ACTA HYDROBIOL.	20	4	305—322	KRAKÓW 1978

KAZIMIERZ PASTERNAK, HENRYK KASZA

Stosunki chemiczne i produkcja pierwotna fitoplanktonu w podgrzanej wodzie zbiornika rybnickiego*

Chemical relations and primary production of the phytoplankton in the warmed water of the reservoir Rybnik

Wpłynęło 19 grudnia 1977 r.

Abstract — The magnitude of primary production in the warmed water of the reservoir „Rybnik" has been shown in a two years' cycle (1976, 1977) against the background of the content of biogenous macro- and microcomponents and the influence of warm discharge waters on some other physico-chemical properties of its water has been presented. The total annual production of the phytoplankton was 140 to 473 g $C/m^2 \cdot$ year, whereas, the maximum daily production reached the value of 5.456 g $C/m^2 \cdot 24$ h. The factors stimulating such a high primary production in the investigated reservoir are, apart from the increased temperature: a high content of mineral phosphorus and nitrogen in the water, and an increased (not toxic yet) concentration of some of the microelements (Mn, Zn, Co, Ni, and Cu). The increase assimilation rate causes a quick uptake of biogenous substances from the water in the reservoir. A decrease in their amount begins already in the early spring and does not end before the coming of autumn in spite of constant inflow of great amounts of trophic substances with the water of the River Ruda.

In the recent years papers have more and more frequently been published on the influence of warming water on aquatic organisms (Stuart, Stanford, 1978). In our country H. Soszka and G. J. Soszka (1976) listed the bibliographical data on the reaction of the biocenoses of the lakes and artificial water bodies which take in warmed waters from traditional and atomic power plants. The influence

* Praca wykonana w problemie węzłowym 10.2.

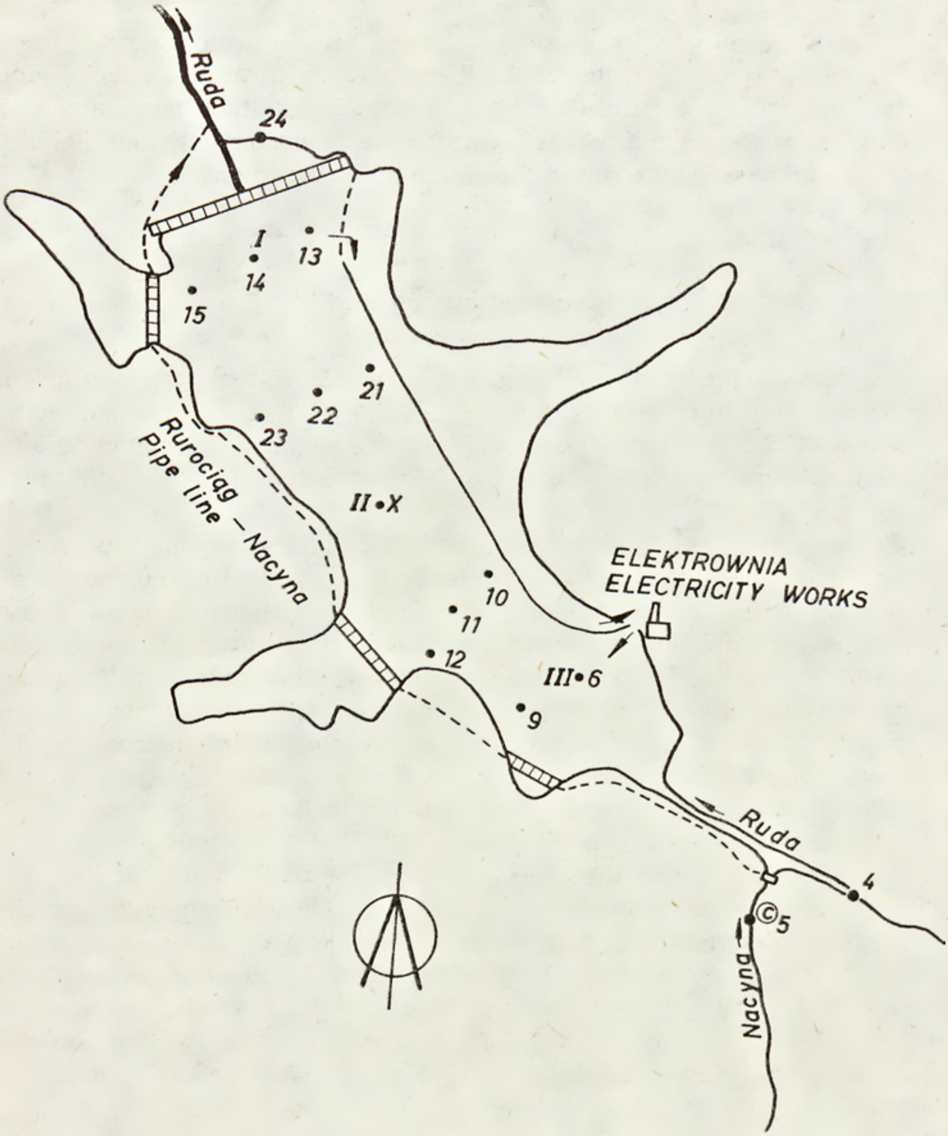
of increased water temperature on the production of the phytoplankton is presented, among others, in the mentioned publication. According to the data taken from this paper it may be said that researchers in their prevailing part agree as to the fact that in warmed waters the production increases. In the lakes of Konin, e.g., it was found that the primary production in the warmed lake is twice as high as in the lake of normal natural thermotics (Sosnowska, Zdanowski, Korycka 1975). In the Koniakowski reservoir, on the other hand, it was found that the production increased only slightly (Pidgajko et al. 1970) by 3.5°C after the water was warmed.

In warmed waters the oxygen content is a very essential chemical factor, since at a constant mineral salt content a decrease in its solubility takes place there concomitantly with temperature increase. It follows from the available literature that the oxygen content in the lake water decreases slightly or does not change at all as a result of an increased rate of organic matter mineralization (Ejsmond-Karabinowa et al. 1975, Langford 1971, Sosnowska, Zdanowski, Korycka 1975). Acceleration of decomposition processes of organic matter causes, according to some authors (Braune, Uhleman 1968 Langford 1971), an increase in the mineral nitrogen concentration and, according to some others, an increase in inorganic phosphorus concentration (Sosnowska, Zdanowski, Korycka 1975). On the other hand, according to Konenko and Abramska (1971) the amounts of phosphorus and nitrogen accumulated in such waters undergo some reduction as a result of their quick utilization by the developing phytoplankton.

The aim of the present paper was to obtain an answer to the question how high the content is of the phytoplankton primary production in the warmed reservoir Rybnik against the background of the content of the biogenous micro- and macrocomponents; it was also intended to show what in general the influence of discharge waters is on some other physico-chemical properties of the water.

