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BAZYLI CZECZUGA

Próba ujęcia stosunków ilościowych i produkcji biomasy bakterioplanktonu — An attempt at establishing the production and numerical relations of bacterioplankton biomass

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Plants and animals dying in a water reservoir, as well as other organic substances, are subject to mineralisation. Bacteria play a decisive role in the mineralisation of organic substance, enriching the reservoirs, by means of decomposition of organic matter, in nourishing salts, to the profit of producers. The role of bacteria in a water reservoir cannot be limited to the mineralisation of organic substance as they appear not only as reducers but are also food for organisms. It was observed in the investigations of Gorbunov (1946), Rodina (1949, 1951, 1954, 1958), Žukova (1954, 1957, 1957 a), Kožova (1956), Edmondson (1957), Novožylowa (1958) and Manuilova (1958) that the importance of bacteria as nourishment for aquatic invertebrates is equal to that of phytoplankton. Investigations on bacteria dynamics in individual water reservoirs are therefore very important, not only from the point of view of theoretical hydrobiology, but also from that of fishery (Starmach 1959).

The method of calculating the amount of bacteria in a water reservoir is of great importance for the adequate assessment of bacteria dynamics. The research work undertaken by Razumov (1932) and Bere (1933) demonstrated that the number of bacteria calculated by sowing on suitable culture media does not correspond to the actual amount. The use a direct method of calculation permits a more exact assessment of numerical relations. The amount of bacteria calculated by means of sowing is often only a hundredth or even a thousandth part of the number calculated by using a direct microscopical method. This is also confirmed by the investigations of Salimovskaja-Rodina (1938), Daubner (1956), Pokorny (1957) and Gambarjan (1957) and Jannasch and Galeny (1959).

The direct method of calculating the amount of bacteria initiated by Cholodny (1928, 1929) and expanded by Razumov (1932) has at present many supporters. The direct counting of bacteria under the microscope allows us to assess the part taken by bacterial biomass in the output of a water reservoir, to calculate the intensity of reproduction of bacteria etc.

The amount of bacteria determined at the moment of sampling represents the resultant of two opposite processes: the incessant reproduction of bacteria and their devouring by the zooplankton. As rezults from the above, the problem of these two processes, in opposition to each other and enabling us to calculate the production of bacterioplankton biomass, is very important. It can also furnish orientative indications as to the rate of mineralisation of organic substance in investigated reservoirs.

It is not the aim of this work to present a detailed numerical description of separate physiological groups of bacteria. The author wishes to give a general quantitative estimate of bacterioplankton at various levels of the Rajgród lakes in different seasons of the year.

Method

The investigations were carried out in the winter, spring, summer, and autumn of 1959. Samples of water were collected in about the deepest places of the Dręstwo lake, near the village of Dręstwo, and in the Rajgrodzkie lake in the northerh part of the Rajgród bay, near the small town of Rajgród, at intervals of several meters, from the surface to the bottom of the lake. The water was collected by means of a Ruttner batometer into small sterilised bottles with tight-fitting stoppers, with a 255—260 ml capacity. 5% formalin was immediately added, the stopper covered with paraffin and topped with a cap. The samples were then sent to the laboratory, where 10 ml of water from each bottle was thrice filtrated through No 3 membrane filters (made in the USSR). Bacteria on the membrane filters were stained with 5% erythrosin solution in 5% phenol solution and counted by the method of direct calculation filters (Razumov 1932) under immersion, magnified 900 ×.

To determine the intensity of bacteria reproduction the method worked out by Razumov (1948) was applied. A sample of water collected from the trophogenic stratum of the lake was filtrated trough a No 0 sterilised membrane filter in order to separate the plankton. Small bottles were then filled with the filtrated water. Special care was taken to ensure that the bottles were of equal size (225—260 ml), so as to prevent the phenomenon observed by Zo Bell and Anderson (1936) (bacteria reproduce themselves more rapidly in smaller bottles).

