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The comparison of microbial production and destruction of organic matter in the bottom sediments of streams on agricultural and forest types of catchment, and sublittoral of the Dobczyce dam reservoir (southern Poland)

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Abstract: In general, the phosphate and nitrite concentration in the waters, and C-org, biomass, production, and respiration of algae (Ba, Pr, Ra) in the bottom sediments were greater in the agricultural area. The ammonia and nitrate concentration, and biomass, respiration of bacteria (Bb, Rb), oxygen (RO), and total respiration of epibenthic communities (RT) as well as the respiration of the remaining organisms (Rr) were greater in the forest area than in the agricultural one.

Key words: streams, estuaries, reservoirs, sediments, bacteria, algae, biomass, respiration, primary production.

1. Introduction

Microorganisms are responsible for production (algae) and destruction (bacteria, fungi, protozoa) of organic matter and regeneration of inorganic nutrients in aquatic environments. In running waters the production of organic matter takes place in the surface layer of the bottom sediments. In the lenitic ones, this process occurs both in the photic zone of the water column and in the surface layer of the bottom sediments.

Contrary to lenitic waters, the production of organic matter in lotic ones is usually too small to maintain the life of the biocoenosis. In these cases, the inflow of allochtonous organic matter is the main alimentary source (Petersen et al. 1989). Depending on the character of the catchment and all the environmental conditions, the activity of microorganisms in the bottom sediments is heterogeneous.

The aim of this study was to compare the production and destruction of organic matter in the bottom sediments of agricultural and forest streams, belonging to the same immediate catchment of the Dobczyce dam reservoir, and the two different part of its sublittoral.

2. Study area, material, and methods

The investigations were carried out in the immediate catchment area of the dam reservoir on the 60th kilometre of the River Raba, in the vicinity of Dobczyce, about 25 kilometres south of Cracow.

The catchment and the reservoir are situated within the Wieliczka Plateau range, built of Silesian flysch of different age and mosaic distribution. In a large part of the catchment area soils are formed of fine-grained sands, originating from flysch rocks (Pasternak 1969).

The reservoir is chiefly fed by the River Raba, which brings in 88.6% of the total water inflow. The rest is supplied directly by the catchment (8.8%) and by atmospheric precipitation on the surface of the reservoir (2.6%) (Mazurkiewicz 1988).

The investigations covered two streams, one of which drained an agricultural and the second one a forest area, flowing into the reservoir on opposite sides. The first stream flows into the reservoir in the region of the Wolnica creek and the second one in the region of the eastern part of the Myślenice basin (fig.1).

Samples of bottom sediments were collected during the vegetation seasons April-October 1991 and 1992 at monthly intervals, from the surface layer of 0.5 cm, at three stations in each stream: 1 - above its mouth (sandy bottom), 2 - the mouth section, the so-called estuary (muddy-sandy bottom), and 3 - the reservoir near the stream mouth (muddy bottom). At each station nine subsamples were taken and mixed, yielding a mean sample for the given station. In the water overlying the sediments the temperature, pH, and PO_4, NH_4, NO_3, and NO_2 concentrations were determined.

Dry weight and organic matter content in the bottom sediments were determined at 105°C and 550°C, respectively. According to Jørgensen (1979), it was accepted that organic carbon (C) constitutes 50% of ash-free organic matter.

The total respiration of epibenthic communities (RT), including aerobic and anaerobic processes, was determined using the method based on the measurement of CO_2 release, by means of an infrared