Characteristics of the reservoir Rybnik

The dam reservoir at Rybnik (fig. 1) was built on the River Ruda. Its surface area is about 555 ha, its maximum depth 11 m. Its water is used for water supply and for cooling the equipments of the Rybnik power plant. The discharge of warm water is 25 to 33 m^3/sec. These huge amounts of post-cooling waters circulating along the axis of the reservoir, directed by a special concrete partition wall cause an increase in water



Ryc. 1. Plan zbiornika Rybnik z rozmieszczeniem stanowisk badań produkcji pierwotnej fitoplanktonu i makroelementów (I, II, III) oraz mikroelementów (X, 6—23). 24 — odpływ ze zbiornika; 4 — rzeka Ruda; 5 — rzeka Nacyna

Fig. 1. Sketch of the reservoir „Rybnik" with distribution of investigation stations of phytoplankton primary production and macroelements (I, II, III), and of microelements (X, 6—23). 24 — outflow from the reservoir; 4 — the River Ruda; 5 — the River Nacyna

temperature to 15°C in spring and 26 to 28°C in summer. In winter, water temperature in the reservoir does not fall below 5°C.

Apart from the water of the River Ruda, highly polluted and salted waters of the River Nacyna periodically flow into the reservoir as well.

This takes place when during high water flows special pumps prove unable to pump all the water of the River Nacyna through a special pipe system beyond the territory of the reservoir. In addition, some amounts of chemical substances find their way to the reservoir with the dusts of aerosols and gases emitted into the air by the power plant.

Investigations method

For measurements of the primary production the oxygen method of bright and blackened bottles was applied. The bottles were placed at the depths: 0, 1, 2.5, and 7 m. The exposition time was 24 hours. Experiments started, as a rule, at 9.30 a.m. Oxygen was determined by Winkler's method.

Since in this method of primary production measurements the amount of oxygen emitted during exposition is the measurement of the magnitude of the transformation of sun energy into potential chemical energy (oxygen is emitted during the process of water phetolysis) the coefficient 1 mg O_2 = 0.299 mg C (Vinberg 1961) was applied for calculations of the amount of the produced organic matter. The measurements of the primary production were carried out at the station in the zone of the reservoir close to the dam in the years 1976 and 1977 (fig. 1).

The amount of chlorophyll "a" was determined spectrophotometrically by use of the formula proposed by SCOR-UNESCO (1964).

Simultaneously with the measurement of the primary productivity the concentration of some indicators and chemical macrocomponents of the water were determined at 2 to 4 week intervals. This was carried out at the above mentioned station and in the central and upper zone of the reservoir according to the methods given by Just and Hermanowicz (1955). The waters of the tributaries the Ruda and the Nacyna, were also analysed at stations 4 and 5 situated before their mouths to the reservoir (fig. 1).

The content of more important biogenous microcomponents and iron was determined in the water of the reservoir in every season of the year (winter, spring, summer and autumn). This was carried out by means of a spectrophotometer of atomic absorption, bearing the Perkin Elmer 403 trade-mark in fresh water samples or fixed with nitric acid concentrated by evaporation.

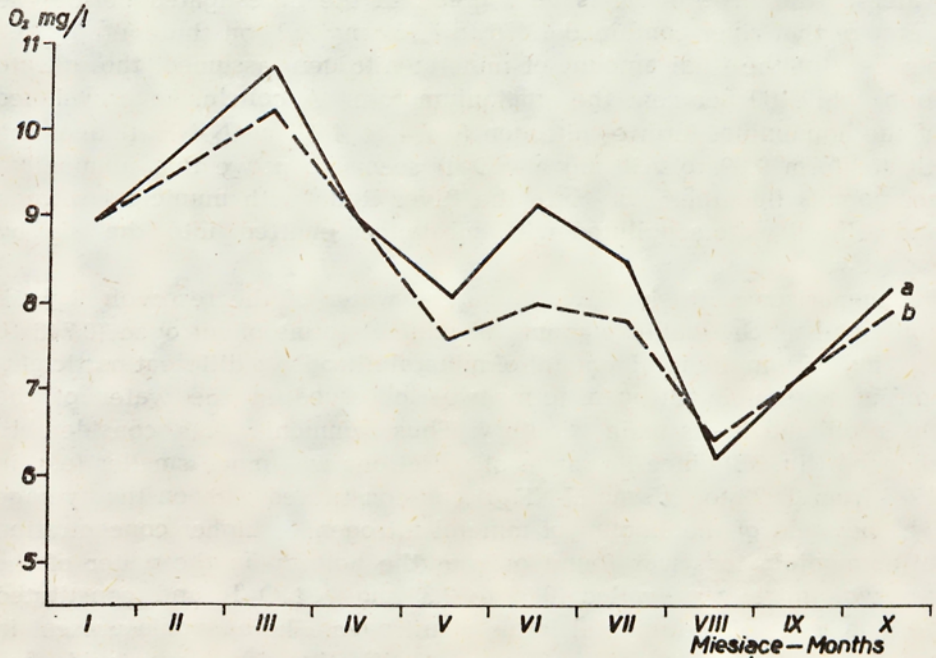
The intensity of sun radiation was measured by D. Augustyn at the Experimental Laboratory of the Polish Academy of Sciences at Zaborze, situated not far from the reservoir. Out of technical reasons, during the investigations it was not possible to collect all the necessary data on sun energy.

Investigation results

General characteristics of the chemical relations in the reservoir

The water of the River Ruda falling into the reservoir had a fairly high organic pollution. The BOD_5 varied from 2.1 to 6.49 mg O_2/l.

The values of the indices of this organic pollution decreased in the water of the reservoir (1.0 to 6.08 mg O_2/l) in comparison with the water of its main tributary, i.e., of the River Ruda. The sedimentation processes and temperature increase of the water, thus, contribute to the improvement of water quality in the reservoir. In the summer months smaller differences in the BOD_5 values in the River Ruda and in the reservoir were recorded. This is probably caused by an accelerated mineralization process of the organic matter in the river during the summer months, with a simultaneous slight increase in the BOD_5 value of the water in the reservoir in summer due to a more intensive development of the phyto-plankton. In 1977 this phenomenon was influenced, to a certain extent, by the fact of a more frequent than usually water exchange in the reservoir in that year. This happened as a results of high water levels in these



Ryc. 2. Ilość rozpuszczonego tlenu w powierzchniowej (a) i przydennej (b) warstwie wody w pobliżu zapory zbiornika w 1977 r.

Fig. 2. Amount of oxygen dissolved in the water surface layer (a) and in the water layer close to the bottom (b) near the dam of the reservoir in 1977

two rivers brought about by exceptionally heavy rainfalls during that summer.