String was attached to the bottles and they were let down to the same depth as that from which the samples had been taken. At the beginning and at the end of the experiment the amount of bacteria was determined by means of the method described above. The experiments lasted from 8 to 19,5 hours. The intensity of reproduction of bacteria was calculated by means of the formula:

$$G = \frac{t \lg 2}{\lg B - \lg b}$$

(G — time in which the amount of bacteria was doubled; t — hours of duration of the experiment; B — amount of bacteria at the end of the experiment (water filtered through the filter No 0); b — amount of bacteria at the beginning of the experiment).

Simultaneously the production of bacterial biomass per 24 hours was calculated. When bottles with water filtrated througt the No 0 filter were placed in the lake (to calculate reproduction intensity), bottles of the same capacity filled with non-filtrated water, taken direct from the lake, were also placed at the same depth from which the water had been taken. This made it possible to count the amount of bacteria devoured by zooplankton. Production of the biomass of bacteria in 24 hours (P) was calculated according to the formula of Ivanov (1955):

$$P = \left(\frac{b}{G} + \frac{b - B}{t}\right) \cdot 24$$

(B — amount of bacteria at the end of the experiment non-filtered water).

In order to calculate the biomass of bacteria 100 spherical and 100 club-shaped bacteria from each of the lakes were measured. They were compared with corresponding geometrical figures (sphere and cylinder) and their volume was calculated. The specific weight of the bacteria was fixed at 1.028 (Zo Bell 1946). Samples of water for determining the chlorophyll content were collected from the same place, which made it possible to judge the phytoplankton dynamics. Having data concerning the intensity of reproduction of bacteria, the biomass, and the relation of 24 hours production to the biomass, the amount of organic substance subject to mineralisation can be counted. When calculating this index the formula of Ierusalimskij (Kriss 1959) was employad:

$$P = (a.\,m.\,c.) + (b.\,m.)$$

(P — amount of organic substance subject to complete mineralisation; a — trophic coefficient, i. e. the consumption of energetic material in the form of organic matter and the increase of the biomass of bacteria; b — coefficient of fundamental metabolism, i. e. the consumption of energetic material in the shape of organic matter for the needs of „fundamental" („basic") metabolism in 24 hours; m — biomass of bacteria (dry weight); c — 24 hours coefficient P/B).

On the basis of data obtained by Vinberg (1946) it was considered, that a = 3, b = 0,5 in 24 hours, as did Kriss (1959). The amount of chlorophyll in the phytoplankton of investigated lakes was determined by means of the method of V i n b e r g and S i v k o (1953).

General amount of bacteria in different seasons and on different water levels in the investigated lakes

As has already been mentioned previously (C z e c z u g a 1958, 1959, 1959 a, 1960 a) the Rajgród lakes are of different types from the point of view of production of organic substance. The Białe lake is mesotrophic, resembling even the group of oligotrophic lakes (in comparison with the remaining Rajgród lakes), while the Rajgrodzkie lake and the Dręstwo lake belong to the mesotrophic type. The Krzywe lake abounds in organic substance and may be considered as belonging to the group of eutrophic lakes while the Ślepe lake, gradually covered by vegetation, with water containing large amount of humus compounds may be classed as a dystrophic lake.

The Białe lake: The greatest amount of bacteria was found in the month of February, when the lake was still with ice (Tab. I). At this time most of the bacteria gathered immediately under the ice cover and in the bottom strata. In spring, however, the number of bacteria diminished to 549 thousand in 1 ml of water on the average, at a maximum depth of 10 m. In summer the total amount of bacteria is slightly lower than in the winter period. In a vertical disposition of bacteria the smallest number was found in the metalimnion, the largest in strata near the bottom. In autumn, the mean amount of bacteria was nearly as large as in the spring period, the smallest number being in the surface stratum and the largest in strata near the bottom.

The Rajgrodzkie lake: Numerical differences of bacteria in different seasons in this lake (Tab. I) resemble those of the Białe lake. The greatest amount of bacteria was found in February and towards the end of August and the smallest in November and April. In the autumn and winter periods, in a vertical disposition, the amount of bacteria augments from the surface of the lake to the stratum near the bottom. In spring, however, the strata near the bottom and those near the surface contain a smaller amount of bacteria than the central ones (5—15 m). A characteristic trait of the vertical disposition of bacteria in the third decade of August was that the smallest amount was found in the metalimnion, in comparison with that of the epi- and hypolimnion. This confirms a previous statement by the author (C z e c z u g a 1959 b) that bacteria in the Rajgrodzkie lake do not cause an oxygen minimum as K u z n i e c o v (1952) observed in the Glubokoe lake. The maximum amount of bacteria was found in the bottom stratum.

