starzecka and Bednarz 1998). Also the model of energy flow through the bottom sediments of the littoral zone of the reservoir with special regard to algae, bacteria, and roach, *Rutilus rutilus* (L.) was elaborated and demonstrated the great role of epibenthic organisms in the energy release from the littoral bottom sediments (Starzecka et al. 1999).

The aim of the present study was to determine whether metabolic processes took place in the surface layer of bottom sediments on a cross-section of the Dobczyce Reservoir, from the littoral to the deep zone of the reservoir, so-called profundal.

2. Study area

The Dobczyce Reservoir (49°57' N, 20°2' E, altitude 270 m) is situated at the 60th km of the course of the River Raba and about 25 km south-east of Cracow. The capacity of the reservoir, the main source of drinking water for Cracow, is 120 10^6 m^3, the surface area 1000 ha, maximum depth 28 m, mean depth 11 m, the whole water being changed on average 3.6 times a year. Most of its banks are steep. The littoral zone (to 5 m in depth) is found in the headwaters and in side bays. Despite such formation, this zone composes up to 25% of the total area of the reservoir. The main tributary is the River Raba (88.6% of the annual inflow). The remaining inflow consists of runoff from the immediate catchment of the reservoir and atmospheric precipitation. The reservoir is thermally stratified from April to October and its water are mixed twice a year.

During the stratification period of 1995 water transparency ranged from 1.4 to 3.8 m (G. Mazurkiewicz unpubl.); thus the photic zone included the greater part of the littoral while sessile algae capable of photosynthesis appeared in the bottom sediments of this zone. However, the bottom sediments, in the so-called profundal zone (10–20 m depth) of the reservoir lie below the limnetic zone and characterized the lack of active sessile algae. The algal cells settled from the water column, were present here in the sediments in small quantities, but were unable to photosyntheze, even in laboratory conditions (T. Bednarz unpubl.). It is well known that in the deep profundal zone of lakes bottom fauna live in small numbers. There mainly occur Bivalvia, Gastropoda, Oligochaete, and red Chironomidae, which are resistant to oxygen deficit and the presence of hydrogen sulphide. Of active bottom flora, only fungi and bacteria often carry out the mineralization of organic matter with H_2S release (Michałkiewicz 1990).

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3. Material and methods

The investigations were carried out in the Dobczyce Reservoir at four stations in the following zones: 1 – shallow littoral (0.5 m depth), 2 – deep littoral (5 m depth), 3 – so-called shallow profundal (10 m depth), and 4 – deep profundal (20 m depth) (Fig. 1). Samples of the surface layer of bottom sediments (0.5 cm) were

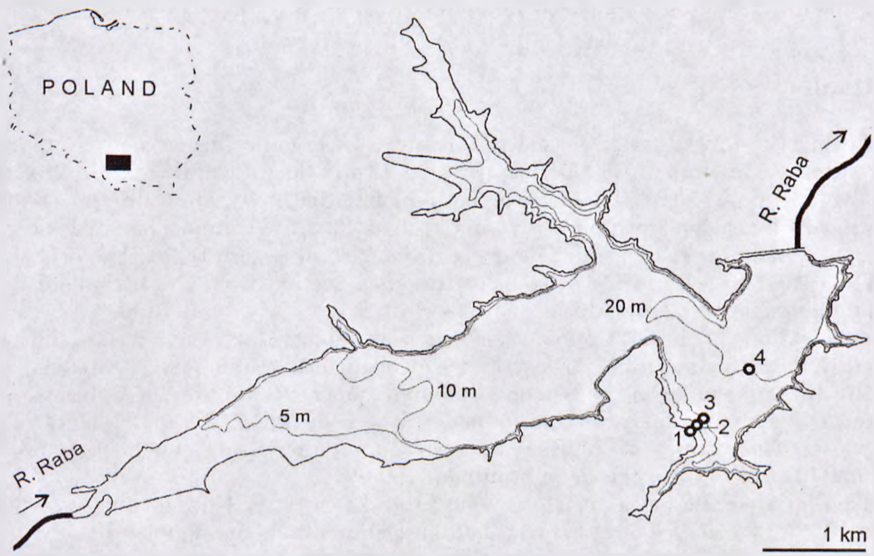

Fig. 1. Location of sampling stations (1–4) on the Dobczyce Reservoir.