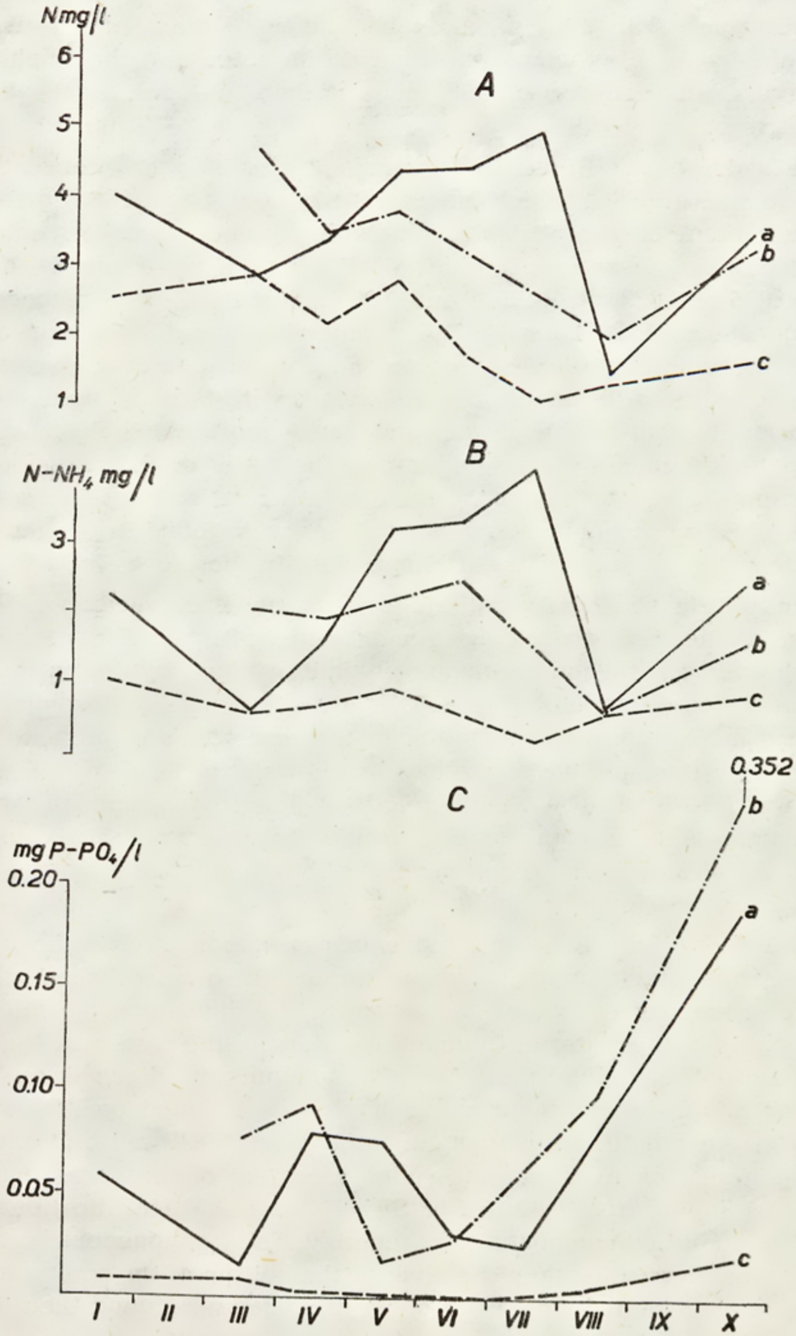
The improvement of water quality in the reservoir is also reflected in the content of oxygen dissolved in its water (fig. 2). The investigations carried out showed that the water in the reservoir Rybnik is, throughout its depth, well oxidated. In 1976 water saturation varied from 52 to 110 per cent and in 1977 it oscillated between the values 59 to 113 per cent, its concentration being 4.80 to 9.28 mg O_2/l and 5.25 to 10.56 mg O_2/l respectively. As a rule slightly higher amounts of oxygen were found in the surface layers of the water in the reservoir. The waters with which the reservoir is supplied, i.e., those of the River Ruda and especially of the River Nacyna contained slightly smaller amounts of oxygen, since the concentration range was within the limits 4.96 to 10.37 mg O_2/l and 6.05 to 8.35 mg O_2/l respectively, while the saturation with oxygen was 48.8 to 104.6 per cent and 60.7 to 75.2 per cent respectively.

The water of the River Ruda is, as a rule, richer in trophic components than the water in the reservoir. The content of biogenous components, of nitrogen and phosphorus, in the water of the reservoir and of its main tributary, i.e., the River Ruda in 1977 is presented in fig. 3.

The amount of nitrogen brought into the reservoir Rybnik with the water of the River Ruda is very great. In the investigated period the water of that river contained 1.476 to 4.982 mg N/l; on the average 38.2 per cent of the total amount of mineral nitrogen assumed the nitrate form, while 60 per cent the ammonium form. A conclusive prevalance of the ammonium form of nitrogen (0.474 to 4.02 mg N-NH_4/l) over the nitrate form 0.89 to 2.30 mg N-NO_3/l) seems to prove that ammonium compounds find their way into the River Ruda with municipal sewage and rainfall waters polluted with substances emitted into the air by industry.

In comparison with the River Ruda the water of the reservoir Rybnik contained much smaller amounts of mineral forms of nitrogen (0.746 to 3.03 mg N/l). In the total amount of mineral nitrogen a different participation of particular nitrogen forms was observed in the water of the reservoir and in its main tributary. Thus, ammonia was considerably reduced (fig. 3B) since its range of variations was much smaller (e.g. in 1977 from 0.022 to 1.13 mg N-NH_4/l) and constituted only on the average 24.3 per cent of the amount of mineral nitrogen. A higher concentration of ammonium ions was found only at the bottom. In the water of the reservoir nitrates prevailed (0.55 to 2.33 mg N-NO_3/l) and constituted 70.6 per cent of the mineral forms of nitrogen. The ammonia present in the water of the reservoir underwent nitrification which was evidenced by the occurrence of nitrites (0.059 to 0.247 mg N-NOL_2/l).

As it follows from fig. 3A, the highest mineral nitrogen content was found in the water of the reservoir in winter. With the course of the



Ryc. 3. Zawartość azotu mineralnego (A), azotu amonowego (B) i fosforanów (C) w wodzie rzeki Ruda (a), rzeki Nacyna (b) i zbiornika (c) w pobliżu zapory w 1977 r.

Fig. 3. Mineral nitrogen content (A), amonium nitrogen content (B), and phosphate content (C) in the water of the River Ruda (a), the River Nacyna (b), and of the reservoir (c) near the dam, in 1977

vegetation period its amount gradually decreased, this being caused by its uptake by the phytoplankton. It should be noted that the trophic surface layer contained less of that element than the layer at the bottom of the reservoir.

The water of the River Ruda contained also a high a concentration of phosphates (fig 3C) which amounted from 0.014 to 0.186 mg $P\text{-}PO_4/l$.