The Dręstwo lake: A somewhat different type of quantitative

Tab I

Amount of bacterioplankton (in thousands/ml) at different depths and its biomass in Rajgród lakes

	Lake / Depth in m	Białe				Rajgrodzkie				Dręstwo				Krzywe				Ślepe			
		Winter 10.II.	Spring 25.IV.	Summer 28.VIII	Autumn 29.IX.	Winter 11.II.	Spring 27.IV.	Summer 28.VIII	Autumn 29.IX.	Winter 11.II.	Spring 29.IV.	Summer 26.VIII	Autumn 28.IX.	Winter 10.II.	Spring 28.IV.	Summer 28.VIII	Autumn 29.IX.	Winter 10.II.	Spring 28.IV.	Summer 28.VIII	Autumn 29.XI.
Amount of bacterioplankton	0	1730,0	361,1	878,2	392,6	1460,0	1000,9	1360,0	714,4	1499,4	996,8	572,0	1683,9	2588,4	1146,0	2419,0	1028,2	2818,2	1530,8	785,0	1373,8
	0,75	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2512,0	1530,9	910,6	1424,8
	3	—	—	—	—	—	—	—	—	—	—	—	—	2653,4	1189,4	2537,6	1330,6	—	—	—	—
	5	1420,8	596,5	895,0	486,7	1456,2	1130,5	1338,4	761,5	1495,5	1106,9	934,1	1636,7	—	—	—	—	—	—	—	—
	6	—	—	—	—	—	—	—	—	—	—	—	—	1644,6	1216,8	2622,0	1511,1	—	—	—	—
	10	1405,8	773,3	1369,1	798,6	1577,0	1114,7	1379,8	828,6	1727,1	1236,4	961,5	1680,0	—	—	—	—	—	—	—	—
	12,5	—	—	726,2	—	—	—	1118,6	—	—	—	—	—	—	—	—	—	—	—	—	—
	15	1480,0	494,5	1307,0	781,1	1715,5	1165,7	1491,5	891,0	—	—	—	—	—	—	—	—	—	—	—	—
	20	1500,0	521,9	1534,7	743,5	1797,6	1040,3	1178,0	887,0	—	—	—	—	—	—	—	—	—	—	—	—
	25	1520,0	—	1789,9	832,1	2051,2	930,2	2319,7	879,2	—	—	—	—	—	—	—	—	—	—	—	—
	27	—	—	—	—	2782,8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	average	1509,4	549,5	1214,3	672,4	1834,3	1063,7	1455,1	826,9	1574,0	1113,4	822,5	1666,9	2295,5	1184,1	2526,2	1289,9	2665,1	1530,8	847,8	1399,3
Biomass	0	408	110	215	91	363	246	355	173	333	230	155	366	625	273	595	249	1139	619	346	546
	0,75	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1016	619	401	567
	3	—	—	—	—	—	—	—	—	—	—	—	—	633	284	625	322	—	—	—	—
	5	335	178	219	113	352	278	349	184	332	256	253	356	—	—	—	—	—	—	—	—
	6	—	—	—	—	—	—	—	—	—	—	—	—	394	290	645	366	—	—	—	—
	10	330	226	335	186	381	291	360	201	363	286	260	366	—	—	—	—	—	—	—	—
	12,5	—	—	177	—	—	—	291	—	—	—	—	—	—	—	—	—	—	—	—	—
	15	339	150	320	181	414	304	390	216	—	—	—	—	—	—	—	—	—	—	—	—
	20	354	158	376	172	434	271	307	214	—	—	—	—	—	—	—	—	—	—	—	—
	25	355	—	439	192	496	243	606	212	—	—	—	—	—	—	—	—	—	—	—	—
	27	—	—	—	—	672	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	average	353,5	164,4	297,3	156,0	444,5	272,0	379,7	200,0	342,7	257,3	222,6	362,7	550,7	282,3	621,7	312,3	1077,5	619,0	373,5	556,5

differences of bacteria appeared here (Tab. I). Maximum quantities of bacteria are visible in autumn (November) and in winter (February) there being slightly less in spring and the least in summer. Nearly everywhere the amount of bacteria is geater in the bottom stratum.