collected at monthly intervals from April to October 1995 using a tube sampler. In the sediments the following parameters were determined: 1) the ash free organic matter (C-org.; as the loss on ignition at 550 °C), 2) total respiration of epibenthic communities (RT; as the amount of CO_2 release, measured by means of the Infralyt IV (VEB Junkalor, East Germany) infrared gas analyzer), 3) biomass of heterotrophic bacteria (Bb; using the estimated number of heterotrophic bacteria in the sediments and biomass coefficient 6.05 10^{-14} g C, according to Watson et al. 1977), 4) biomass of algae including cyanobacteria (Ba; the chlorophyll *a* method with ethanol extraction according to Sartory (1982), with the assumption that 1 µg of chlorophyll *a* is an equivalent of 50 µg C, according to Jørgensen 1979), 5) photosynthesis of algae (F; light and dark bottle method and Oxi 530, WTW, Weilheim, Germany oxygen electrode), 6) respiration of heterotrophic bacteria (Rb; the bacterial fraction was isolated from sediments as follows: 100 g of fresh sediments suspended in 900 g of autoclaved water from each station and filtered through Whatman GF/C glass microfibre filters; after the cultivation of filtrates in darkness at 20 °C during 12–16 h, the number of viable heterotrophic bacteria in the filtrates was determined by the plate method and their oxygen uptake was determined using the Oxi 530 oxygen electrode; next, the oxygen uptake per 1 bacterial cell was calculated, and multiplied by the number of heterotrophic

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bacteria earlier determined in the fresh sediments), and 7) coefficients Rb/Bb showing the energy expenditure per biomass unit of bacteria.

All the measurements were carried out in 3 replications and the results given as the mean (±SD) from the stratification period (April–October) and expressed in kJ m^{-2} or kJ m^{-2} 24 h^{-1}, on the assumption that 1 g C in sediments, biomass of bacteria, and biomass of algae corresponds to 4.9 kcal, i.e. 20.53 kJ (Cummins 1967). According to the equation of photosynthesis, in calculating of the respiration it was assumed that 1 g CO_2 released is the equivalent of 10.75 kJ, and 1 g O_2 consumed by bacteria or released by photosynthesis is the equivalent of 14.78 kJ.

4. Results

During the investigation period the amounts of organic carbon were similar in the bottom sediments of the shallow (Station 1) and deep littoral (Station 2) zones (2956 ±646 and 3020 ±854 kJ m^{-2} of bottom) but distinctly lower in the shallow (Station 3) and deep (Station 4) profundal ones (2045 ±878 and 985 ±422 kJ m^{-2}) (Fig. 2.). A similar decreasing tendency of biomass of heterotrophic bacteria from 4.64 ±3.6 to 2 ±0.8 kJ m^{-2} of bottom in the cross-section from the littoral to deep profundal zones was observed.

Respiration of heterotrophic bacteria was highest in the shallow littoral (19 ±13.1 kJ m^{-2} day^{-1}) and lowest in the deep littoral sediments (10 ±6.9 kJ m^{-2} day^{-1}). In the shallower and deep profundal zones respiration of heterotrophic bacteria was similar and was maintained on the level 12.1 ±13.2 and 12.7 ±11.4 kJ m^{-2} day^{-1}. The values of Rb/Bb ratio showed an increasing tendency from the shallow littoral (4.0) to the deep profundal zone (6.1).

The greatest biomass of algae (348 ±188 kJ m^{-2}) and their photosynthetic activity (65 ±48 kJ m^{-2} day^{-1}) in the bottom sediments of the shallow littoral zone were found. In the deep littoral zone these parameters were about 3 times smaller. In the profundal sediments a very small biomass of algae, below the detection limit of the method used, and the absence of photosynthetic activity were recorded.

Total respiration of bottom communities on the cross-section from littoral to profundal zones had no regular tendency. In the shallower profundal zone the highest value of total respiration (960 ±513 kJ m^{-2} day^{-1}) was observed. A slightly smaller value (851 ±395 kJ m^{-2} day^{-1}) in the shallow littoral zone was found. However, in the deep littoral as well as in the deep profundal zones about 2–4 times smaller values of total respiration were recorded (Fig. 2).

The greatest charge of energy flowing through the bacterial link (Bb+Rb) was noted in the shallow littoral (23.3 kJ m^{-2} day^{-1}) and the smallest one was in the deep littoral zone (11.8 kJ m^{-2} day^{-1}), while in the bottom sediments of the shallower and deep profundal zones this energy charge was similar, on the level 14–15 kJ m^{-2} day^{-1}. In the shallow littoral zone 20% of energy was bioaccumulated in the bacterial biomass, and 80% of it was released by its respiration. In the deep littoral and shallower profundal zones these values were similar and amounted to 17 and 83%. In the sediments of the deep profundal zone 14% of energy was bioaccumulated in the bacterial biomass and 86% of it was released as the result of bacterial respiration (Fig. 3).