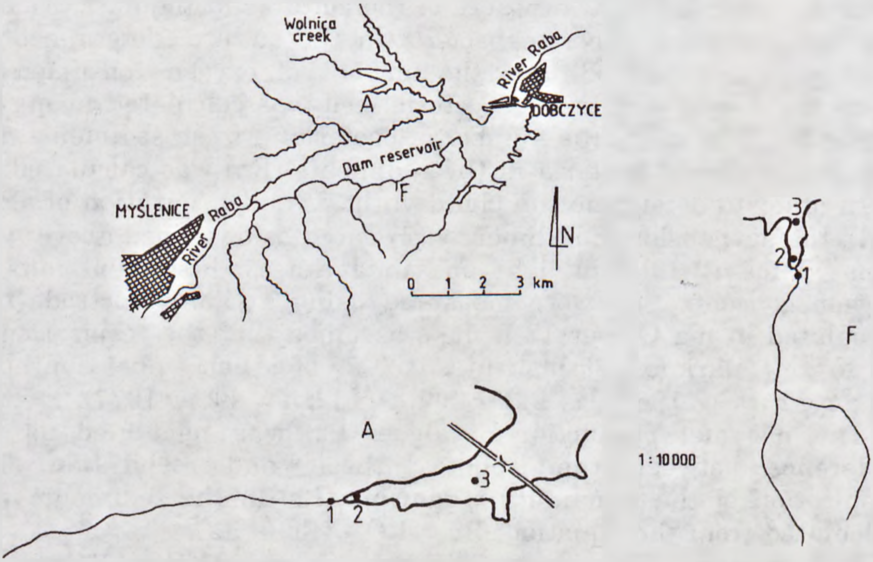

Fig. 1. Situation plan of the investigated area - agricultural - A, and forest - F catchments. Sampling sites: 1 - stream; 2 - estuary; 3 - reservoir

gas analyser (INFRALYT IV), and calculated in mg C per 24 h. A detailed description of this method is given by Starzecka and Bednarz 1993b.

Similarly as in the previous paper (Starzecka, Bednarz 1993a), oxygen respiration was determined on the basis of the losses of oxygen dissolved in the water suspension of the sediments (100 g of fresh sediment suspended in 1000 cm^3 of autoclaved water taken from each station), after 12-16 h exposure of samples in darkness by means of a Clark electrode and calculated in mg O_2 per 24 h. The diel oxygen respiration (RO) of epibenthic communities in the bottom sediments was calculated as the difference between oxygen respiration during 24 h and the photosynthesis of algae during 12 h. The coefficient RQ illustrating RT/RO ratio was also calculated.

The biomass of bacteria was determined using the total number of heterotrophic bacteria in the sediments estimated by the agar plate method, assuming that 1 bacterial cell contains 6.05×10^{-8} µg C (Watson et al. 1977).

The biomass of algae was estimated on the assumption that 1 µg of chlorophyll *a* corresponds to 50 µg C (Jørgensen 1979). Chlorophyll *a* was determined by ethanol extraction (Sartory 1982).

The bacteria fraction was isolated from the bottom sediments using the method given by Starzecka and Bednarz 1993b. Oxygen losses in the filtrate were determined by applying a Clark electrode, after 12-16 h exposure of the cultures in the dark. Taking into account the number of bacteria in the culture (determined by the agar plate method) and the amount of oxygen consumed by them, the respiration of one bacterial cell was calculated in mg O_2 per 24 h. Then, using the number of bacteria in fresh sediments, the diel respiration of bacteria in the sediments (Rb) was calculated.

In order to determine the photosynthesis and respiration of algae (Ra), the suspension of sediments (prepared as described above) was exposed for 12-16 h in light and in darkness. Rises and falls in oxygen concentration were measured using a Clark electrode and calculated in mg O_2 per 12 h. It is assumed that the respiration of algae in darkness constitutes 20% of their photosynthesis (H a r g r a v e 1969; H i l l b r i c h t - I l k o w s k a 1977).

The net diel production of algae (Pr) was calculated as the difference between their photosynthesis and respiration. The respiration of the remaining organisms (Rr) in the sediments was calculated from the equation: Rr = RO - (Rb + Ra).