The Krzywe lake: Seasonal variances in the amount of bacteria in this lake (Tab. I) have a similar course to those of the Białe and the Rajgrodzkie lakes. The greatest amount appears in winter and summer, the smallest in autumn and spring. A smaller quantity of bacteria was found in the bottom stratum of water in the month of February. Samples of water from this depth contained less chlorophyll, but a considerable amount of zooplankton — especially of *Eudiaptomus graciloides* (Czeczuga 1960). It might be conjectured that the above phenomenon depends on the devouring of bacteria and phytoplankton by this small crustacean, which is known as a good filtrator. In the remaining seasons of the year the amount of bacteria increases from the surface towards the bottom strata.

The Ślepe lake: In this lake, the smallest amount of bacteria during the season appeared towards the end of August, the largest in winter.

Tab. II

Mean amount of bacterioplankton in Rajgród lakes (thousands/ml)

Lake	Number of bacteria
Białe	986,4
Rajgrodzkie	1295,0
Dręstwo	1294,4
Krzywe	1823,9
Ślepe	1610,7

A comparison of average numbers of bacteria in 1 ml of water (Tab. II) shows that the smallest amount appears in the Białe lake and largest in the eutrophic Krzywe lake. As compared with data presented by other authors (Kuzniecov 1952, Belackaja 1959) they closely resemble those for particular types of lakes.

As would from the data of Kuzniecov (1952), the maximum amount of bacteria in reservoirs can be observed in most cases at the end of the summer stagnation or in the period of autumn circulation and the minimum during the winter. The results obtained for the Rajgród lakes do not correspond on the average to those of Kuzniecov. This discrepancy by no means indicates that during the winter period the smallest amount of bacterioplankton appears in the Rajgród lakes, as a very great number of bacteria was found in winter. This phenomenon can be explained by specific meteorological conditions. In 1958, the biological summer extented to the autumnal period of the calendar as the results of a very warm autumn which, in turn, encroached upon the winter period. The Rajgród lakes were ice-bound as late as January

1959. Up to the time when the water in the lakes was frozen, rainwater flowing in from the fields brought organic substance, which in turn caused a mass development of bacterioplankton during the winter period. It may be seen, therefore, that meteorological conditions have a considerable though indirect influence on the amount of bacterioplankton in water reservoirs.

Quantitative relations of bacteria and phytoplankton

Some authors are inclined to consider that with the increase of phytoplankton in a water reservoir the total amount of bacteria is raised (Waksman et al. 1933, 1937, Zo Bell 1946, Kriss and Rukina 1952, Guseva 1951, Kuzniecov 1954, 1957, Kožova 1956, Kurasava 1959). Others maintain that phytoplankton, and principally blue-green algae, inhibit the intensity of reproduction of bacteria in water reservoirs (Razumov 1948, Novožylova 1957, Manuilova 1959). This ist also mentioned by Lefevre (1958). In connection with this the present author wished to observe the relations existing at different seasons in the investigated lakes between the phytoplankton and the number of bacteria. No simple dependence between the amount of chlorophyll and that of bacterioplankton, as results from Fig. 1, ABCD can be perceived. Ruban (1959) observed a similar phenomenon in the sea. In all the investigated lakes, with the exception of Ślepe lake, the number of bacteria was considerable in the winter period, in spite of a small amount of chlorophyll. The same was observed in spring in the Ślepe lake. In spring an inverse relation can be observed in the remaining lakes, i.e. far fewer bacteria and more chlorophyll. The relation between the amount of phytoplankton and that of bacteria existing in a given season is subject to change at different depths, i.e. as the amount of phytoplankton rises the number of bacteria increases, and vice versa (Fig. 1, ACD). This cannot be stated in the case of the Rajgrodzkie lake in the winter and spring period. It must be stressed that, in spite of a large quantity of blue-green algae in the summer period, no smaller amount of bacteria was found, although the intensity of reproduction in this lake is very low in general.