The content of phosphates in reservoir also decreased considerably. The amounts of these ions found in 1976 and 1977 were only within the limits 0.005 to 0.033 mg $P\text{-}PO_4/l$ and 0.00 to 0.02 mg $P\text{-}PO_4/l$ respectively. The concentration 0.04 mg $P\text{-}PO_4/l$, found only once in the upper zone of the reservoir in its layer close to the bottom, has been overlooked. In this zone the water of the reservoir mixes with the cold waters of the tributaries flowing at the bottom and hence most probably this high phosphate content. In winter and spring the water of the reservoir contained more of that component than in other seasons of the year. In summer mostly trace amounts of phosphates were found in the reservoir, in autumn the amount of these ions evidently increased.

It may be concluded from the above presented characteristics of the content of the basic trophic components, i.e., nitrogen and phosphates, that phosphorus is a macrocomponent limiting the growth and development of the phytoplankton. This is evidenced by traces of this component during a more intensive vegetation in the reservoir and increase in its content at a later period, as well as by the relation N : P which, e.g. in 1976, was 72-186 : 1. The weight relation of nitrogen and phosphorus in the biomass of the plankton is, according to S t u m m (1964), approximately 7.2 : 1 and so the requirement for these components in the water of the reservoir should be similar.

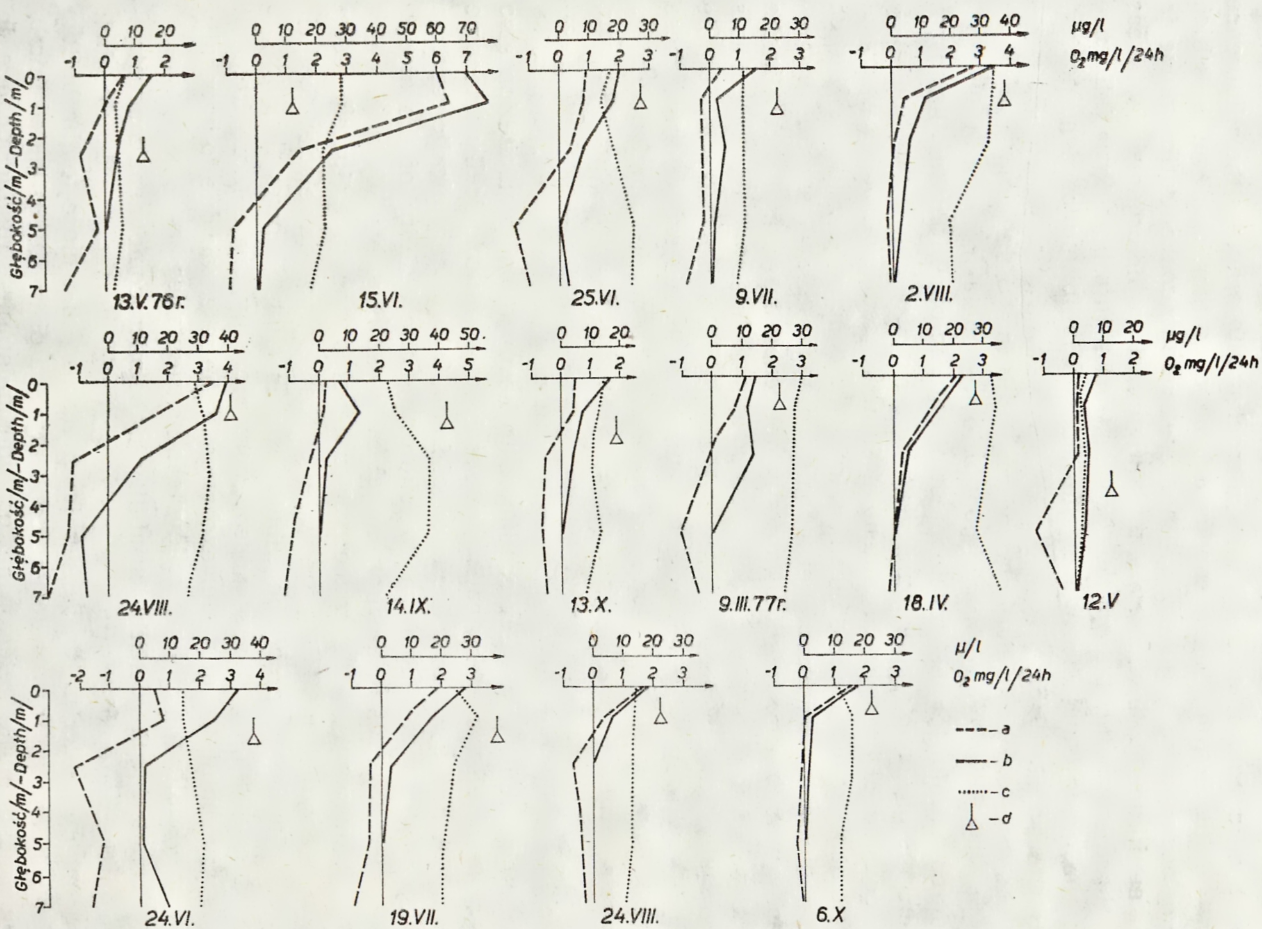
Apart from these two basic biogenous macrocomponents the investigated waters were also analysed for the content of silica, since this ion is a component of the water necessary for the development of diatoms. Its amounts in the water of the main tributary of the reservoir, the River Ruda, were 4.15 to 25.24 mg SiO_2/l. The amounts of silicon were 0.00 to 1.11 mg SiO_2/l, its maximum value having been found on 24th August 1976; on other dates its amount did not exceed 0.43 mg SiO_2/l. In the following year of investigations a higher content of silica was found, its amounts ranging from 0.30 to 5.95 SiO_2/l. A vertical stratification of the distribution of that component was reported. The trophogenous layer contained much less silica than the layer at the bottom of the reservoir. Also in the summer period smaller amounts of silica were found then than in early spring and in autumn.

From the microcomponents occurring in the water of the reservoir and in its tributaries only those heavy metals which play a more essential role in the development of aquatic organisms were determined in these investigations (Table I). The mineral microelements, because of their trace amounts, do not influence so much the chemical situation in the water itself as many physiological processes of the organisms living in it, among them especially the enzymatic processes. Every organisms has its specific requirements as to the microelements, whereas their influence on the life in the water depends on the concentration level in which they occur in it. In general, within the average concentration range in the environment they have a stimulating effect on the organisms whereas at those exceeding the optimum concentration threshold their influence on the growth and metabolism starts to be inhibiting or even toxical (Pasternak 1976).