The measurements were carried out at 21°C (±1°C) in 3 replications and the results given as arithmetical means calculated per joule (J) per 12 or 24 hours and 1 g C. According to the equation of photosynthesis, in the calculations concerning respiration the assumption was that 1 mg O_2 = 14.78 J and 1 mg CO_2 = 10.75 J. On the other hand, it was assumed that 1 mg C = 4.9 cal (C u m m i n s 1967) = 20.53 J.

The comparison of the two investigated areas was carried out by means of a logarithmic comparative coefficient (LCC). The coefficient determined the ratio of the logarithm of the parameters measured in the agricultural catchment to that of the forest one. The positive value of LCC evidenced larger values of the parameters in the agricultural catchment, and a negative one in the forest one.

3. Results

The temperature of the water and NH_4, NO_3, and NO_2 concentrations were increased from the stream to the reservoir in both catchment areas. However, PO_4 concentration in the water was at a uniform level in the agricultural area, contrary to the forest one, where a decreasing tendency was observed, the organic carbon content in fresh bottom sediments increasing in the forest and decreasing in the agricultural catchment on the stream - reservoir line (fig. 2).

The fluctuations of physical and chemical parameters at the particular stations were similar in the two areas. The exception was PO_4 concentration in the water from the forest area, where the fluctuations were greater (fig. 2).

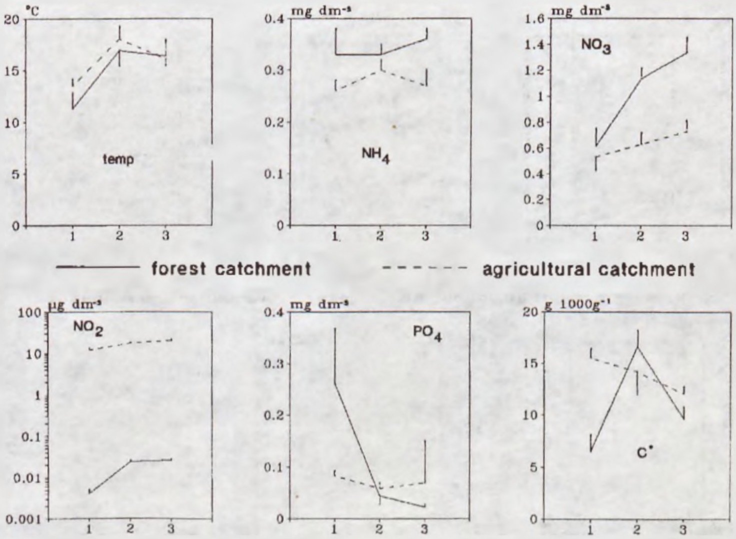

Fig. 2. Physico-chemical features of waters above the bottom sediments (± 1SE). 1 - stream, 2 - estuary, 3 - reservoir, C* - organic carbon concentration in the bottom sediments

The biological parameters determined in the surface layer of the bottom sediments of the investigated environments demonstrated much greater differences (figs 3,4). On the stream - reservoir line of the agricultural and forest areas an increasing tendency in Pr, Rb, RT, RQ, Rb/Bb, and Ba in the agricultural area only were found. However, the values of Bb, Rr, RO, and Ba represented a decreasing tendency on the stream - reservoir line only in the forest area. In the bottom sediments of the estuaries in both agricultural and forest areas also a disturbance in the tendencies mentioned above was most often observed.The fluctuation of the Ba, Pr, Ra, Rr, RO, and RT values were smaller in the forest area and those of Bb and Rb in the agricultural one. The greatest fluctuations of biological parameters occurred in the bottom sediments of the estuaries, especially in the case of Ra, Pr, Rr, and RO in the agricultural area (figs 3,4).

The application of LCC showed certain differences between the two investigated areas. The temperature of the water was slightly higher, and NO_2 concentration was about 3 orders of magnitude higher in the agricultural catchment than in the forest one. The concentration of PO_4 in the water and organic carbon concentration in the bottom sediments were in general also greater in the agricultural area. Exceptions were PO_4 concentration in the forest stream and C-org. concentration in the sediments of the forest estuary, where these values were greater than in the agricultural area. The amounts of NH_4 and NO_3 were greater in the water from the forest area (fig. 5).