When analysing the relation of bacteria to phytoplankton, as of one producer to another, the necessity of a simple dependence becomes comprehensible. It must be remembered, however, that the organic substance necessary for the life of bacteria is not produced only by phytoplankton. A considerable part of organic substance is brougt to the lake by water trickling down from adjacent fields or derives from the decomposition of higher vegetation and from phytoplankton. About one half of the organic substance existing in water may appear in a dissolved form (Krogh and Lange 1932).

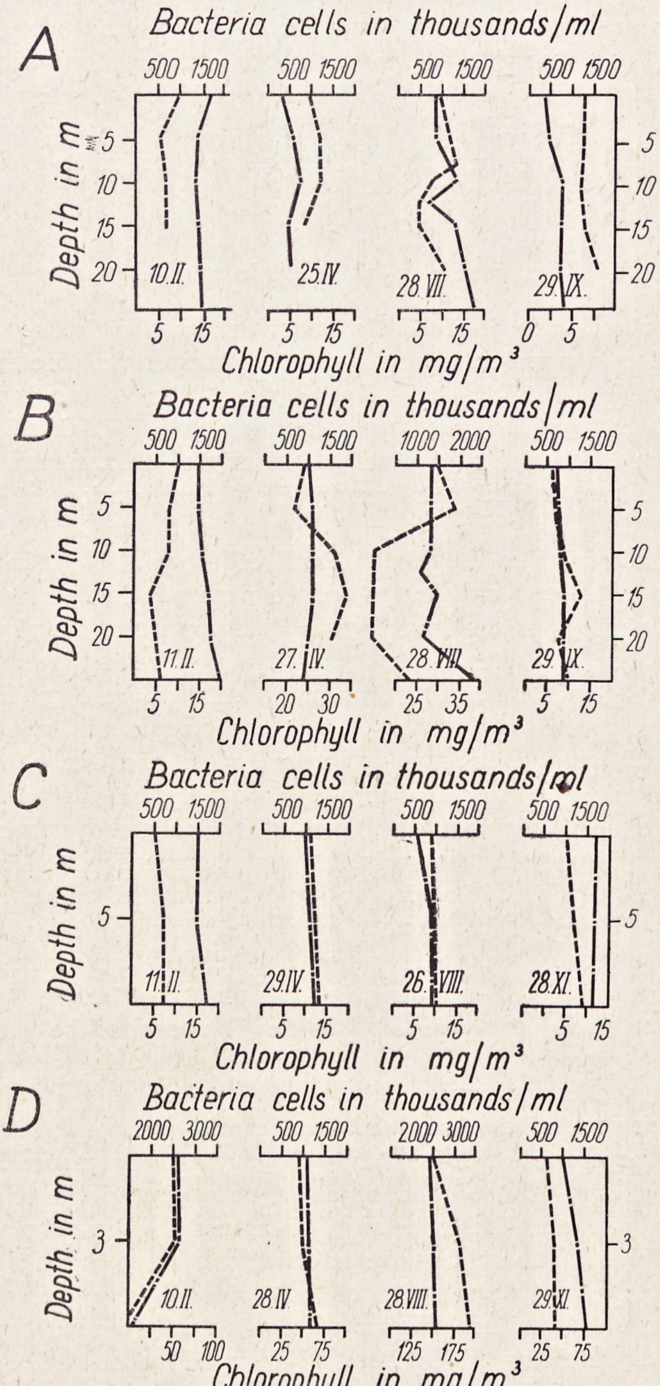

Fig. 1. Amount of bacteria and chlorophyll at different depths of the lakes: Białe (A), Rajgrodzkie (B), Dręstwo (C), Krzywe (D). ——— bacterioplankton; — — — chlorophyll,

In seas and oceans, where this kind of imported material is of lesser importance, the maximum amount of bacteria concentrates in strata in which photosynthesis takes place (Zo Bell 1946, Kriss 1959). A similar phenomenon can be observed in oligotrophic lakes, such as Sevanga (Gockha) (Gambarjan 1957) and Baikal (Kuzniecov 1957). Phytoplankton must undoubtelly be considered as the source of organic substance on which depend the dynamics of phytoplankton in water reservoirs. The percentage of organic substance deriving from phytoplankton is, however, liable to fluctuations in the lakes in the space of a year, which renders more difficult a confirmation of the interdependence of phytoplankton and bacterioplankton. This concerns in the first place water reservoirs with a greater productivity.