As it follows from the obtained results (Table I) the aquatic environment of the reservoir does not contain heavy metal concentrations considered harmful for the development of aquatic organisms (neither other elements of considerable toxicity as, e.g., Hg, Cd, Pb). It can, however, be considered as an environment of an increased level of heavy metal content in comparison to clean water. This concerns, before all, such microelements as zink, nickel, cobalt, manganese and such a macrocomponent as iron. This fact is easily noticeable in spite of it that in the reservoir Rybnik a considerable decrease in the amount of heavy metals takes place in the water. It is worth noticing that specially favourable conditions prevail in that reservoir for quantitative reduction of these metals from the water. These conditions are often made to include a mass development of phytoplankton and epiphytic algae in the reservoir, favoured by increased water temperature and the content of great amounts of the basic biogens as well as its other chemical properties. To the other water properties conducive to heavy metal precipitation also by way of physico-chemical processes belong: a periodically intensive oxidation of the water, exhaustion of free CO_2, a highly alcalic reaction of the water (resulting from the photosynthetic activity of the algae), and great reserves of alcalic mineral salts (Ca, Mg, Na, K) in it.

The decrease in the concentration level of the investigated heavy metals recorded in 1977 in the water of the reservoir in relation to their content in the water of the tributaries was slightly lower than in the previous years. This was caused, most probably, by a more frequent that year than is usual, water exchange in the reservoir due to unusually heavy rainfalls and high water levels in its tributaries.

Considering the vertical variability in the microcomponent concentration in the water of the reservoir it may be found that, as a rule, their content is smaller in the surface layer than in that close to the bottom (Table I). During the season the concentration of the investigated microcomponents in the water of the reservoir undergoes a distinct change. In general, most of the heavy metals occur in the water in winter and least during the summer-autumn season.

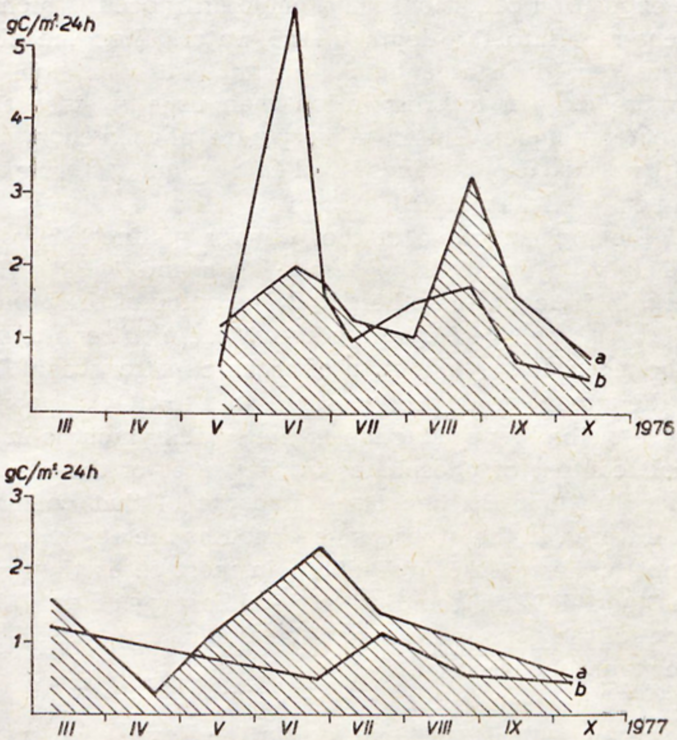


Ryc. 4. Produkcja pierwotna fitoplanktonu w zbiorniku Rybnik: a — produkcja netto; b — produkcja brutto; c — chlorofil „a"; d — przeźroczystość. Wartości średnie z badanych stanowisk

Fig. 4. Phytoplankton primary production in the reservoir Rybnik. a — net production; b — gross production; c — chlorophyll „a"; d — transparence. Mean values for the investigated stations

Primary production

The primary production of the phytoplankton in the reservoir Rybnik was shown in figs 4 and 5. In 1976 the highest value of the total production was found on 15th June. It was 5.456 g C/m². 24 h., whereas in May, early in July and in September the total production was almost 8 times lower than the maximum one. The cause of a relatively low photosynthesis in July could be a rather low sun radiation on the day when measu-



Ryc. 5. Produkcja pierwotna brutto (b) i destrukcja (a) w zbiorniku Rybnik w roku 1976 i 1977

Fig. 5. Primary gross production (b) and destruction (a) in the reservoir Rybnik in the years 1976 and 1977

rements were taken (Table II) and a poor phytoplankton (low content of assimilatory pigments in the water of the reservoir, fig. 4). In August an increase in the productivity of the phytoplankton photosynthesis was found again, the primary production, however, being at that time about three times smaller than the maximum one.

The mean daily production of organic matter was 1.587 g C/m². Assuming the length of the vegetation period of photosynthetizing aquatic organisms as 180 to 270 days the annual production would be 2.86 to 4.28 t C/ha.

It is worth mentioning that on 24th August 1976 an untypical value of primary production (fig. 4) was reported. At the depths of 5 and 7 m there was less oxygen in the white bottles than in the blackened ones; this seems to indicate that photosynthesis took place under conditions deprived of light access. Evidently, such a phenomenon does not occur. This unnatural difference in the white and blackened bottles is accounted for by Müller (1966) in the following way: it may happen, that during the exposition conditions may temporarily occur which permit the light to penetrate into the depth of the water. Then the algae in the white bottles reproduce at a quick rate and after he light disappears they use more oxygen for respiration than usually since they are in a much greater number. This is a very rare phenomenon. It was also mentioned by Dugdalle and Wallace, and Vinberg (quoted after Vollenweider, 1969).

In 1977 the highest value of the primary production was found in March and July. It was 1.232 g $C/m^2 \cdot 24$ h and 1.133 g $C/m^2 \cdot 24$ h respectively. In June, on the other hand, the value of the production was lowest (0.451 g $C/m^2 \cdot 24$ h). Low values were also reported in autumn months. The mean daily production of organic matter was 0.777 g $C/m^2 \cdot$ $\cdot$ 24 h and the annual production was 1.40 to 2.10 t C/ha · year.

The cause of the low production in the summer months in 1977 might be too small content of phosphates in the water of the reservoir. June was, in fact, the month when trace amounts of that component were found in the water. In the other summer months the amounts of phosphates were not higher than 9 μg $P\text{-}PO_4$/l. In most cases they reached the value 7 to 8 μg $P\text{-}PO_4$/l. According to Vollenweider (1968) a mass development of the algae starts when the amounts of mineral phosphorus exceed the value 10 μg $P\text{-}PO_4$/l.