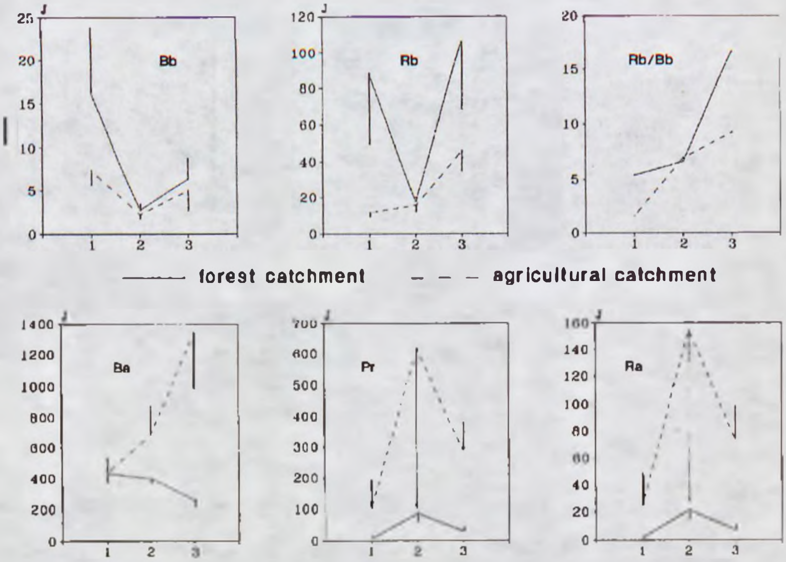

Fig. 3. Biomass of: bacteria - Bb, algae - Ba; production of algae - Pr; respiration of: bacteria - Rb, algae - Ra in J g^{-1} C 24 $h^{-1}$and ratio of Rb/Bb (±1SE). 1 - stream, 2 - estuary, 3 - reservoir - 3

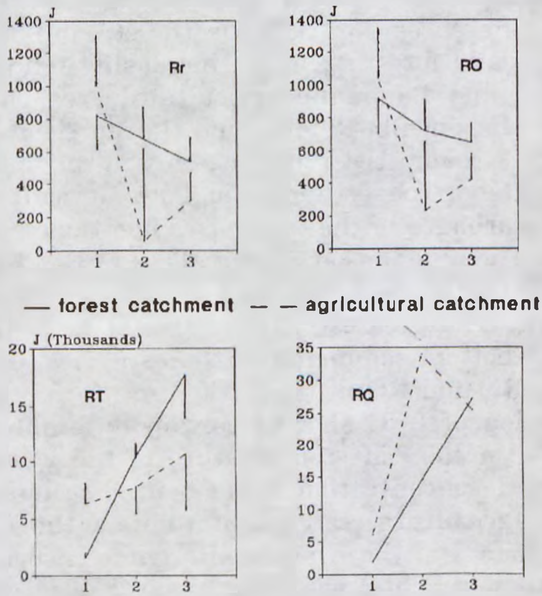

Fig. 4. Respiration of the remaining organisms - Rr; oxygen - RO, and total - RT respiration of epibenthic communities, in J g^{-1} C 24 h^{-1} and RT/RO ratio - RQ (±1SE). 1 - stream, 2 - estuary, 3 - reservoir