Bacterioplankton biomass

For the calculation of the bacterioplankton biomass the cubage of cells of differently shaped bacteria must be known. As spherical and cylindrical shapes of bacteria cells dominate in the lakes, Tab. III presents their cubage, which in the two kinds, club-shaped and cylindrical, is about the same in most of the investigated lakes, however, this cubage is much larger for bacteria from the Ślepe lake. The subage of bacteria cells varies in different water reservoirs (Tab. III) and this must be considered when comparing bacterioplankton biomass from different sources.

Tab. III

Volume of bacteria cells in Rajgród lakes and other water reservoirs (in μ^3)

Reservoir	Cubage of goblet cells	Cubage of spherical bacteris	Author	
Białe	0,652	0,200		
Rajgrodzkie	0,610	0,222		
Dręstwo	0,642	0,200		
Krzywe	0,609	0,219		
Ślepe	0,710	0,388		
Various USSR lakes	1,6 *)		Kuzniecov	1954
" "	1,0 *)		Ivanov	1955
Baikal	1,2-1,5	0,5-4,0	Kožova	1956
Sevanga (Gokcha)	2,35	0,52	Gambarjan	1957
„Šemetovo" ponds		0,278	Belackaja	1958
Narocz	1,422	0,353	"	1958 a
Batorin	1,752	1,046	"	" "
Miastro	0,981	0,374	"	" "
Azov Sea: Spring	1,10	0,16	Žukova	1959
Summer	0,88	0,10	"	"

*) volume of goblet + spherical cell.

Ž u k o v a (1959) observed considerable fluctuations in the size of bacteria cells in the Azov Sea at different seasons. In the Rajgród lakes, however, no difference in the size of cells was found in the course of a year. A no less important question, on which the size of the bacteria biomass depends, is the amount of spherical and cylindrical bacteria. Spherical bacteria usually dominanted in the investigated lakes (Tab. IV), the least number of them appearing in spring in the waters of the Białe lake, while the largest amount was found in autcmn in the Ślepe lake.

Tab. IV

Percentage of spherical bacterioplankton cells in Rajgród lakes at different seasons

Lake	Winter	Spring	Summer	Autumn
Białe	92,0	77,0	90,0	93,0
Rajgrodzkie	95,0	94,0	90,0	95,0
Dręstwo	95,0	93,0	84,0	96,0
Krzywe	95,0	95,0	93,0	94,0
Ślepe	95,0	95,0	84,0	97,0

The greatest bacterioplankton biomass was observed in the winter season in the Białe lake (353,5 mg/m^3; Tab. I) and the smallest in autumn (156,0 mg/m^3 on the average). Changes of a similar type in the biomass were observed in the Rajgrodzkie lake, mean numbers for bacterioplankton biomass in this lake being somewhat higher. In the Dręstwo lake the maximum bacterioplankton biomass appears in autumn (363 mg/m^3) and in winter (343 mg/m^3) whereas in the Krzywe lake it appears in summer (622 mg/m^3) and in winter (551 mg/m^3). The greatest bacterioplankton biomass was found in the Ślepe lake during the winter period (1078 mg/m^3), and amounted to over 1 g in a m^3 of water (in some lakes bacterial biomass reaches even 10544 mg/m^3 (B e l a c k a j a 1958)).

In the most productive Azov Sea the maximum biomass amounts to 76 mg/m^3 (Ž u k o v a 1959). In the oligotrophic Sevanga lake (Armenia) fluctuations of biomass from 56 mg/m^3 to 1442 mg/m^3 were observed by G a m b a r j a n (1957) in November.

Intensity of multiplication and production of bacteria

Intensity of reproduction and bacterial biomass production the accurate determination of bacterioplankton biomass in water reservoirs does not give a true picture of the dynamics of living organic matter in the shape of bacterial cells if we do not posses data concerning the rate of reproduction of the bacteria in the actual conditions of a given reservoir.