In the case of benthic algae, living only in the littoral zone, the pool of energy stored in their biomass and fixed in primary production together, was greater in the shallow littoral zone (77.6 kJ m^{-2} day^{-1}) than in the deep one (31.7 kJ m^{-2} day^{-1}). Bioaccumulation of energy in the algal biomass constituted 84% in the

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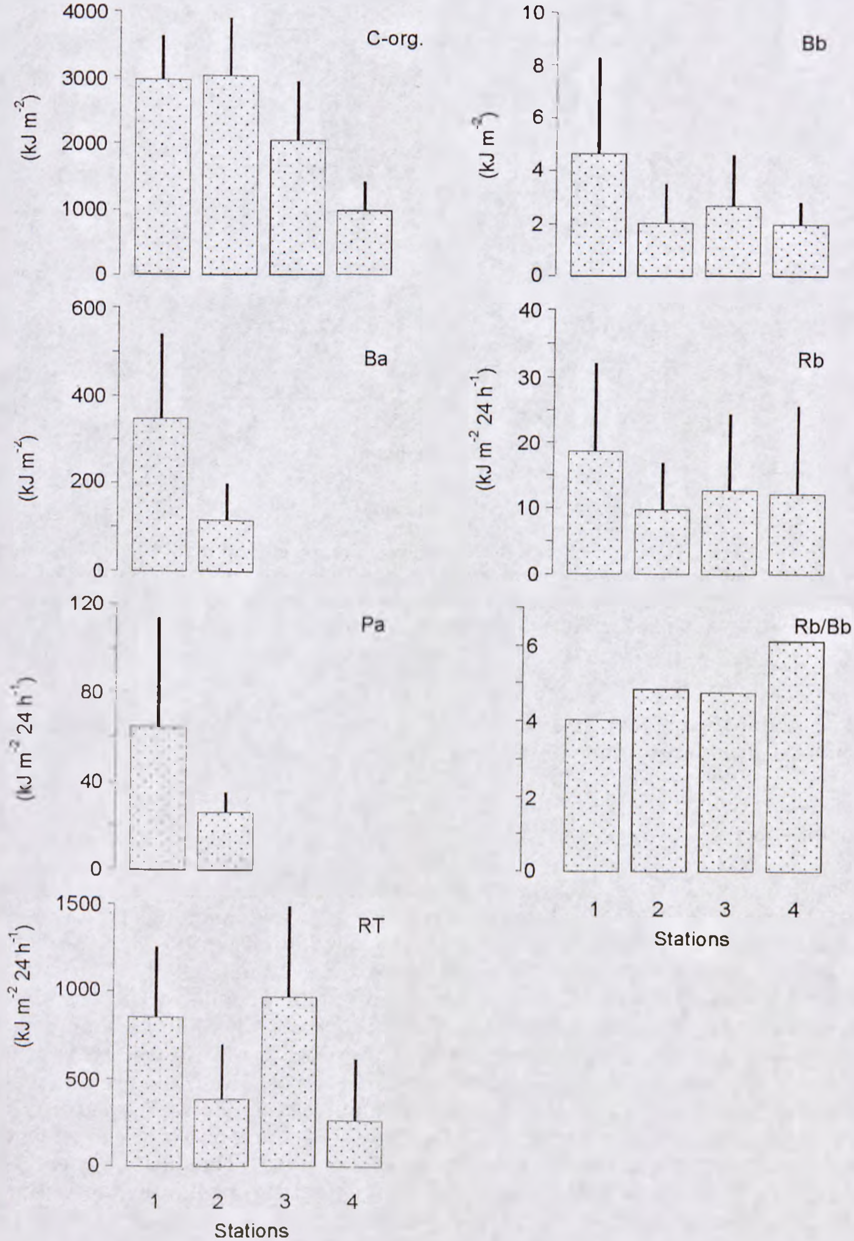

Fig. 2. Mean values and SD of the content of organic carbon (C-org.), biomass of heterotrophic bacteria (Bb), biomass of algae (Ba), respiration of bacteria (Rb), production of algae (Pa), value of Rb/Bb ratio, and total respiration (RT) of epibenthic communities in the surface layer (0.5 cm) of bottom sediments of the Dobczyce Reservoir in the stratification period (April–October) of 1995. Depth zones: Station 1 – shallow littoral (0.5 m), Station 2 – deep littoral (5 m), Station 3 – shallow profundal (10 m), Station 4 – deep profundal (20 m).