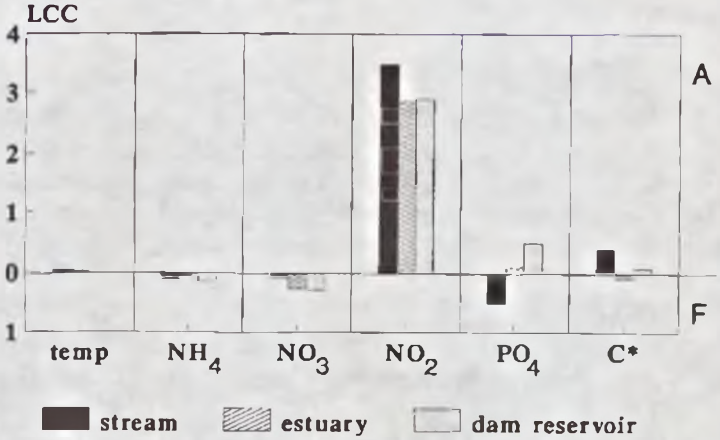

Fig. 5. Comparison of values of physico-chemical parameters of waters in the agicultural - A, and the forest - F catchments; logarithmic comparative coefficient - LCC. C* - organic carbon concentration in the bottom sediments

The values of biological parameters (Bb, Rb, Rb/Bb, Rr, RO, and RT) were in general from a few to ten times higher in the bottom sediments of the forest catchment. However, on the stream - reservoir line Ba, Pr, Ra, and RQ as well as Rr, RO, and RT in the stream only were from a few to ten times higher in the bottom sediments in the agricultural area (fig. 6).

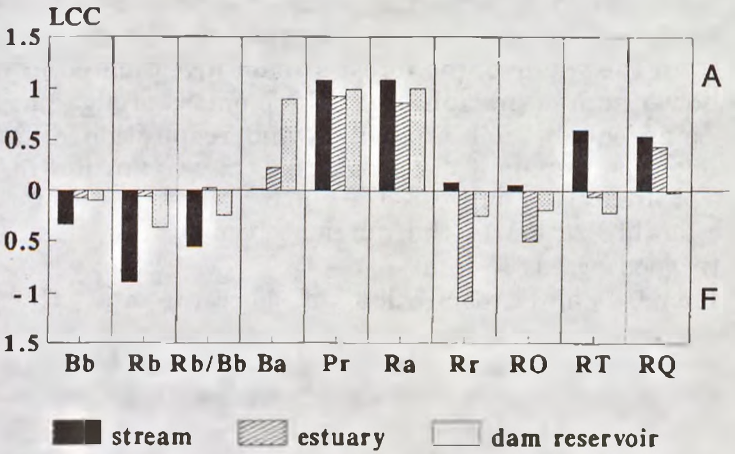

Fig. 6. Comparison of values of biological parameters in the bottom sediments of waters in the agricultural - A, and forest - F catchments. Biomass - Bb and respiration - Rb of bacteria; Rb/Bb ratio; biomass - Ba, production - Pr, and respiration - Ra of algae; respiration of the remaining organisms - Rr; oxygen - RO and total - RT respiration of epibenthic communities; RT/RO ratio - RQ; logarithmic comparative coefficient - LCC

4. Discussion

Bottom sediments are important sites for the mineralization of organic matter and recirculation of nutrients to the water mass (Nixon 1981, Jensen et al. 1990), in which the role of bacteria is significant (Scavia, Laird 1987). Many observations have shown that the water sediment interface plays an important role in the oxygen and nutrient flux between the sediments and the water column (Hargrave 1969, Sundbäck et al. 1991, Moran, Hodson 1992).

In this part of the bottom sediments microbial oxygen respiration (bacteria, algae, fungi, protozoa) may constitute 67% of the oxygen respiration of epibenthic communities, in which the share of bacteria is 25 to 30%, and that of algae 11 to 23% (Hargrave 1969, Saunders 1976, according to Wetzel et al. 1972). In the present study Rb constituted about 1 - 16%, Ra 0.2 - 68%, and Rr (fungi, protozoa, invertebrates) 25 - 97% of the RO of epibenthic communities.