There are but works dealing with this problem in individual water reservoirs. Among rtese are the works of K r i s s et al. (1952, 1954), Ierusalimskij (1954), Kriss and Markianovič (1954), and also Razumov (1948), Ivanov (1954, 1955), Novožilova (1955, 1957), Belackaja (1958 a) and Kuzniecov (1954).

The paper of Ierusalimskij (1954) and Kriss et al. (1954, 1955) are based on a method consisting in placing, for a definite period, in a lake or in the sea, glass plates on which the number of bacteria is calculated. The drawback in this method consists in the fact that it does not ascertain the amount of bacteria devoured by the zooplankton (Ivanov 1954, Jegorova 1954). Winberg and Jarovicyna (1946) observed that about 13% and, after 24 hours, only 8,8% of bacteria living in the water settle on the glass plates. A certain part of the bacteria attached to the plates can be washed off with water (Krasilnikov 1959). The metod worked out by Razumov (1948) permits a more accurate determination of the rate of reproduction of bacteria in water reservoirs, although it provokes some objections from scientists who consider that a certain isolation of the water contained in bottles may activate or inhibit the rate of reproduction of bacteria. When comparing the amount of bacteria in non-isolated water and in water isolated in bottles up to 20 hours at a temperature of 20—22 °C and in a temperature of 5° (Czeczuga 1960 b) in different lakes (in spite of insignificant deviations in individual cases) it can be seen that the number of bacteria in general in open, non-isolated water amounts to 1546 thousand in 1 ml of water, and 1597 thousand per 1 ml in isolated water. As results from the above, the amount of bacteria in water isolated in bottles increases only by 3%, which does not exceed the limit of error of this method. A method based on the isolation of water in bottles showed not, therefore provoke, an, special objections. Belackaja (1958 a) is of the same opinion and came to the conclusion, after comparing different methods for determining the rate of reproduction of bacteria, that the method of isolating water in bottles is simple and accurate. It would seem to answer the requirements of determining bacterioplankton dynamics in water reservoirs.

The intensity of reproduction and the biomass production of bacteria in the investigated lakes during August and November 1959 is presented in Tab. V. In the Białe lake the time needed for doubling the amount of bacteria was 97,6 hours on the average in summer, while it was nearly twice as short in autumn. The production of bacterioplankton biomass per 24 hours was also larger in this lake in the autumn period, i.e. 58 mg/m^3 in August and 121 mg/m^3 in autumn. The relation of production to biomass (coefficient P/B per 24 hours) amounts to a mean of 0,25 on August 28, while it is 0,34 in November. The same was observed in the Rajgrodzkie lake. Bacteria reproduce themselves with a greater intensity in the autumn period than during summer (August 27). In the photic zone of the Rajgrodzkie lake a double amount of bacteria was