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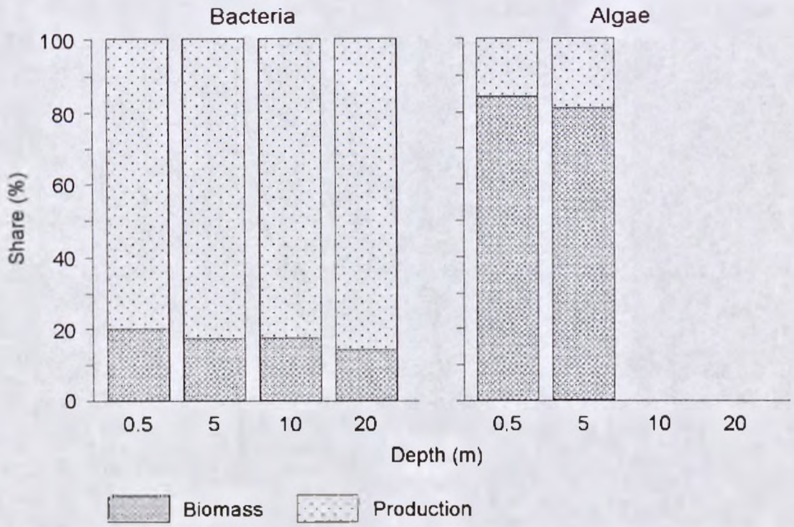

Fig. 3. The percentage share of energy flowing through bacterial and algal links in the surface layer (0.5 cm) of bottom sediments of the Dobczyce Reservoir in the stratification period (April–October) of 1995. Depth zones: 0.5 m – shallow littoral (Station 1), 5 m – deep littoral (Station 2), 10 m – shallow profundal (Station 3), 20 m – deep profundal (Station 4).

shallow and 81% in deep littoral zones, but only 16% and 19% of energy were assimilated in algal primary production (Fig. 3).

5. Discussion

The measurements of respiratory processes which took place in the sediments of the Dobczyce Reservoir comprised both aerobic and anaerobic processes. The dissolved oxygen content in the water at the maximum depth (near the bottom) during the investigated period ranged from 6 to 12 mg O_2 L^{-1}, although in September, during a water bloom (Bucka and Wilk-Woźniak 1998), it was low (about 0.6 mg L^{-1}; Mazurkiewicz unpubl.). For this reason it could be supposed that in the bottom sediments of the deep zone of the Dobczyce Reservoir there was no domination of anaerobic metabolic pathway of decomposition of the organic matter. The lowest total respiration of epibenthic communities found in the surface layer of bottom sediments at a depth of 20 m indicated the small number of bottom organisms living there, other than bacteria and fungi. The fact of there being a twice greater share of bacterial respiration in total respiration in the sediments of this zone (in comparison with the remaining stations) indicated that these conclusions were correct and demonstrated the important role played by bacteria in the breakdown of organic matter.

In the shallow littoral zone of the reservoir the greatest biomass and respiration of bacteria with at the same time the smallest energy expenditure per their biomass unit, showed that the available substrate for microbial consortia was decidedly greater there than in the remaining investigated reservoir sediments, especially in the deep profundal zone. In the latter zone an about 3 times smaller

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content of organic carbon was also found. The greatest biomass and photosynthetic activity of algae in the shallow littoral zone undoubtedly affected the development of bacteria. As is known, bacteria are directly supplied with organic carbon from the phytoplankton through exudation from healthy cells and by lysis of senescent and dead cells, and indirectly through egestion by grazers. The presence of this pathway has been suggested as an important source of reduced carbon for bacteria in the littoral zone (Olsen et al. 1986, Vadstein et al.1989).

The organic matter sedimented from the water column to the profundal bottom sediments had previously been mineralized in the water, therefore organic matter more resistant to bacterial decomposition was present in the profundal sediments (Amblard et al. 1992). The same observations were made in the present work, in which the greatest energy expenditure per bacterial biomass unit was found in the bottom sediments of the deep zone of the reservoir.

Taking into account the amount of energy released from the bottom sediments of the littoral zone (up to 5 m) of the reservoir as 100%, it could be seen that the energy released from bottom sediments at a depth of 10 m (shallow profundal) was 79%, whereas in the sediments at 20 m it was only 21%. In conclusion it may be said that the littoral zone of the Dobczyce Reservoir plays the most important role in the whole metabolism of the reservoir sediments, despite the fact that this zone forms only 25% of the total surface area of the reservoir.

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