In spite of the fact that the investigations were carried out in two subsequent years, which differed from each other as concerns the sum of annual precipitation (1991 - 844 mm; 1992 - 696 mm, according to Suliński, Sułkowski, unpubl. data) and, thus in the amount of the surface runoff, the differences observed in the values of the chemical and biological parameters can be referred to the character of the agricultural or forest catchment. It can, inter alia, be evidenced by the greater concentration of nutrients (PO_4, NH_4, NO_3) in the water of the forest stream investigated in the year with the lower sum of precipitation. The biomass of algae in the two streams being equal, their production and respiration differed and were by 1 order of magnitude greater in the stream flowing in the agricultural area. This suggested a much greater metabolic activity and a better utilization of the nutrient pool by the algae growing there with good access to light.

The biomass and respiration of bacteria and the energy expenditure per biomass unit were distinctly greater in the waters of the forest catchment. Not only were a greater bioaccumulation and energy release at this level of biocoenosis indicated here, but also the presence of organic matter more refractory to bacterial decomposition than that in the agricultural catchment.

In spite of the differences in the character of the catchments and those between the two periods of observation, the direction of changes in the processes of production and destruction of the organic matter occurring on the surface layer of the bottom sediments in the two catchments was the same. Both in the forest and agricultural catchment the rise in intensity of the total respiration of epibenthic organisms measured as release CO_2 was observed on the stream - reservoir line. On the same line a decrease in oxygen consumption and an increase in the value of the RQ coefficient took place. This indicated a distinct rise in the share of anaerobic processes in the decomposition of organic matter in the direction from the streams to the sublittoral of the reservoir.

Besides, the rise in "the cost of maintenance" of bacteria (Rb/Bb) in the bottom sediments on the stream - reservoir line in both the investigated areas provided evidence of the presence of organic matter more easily degradable by bacteria in the bottom sediments of the streams and of that less easily degradable in their mouth zones, and in the sublittoral of the dam reservoir.

5. Polish summary

Porównanie mikrobiologicznej produkcji i destrukcji materii organicznej w osadach dennych potoków o rolniczym i leśnym typie zlewni oraz sublitoralu zbiornika zaporowego w Dobczycach (Polska południowa)

W latach 1991-1992 przeprowadzono badania potoków o rolniczym i leśnym typie zlewni, oraz ich stref ujściowych i sublitoralu zbiornika zaporowego w Dobczycach, w rejonach Zatoki Wolnica i Basenu Myślenickiego (ryc. 1).

W wodach obu zlewni na linii potok - zbiornik oznaczono temperaturę i zawartość ważniejszych biogenów, a w wierzchniej, 0,5 cm warstwie osadów dennych określono zawartość C-org. oraz produkcję i destrukcję materii organicznej (ryc. 2 - 4).

Stosując logarytmiczny współczynnik porównawczy (LCC) wykazano, że przy podobnej temperaturze wody, stężenie fosforanów i azotynów w wodzie oraz zawartośc C-org. w osadach były od kilka do 1000 krotnie większe w zlewni rolniczej niż leśnej. Natomiast w wodach zlewni leśnej, w porównaniu z rolniczą, stwierdzono większą zawartość azotanowej i amonowej formy azotu (ryc. 5). Wartości biologicznych parametrów, takich jak biomasa (Bb) i respiracja (Rb) bakterii, respiracja reszty organizmów (Rr) oraz tlenowe (RO) i całkowite (RT) oddychanie epibentycznych zbiorowisk były od kilka do dziesięciokrotnie większe w osadach wód zlewni leśnej. Natomiast biomasa (Ba), produkcja (Pr) i respiracja (Ra) glonów były kilka do dziesięciokrotnie większe w osadach dennych wód zlewni rolniczej (ryc. 6).

Zarówno w rejonie Zatoki Wolnica jak i Basenu Myślenickiego, w osadach dennych wód na linii potok - zbiornik obserwowano wzrost intensywności procesów beztlenowych i udziału materii organicznej trudniej podlegającej dekompozycji bakteryjnej.

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