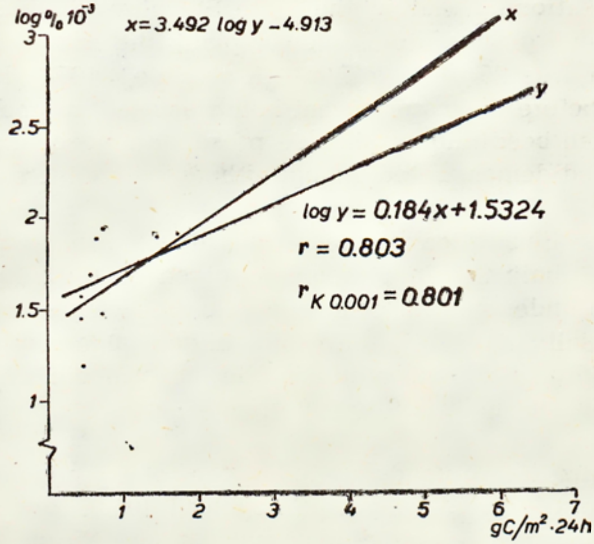
In spite of the fact that the year 1977 was exceptionally poor in sunshine, the amounts of sun energy, on the days when measurements were taken, were relatively great (Table II). Since the intensity of plant development depends on the sum of sun energy during the vegetation period, hence, a smaller amount of sun radiation during the summer months could be one of the causes of the relatively low annual primary production. For these reasons, too, smaller amounts of assimilatory pigments (chlorophyll "a") were found in the water of the reservoir than in previous year (fig. 4).

Utilization of the sun energy in the process of photosynthesis was presented in fig. 6 in terms of percentage of energy bound by the phytoplankton (1 mg O_2 = 3.51 cal) in relation to its sum in the PhAR range on the days when measurements were taken (Table II). Utilization of sun energy varied within the range from 0.016 to 0.306 per cent. A curvi-

Tabela I. Zawartość ważniejszych mikroskładników (µg/l) w wodzie zbiornika rybnickiego oraz jego dopływów w 1977 r.
a — zima; b — wiosna; c — lato; d — jesień
p — warstwa przydenna; x — stanowisko wspólne dla produkcji pierwotnej fitoplanktonu

Table I. Content of the more important microelements (µg/l) in water of the Rybnik reservoir and its inflows in 1977
a — winter; b — spring; c — summer; d — autuun
p — layer close to botton; x — station commen for the primery production of phytoplankton

Miejsce badań Locality		Nr stanowiska No of station	Cu				Zn				Mn				Co				Ni				Fe			
			a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d
Rzeka River Ruda		4	11.3	7.3	8.4	5.3	662.5	330.7	320.5	513.0	391.8	405.4	378.4	371.6	8.8	6.8	5.4	11.3	15.0	11.7	10.5	25.8	2030.9	1851.9	3771.2	2069.6
Rzeka River Nacyna		5	17.9	25.0	11.9	10.9	222.5	66.0	124.9	50.4	221.5	314.6	432.4	390.6	15.0	27.0	31.3	23.0	16.3	32.5	40.3	50.0	1792.5	651.6	181.9	1056.5
Zbiornik Reservoir	górna strefa upper zone	6	18.6	15.0	13.5	11.5	150.0	42.6	24.5	23.9	189.0	270.3	113.7	56.9	6.3	3.8	3.9	3.0	8.3	6.4	6.8	12.0	2005.4	182.3	158.0	220.7
		9	15.6	10.2	5.3	13.9	135.0	61.3	9.7	32.1	184.3	329.4	37.9	42.2	6.0	3.8	2.8	2.5	8.3	6.4	4.7	12.3	472.6	520.9	94.6	271.7
		9p	17.0	86.8	10.9	15.2	245.0	62.5	32.0	38.4	225.0	337.9	89.4	54.5	6.3	4.3	3.3	2.4	10.0	8.3	7.1	13.5	425.8	561.3	256.3	223.2
		10	16.0	9.8	9.8	13.0	116.3	58.6	20.6	21.7	179.8	329.4	79.4	49.5	6.0	4.3	3.9	3.8	9.0	6.1	6.6	12.8	375.0	329.9	152.4	190.1
		11	13.0	10.3	11.1	11.4	145.0	70.8	65.5	23.5	179.8	331.5	90.3	48.5	5.0	4.4	2.2	2.8	9.5	5.9	6.8	13.3	304.8	463.0	535.1	215.6
		12	13.5	12.5	10.4	14.2	150.0	62.1	23.4	25.8	195.8	283.1	85.5	52.7	6.3	4.8	4.1	2.4	8.8	6.9	7.6	9.8	390.6	321.2	139.8	236.0
	środkowa strefa middle zone	x	14.8	9.5	11.8	11.3	56.3	40.2	14.9	28.1	185.3	348.4	32.7	45.0	5.0	4.0	2.8	3.0	9.5	5.3	7.9	11.3	304.8	213.5	119.6	182.4
		xp	14.4	9.9	10.5	16.4	177.5	54.7	16.4	62.5	181.0	346.3	107.6	56.2	5.0	4.9	3.0	4.0	9.5	6.7	7.9	12.5	285.1	237.0	174.9	1204.4
		21	13.3	10.6	11.2	10.3	175.0	74.3	28.3	18.3	168.3	367.4	76.4	39.0	6.5	4.9	3.2	4.0	9.5	6.7	9.0	11.3	285.1	431.2	1237.7	187.5
		22	17.5	14.8	9.7	10.2	146.3	51.6	14.0	14.8	155.5	323.0	32.0	38.0	5.0	5.0	2.7	3.0	8.3	6.9	7.4	12.0	445.4	252.6	99.4	131.4
		23	10.5	15.8	9.1	10.2	95.0	54.3	18.8	14.8	119.3	318.9	30.5	31.3	5.0	4.9	2.7	3.5	9.0	7.2	6.6	10.0	246.4	179.8	86.9	136.5
	dolna strefa lower zone	13	22.2	8.0	11.0	12.8	107.5	55.1	44.6	59.4	176.8	259.3	66.4	44.6	4.5	4.3	4.0	2.5	8.8	6.1	5.5	11.0	453.1	206.6	136.9	797.6
		14	14.6	10.2	12.4	10.4	135.0	105.8	73.0	18.3	148.3	321.0	63.4	37.6	4.5	3.8	3.9	2.5	8.8	5.9	6.8	10.6	500.0	224.0	1097.2	220.7
		14p	14.3	8.9	10.4	16.7	145.0	76.1	91.5	32.4	183.0	312.0	363.2	41.1	4.0	3.8	3.9	3.5	9.0	4.8	7.1	11.8	300.8	182.3	1950.0	723.6
		15	13.0	13.2	11.5	30.7	262.0	62.5	54.8	44.2	168.3	359.0	40.0	40.4	4.8	4.9	3.2	3.8	8.8	6.9	6.3	12.8	1139.4	192.8	104.8	718.3
Odpływ ze zbiornika Outflow from the reservoir		24	13.0	8.8	13.4	10.4	208.8	38.7	19.3	19.4	170.3	273.9	102.4	46.0	6.3	4.5	2.3	3.0	8.0	6.4	5.0	11.3	722.6	200.5	158.7	202.8



Ryc. 6. Wykorzystanie energii słonecznej w zakresie PhAR w zależności od wielkości produkcji. r — współczynnik korelacji; r_k — krytyczna wartość współczynnika korelacji przy poziomie istotności $\alpha = 0{,}001$

Fig. 6. Utilization of sun energy within the range PhAR depending on the production magnitude. r — correlation coefficient; r_k — critical value of the correlation coefficient with the significance level $\alpha = 0.001$

linear positive relation between sun energy utilization and photosynthetic activity was found and presented in fig. 6 in a simple form of the type log y=a+bx. A high value of the correlation coefficient (r=0.803) proves a close relation between these two investigated variables. No interrelation between the magnitude of the primary production and the amount of chlorophyll or content of the limiting macrocomponent, i.e., phosphorus has been found; the same refers to microelements.

As it follows from figs 4 and 5 intensive processes of organic matter destruction, caused by high water temperature, took place in the reservoir Rybnik. The compensation point, i.e., the depth at which the processes of organic matter production equal its decomposition was found at the depth from 0.5 to 4 m.

Discussion and results

As it has already been mentioned the maximum daily production of organic matter was in the reservoir Rybnik 5.456 g C/m²; in the vegetative season (annual production) 140 to 473 g C/m². For comparative reasons it is worth mentioning that in the Lake Stechlinsee which gets warm discharge water from the atomic power plant, the annual production of organic matter was 75 to 80 g C/m² (K o s c h e l 1974). It should also be noted that before the water of that lake was used for cooling purposes its character had been oligotrophic. At present an eutrophization process has been started demonstrated, among others, by an increase in its productivity.

For a better illustration of the magnitude of primary production of the reservoir Rybnik the data should be given on the primary production magnitude under natural conditions, i.e., in waters which are not warmed artificially. And so in the Alpine oligotrophic lakes this production is 10 to 25 g C/m² · year and in the mezotrophic lakes of Europe it varies within the limits 150 to 200 g C/m² · year (V o l l e n w e i d e r 1968).

In the fertilized carp ponds at Gołysz the total production of organic matter was about 170 g C/m² · year (W r ó b e l 1962).

As it results from the above given comparisons the warmed water of the reservoir Rybnik is characterized by a high primary productivity. It seems worth noting that fertilized carp ponds were less productive in spite of a higher water fertility (e.g., the resources of phosphorus limiting the growth and development of the algae was 10 to 20 times higher). This may be explained, most probably, by the fact that temperature plays the role of a growth stimulating factor, and the destructive processes proceeding intensively under such conditions decompose quickly the organic matter which in its major part mineralizes before it drops to the bottom. The increased rate of metabolic processes makes up, in a sense, for the scarcity of mineral nutrient compounds. The mineralized biogenous components are immediately used up by the assimilating phytoplankton (B e n n d o r f 1968). Moreover, the phytoplankton has the ability of storing phosphorus during periods when the water of the reservoir is rich in that element and passing a part of its storage of phosphorus from cell to cell during periods of "phosphorus starvation" in the reservoir (M a c k e r e t h 1953). It should be remembered that the water of the River Ruda, the main source of water supply, contained from 0.014 to 0.186 mg P-PO_4/l, whereas, the amounts of phosphates in the reservoir varied from trace amounts to 0.033 mg P-PO_4/l.

The increased concentration of heavy metals is also, without doubt a factor stimulating such a high primary production of the phytoplankton in the warmed reservoir Rybnik. Several factors support this point of view: the considerable decrease in the amount of these metals, highest in the most intensively illuminated surface layer of the water in the reservoir and in the annual cycle in the summer-autumn period when the development of organisms taking up metals is most intensive. According to S. M. B o n e r j e e and S. C. B o n e r j e e's (1967) investigations, among the microelements manganese can play the greatest stimulating role by a favourable influence on the photosynthesis and other physiological processes of the phytoplankton; according to some other authors, this may be also said of cobalt, copper, and zink. Cure et al. (1971) showed that after an addition of cobalt into waters rich in N and P, as it is the case in the investigated reservoir, a several times greater primary production is obtained. As it follows from the experiments of Rotovskaja et al. (1971) mixtures of cobalt, manganese, and copper have also a beneficial influence on the development of the zooplankton and further on the carp and crucian carp fry, i.e., on the secondary production.

Acceleration of metabolic processes in the fish reservoir leads, thus, to a decrease in the amount of nitrogen and mineral phosphorus in its water as a result of their fast uptake by algae and bacteria. This phenomenon was also observed in other reservoirs by Konenko and Abramskaja (1971).

According to Braune and Uhlemann (1968) and Langford (1971) the mineral nitrogen concentration increases, whereas, according to Sosnowska et al. (1975), this increase concerns mainly inorganic phosphorus. As a matter of fact in 1977 the contents of mineral forms of nitrogen and silica in the reservoir were higher than in the previous years; nevertheless, these components underwent a considerable quantitative reduction in the reservoir in relation to their content in the tributaries. A higher concentration of biogenous substances in 1977 was most probably the result of an almost twice lower efficiency of the phosphorus. As a matter of fact in 1977 the contents of mineral forms of ion of nutritive compounds.

It is evident from the list of assimilation and destruction of organic matter (fig. 5) that the process of organic matter decomposition prevails over its production. The water of the reservoir Rybnik is well oxidated,

Tabela II. Suma energii słonecznej w zakresie PhAR ($Cal \cdot cm^{-2}$) w dniach pomiarów (x - wartości interpolowane)

Table II. Sum of the solar energy in the range of PhAR ($Cal \cdot cm^{-2}$) in days of measurements (x - interpolated values)

Data Date	$Cal \cdot cm^{-2}$	Data Date	$Cal \cdot cm^{-2}$
13-14.V. 1976	83.5	26-27.I. 1977	22.6
15-16.VI.	177.9	12-13.V.	239.3
25-26.VI.	240.0	24-25.VI.	281.7
9-10.VII.	78.2^x	19-20.VII.	211.2
2- 3.VIII.	186.5	24-25.VIII.	113.6
24-25.VIII.	212.5	6- 7.X.	160.9
14-15.IX.	113.0^x		
13-14.X.	113.2		

this permitting to suppose that these two phenomena are usually balanced. This fact is corroborated by the results of investigations on oxygen content in warmed waters of lakes (Ejsmont-Karabinowa et al. 1975, Sosnowska et al. 1975), rivers (Langford 1971), and also ponds (Grygierek — quoted after H. Soszka and G. J. Soszka 1976).

STRESZCZENIE

Wody zbiornika rybnickiego służą do schładzania urządzeń elektrowni „Rybnik". Zrzuty wody podgrzanej wynoszące 25—33 m^3/sek. powodują podwyższenie się temperatury wody do 15°C wiosną i do 26—28°C latem. Zimą temperatura wody nie spada poniżej 5°C.

Wpływ podwyższenia temperatury wody w zbiorniku rybnickim objawia się wysoką wartością produkcji pierwotnej. Globalna roczna produkcji fitoplanktonu osiągnęła wartość 140—473 g C/m^2 · rok, natomiast dzienna wartość produktywności pierwotnej wynosiła 5,456 g C/m^2 · 24 h.

Czynnikami stymulującymi tak wysoką produkcję pierwotną w badanym zbiorniku są ponadto duża zawartość w wodzie makroskładników biogennych, zwłaszcza fosforu i azotu mineralnego oraz podwyższone stężenie niektórych mikroelementów (Mn, Zn, Co, Ni i Cu).

Zwiększone tempo asymilacji powoduje szybkie wykorzystanie makro- i mikrosubstancji biogennych z wody zbiornika. Zmniejszenie ich ilości rozpoczyna się już wczesną wiosną i trwa do jesieni, niezależnie od stałego dopływu z rzek i powietrza (opady) wód bogatych w substancje troficzne. Przyśpieszony proces rozkładu materii organicznej, jaki ma miejsce w podgrzanej wodzie zbiornika, wyrównuje w pewnym sensie okresowe niedostatki mineralnych składników pokarmowych.

Mimo zwiększonej szybkości mineralizacji materii organicznej i stwierdzonej przewagi destrukcji substancji organicznych nad ich produkcją (ryc. 5) oraz zmniejszenia się rozpuszczalności tlenu w wyższych temperaturach woda zbiornika rybnickiego jest dostatecznie natleniona i nie wykazuje objawów jego zaniku.

REFERENCES

Benndorf J., 1968. Untersuchungen über die Remineralisierung des Phosphors in der Freiwasserregion der Saidenbachtalsperre. Int. Rev. ges. Hydrobiol., 53, 635—650.

Bonerjee S. M., S. C. Bonerjee, 1967. Fertilization of fish ponds with trace elements manganese for increased production of plankton. FAO Fish. Rep., 3, 132—152.

Braune W., R. Uhlemann, 1968. Studien zum Einfluss der Temperature auf Ammonifikation und Nitrifikation im Flusswasser. Int. Rev. ges. Hydrobiol., 53, 453—468.

Cure V., A. Schneider, J. Chiosila, 1971. Variatia capacitatii trofice in functio de unele elemente biogene si microelemente administrate ca ingrasaminte in bazinele piscicole. Bul. Inst. Cerc. Proiec. Piscic., 30, 2, 3—32.

Ejsmont-Karabinowa J., A. Hillbricht-Ilkowska, A. Karabin, T. Węglańska, B. Zdanowski, 1975. Wpływ wieloletnich i przestrzennych zmian reżimu termicznego na produkcję pierwotną i wtórną planktonu jezior włączonych w system chłodzący. Symp. RWPG „Badania wpływu wód podgrzanych na stosunki termiczne i biologiczne zbiorników wodnych". Warszawa.

Just J., W. Hermanowicz, 1955. Fizyczne i chemiczne badania wody do picia i potrzeb gospodarczych. Warszawa, PZWL.

Konenko A. D., S. J. Abremskaja, 1971. Vlijanie teploobmennych vod na gidrochimiceskij i sanitarnyj reżim nekotorych vodoemov — ochladitelej teplovych elektrostancij Ukrainy. Simp. po vlijaniju podogretych vod, Borok, 30—232.

Koschel R., Primär Produktionsuntersuchungen im Stechlinsee. Limnologica (Berlin), 9, 143—156.

Langford T. E., 1971. The distribution, abundance and life-histories of stoneflies *(Plecoptera)* and mayflies *(Ephemeroptera)* in a British river, warmed by cooling--water from a power station. Hydrobiologia, 38, 339—377.

Mackereth F. J. H., 1953. Phosphorus utilization by *Asterionella formosa* Hass. J. exp. Bot., 4, 296—313.

Müller W., 1966. Helldunkelflaschen — Sauerstoffmethode. Limnologica (Berlin), 4, 281—290.

Pasternak K., 1976. Mikroelementy. (in — K. Starmach, S. Wróbel, K. Pasternak: Hydrobiologia, limnologia. Warszawa, PWN), 161—175.

Pidgajko M. L., T. A. Vinogradskaja, V. Grin, L. G. Lentschina, M. F. Polyvannaja, O. A. Sergeeva, Z. A. Kititsyna, 1970. Biological productivity of the Kurakhov station cooling reservoir. Prel. Pap. UNESCO IBP Sym. on productivity problems of fresh water Kazimierz Dolny, 2, 358—364.

Rotovskaja V. S., E. M. Porochonskaja, S. M. Pančenko, T. G. Litvinowa, 1971. Vlijanie mikroelementov na vodnye organizmy i ryboproduktivnost prudov. Ryb. Choz. Kiev, 13, 87—90.

SCOR-UNESCO, 1964. Report of SCOR-UNESCO Working Group 17 on "Determination of photosynthetic pigments" (Mimeogr.), Sydney.

Sosnowska J., B. Zdanowski, A. Korycka, 1975. Zmiany w chemizmie i produkcji pierwotnej pelagialu podgrzanych jezior konińskich. Symp. RWPG „Badania wpływu wód podgrzanych na stosunki termiczne i biologiczne zbiorników wodnych. Warszawa.

Soszka H., G. J. Soszka, 1976. Reakcja biocenoz na podgrzanie wody. Wiad. Ekol., 117—135.

Stuart T. I., J. H. Stanford, 1978. A case of thermal pollution limited primary productivity in a southwestern U.S.A. reservoir. Hydrobiol., 58, 199—211.

Stumm W., 1964. Diskusionbeitrag zu G. A. Rühlich: methods for removal of phosphorus and nitrogen from sewage plant effluents. Advanc. Wat. Pollut. Res., 2, 216—230.

Vinberg G. G., 1961. Production primaire du plancton lacustre, étudiée à l'aide de trois mèthodes: d'oxygène, du carbon radioactiv et de la chlorophylle. Verh. Internat. Verein. Limnol. 14, 109—112.

Adresy autorów — Authors' addresses

prof. dr hab. Kazimierz Pasternak

Zakład Biologii Wód, Polska Akademia Nauk, ul. Sławkowska 17, 31-016 Kraków

dr inż. Henryk Kasza

Zakład Biologii Wód, Polska Akademia Nauk, Stacja Hydrobiologiczna w Goczałkowicach, 43-230 Pszczyna-Goczałkowice

ERRATA

Strona Page	Wiersz — Line od góry from above	Wiersz — Line od dołu from below	Zamiast Instead of	Powinno być Ought to be
303		5	Cyprino-donte	Cyprinoidonte
310		3	N-NOL$_2$/l).	N-NO$_3$/l),
321	43			V o l l e n w e i d e r R. A., 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. DAS (CSI), 68, 27. V o l l e n w e i d e r R. A., 1969. Primary production in aquatic environments. IBP Handbook, 12. W r ó b e l S., 1962. Wpływ nawożenia azotowo-fosforowego na skład chemiczny wody, produkcję pierwotną fitoplanktonu i przyrosty ryb w stawach — Einfluss der Stickstoff-Phosphordüngung auf die chemische Zusammensetzung des Wassers, auf die Primärproduktion des Phytoplanktons und auf den Fischzuwachs in Teichen. Acta Hydrobiol., 4, 151—204.