Tab. V

Intensity of reproduction and bacterioplankton production in Rajgród lakes

Lake	Date	Temperature of water in °C	Duration of experiment in hours	Amount of bacteria in 1 ml of water (thousands): Beginning of experiment	End of experiment: Water filtrated through No 0 filtre	End of experiment: Non-filtrated water	Time of doubling of bacteria amount in hours	24 h. production: Amount of cells in 1 ml of water (thousands)	24 h. production: Biomass g/m³	24 hours coefficient P/B
Białe	28.VIII.	23,0	15,5	1000,8	1142,0	926,3	81,4	410,2	100,6	0,41
		22,5	15,5	836,0	942,0	863,5	90,0	180,4	45,5	0,21
		23,0	15,5	887,0	969,5	922,4	121,5	120,0	29,9	0,14
						mean	97,6	236,8	58,7	0,25
	20.XI.	5,0	14	1420,8	1809,5	1577,0	40,2	580,6	138,2	0,41
		5,0	14	1504,8	1762,4	1593,5	61,5	435,2	102,8	0,28
		5,0	14	1605,4	1868,3	1652,5	63,8	523,0	124,5	0,32
						mean	55,2	512,9	121,8	0,34
Rajgrodzkie	27.VIII.	22,0	19,5	1220,6	1640,6	1220,7	45,7	640,0	171,5	0,52
		21,8	19,5	1338,4	1665,8	1433,8	62,0	400,5	107,4	0,30
		22,0	19,5	1436,6	1942,8	981,3	45,0	1326,8	355,7	0,92
						mean	50,9	789,1	211,5	0,58
	20.XI.	5,0	14	1460,1	2001,0	1668,1	30,8	781,2	193,8	0,53
		5,0	14	1390,6	1947,0	1711,3	28,8	608,6	151,0	0,44
		5,0	14	1413,1	1923,3	1770,2	31,5	464,6	115,3	0,32
						mean	30,4	618,1	153,4	0,43
Dręstwo	26.VIII.	24,0	10	578,0	1197,0	1087,0	9,5	238,5	66,4	0,41
		24,0	10	573,0	1645,0	864,0	6,6	1385,0	385,4	2,42
		24,0	10	687,0	1837,0	824.0	7,0	2026,5	548,2	2,94
	27.VIII.	22,0	12	1177,0	2583,0	1154,0	10,6	2710,5	733,8	2,30
		22,0	12	1010,0	3042,0	1064,0	7,5	3124,0	823,9	3,09
		22,0	12	1123,0	2834,0	1197,0	9,0	2846,8	792,3	2,53
						mean	8,3	2055,2	570,0	2,28
	19.XI.	5,0	16	1605,0	2280,0	1606,0	31,6	1217,5	293,0	0,76
		5,0	16	1593,0	2273,0	1642,0	31,2	1152,0	250,7	0,72
		5,0	16	1625,0	2312,0	1670,0	31,4	1174,5	262,8	0,72
						mean	31,4	1181,3	268,8	0,73
Krzywe	28.VIII.	23,0	15,5	2190,2	3372,0	2249,0	25,0	2011	509,3	0,91
		22,0	15,5	2209,8	2934,0	1891,5	38,0	1888	478,0	0,82
		23,0	15,5	2159,0	2808,0	2088,0	40,8	1380	339,9	0,64
						mean	34,6	1747,6	442,4	0,79
	20.XI.	5,0	14	2213,0	2531,0	2217,7	72,3	727,2	181.2	0,33
		5,0	14	2268,0	2515,0	2406,0	93,6	344,8	85,9	0,15
		5,0	14	2178,4	2570,0	2170,6	58,6	809,7	201,8	0,37
						mean	74,8	627,2	156,3	0,28
Ślepe	28.VIII.	23,0	8	172,7	816,0	320	3,5	742,0	335,3	4,3
		23,0	8	375,0	832,0	350	6,9	1379,2	623,2	3,7
		23,0	8	482,0	1030,0	370	7,3	1620,0	731,9	3,3
						mean	5,9	1247,1	563,5	3,8
	20.XI.	5,2	14	2559,1	2920,0	2472,8	73,4	984,5	402,3	0,38
		5,2	14	2514,0	2977,3	2456,4	57,4	1149,8	470,0	0,46
		5,2	14	2614,0	2900,0	2535,6	93,4	806,1	329,5	0,30
						mean	74,7	980,1	400,6	0,38

attained in 50,9 hours, but in autumn (November 20) only 30 hours were needed. Bacterioplankton biomass production and the 24 hour coefficient P/B are lower during the autumn period than in August. Other values were observed in the Dręstwo lake. In August the period of doubling of the amount of bacteria lasted 8,3 hours on the average, but in November it took 31 hours. Biomass production in August attained 0,5 g in 1 m³ and 268,8 mg/m³ in November. In summer biomass production is twice as large as its initial amount (P/B = 2,28), while in November the production is only one half of the initial biomass.

In the Krzywe lake bacteria reproduce themselves much more intensively in August than in November. Biomass production is also greater in summer (442 mg/m³) than in autumn (156 mg/m³). The coefficient of production per 24 hours to biomass is higher in the summer period than in the autumn.

The intensity of bacteria reproduction in the Ślepe lake in August is the most considerable in comparison with other lakes.

Data obtained by means of calculation indicate that biomass production in 24 h. (August) amounts to 1247,1 thousand cells in 1 ml of water, corresponding to 563,5 mg/m³. The P/B coefficient for 24 h. amounts to 3,8. As results from the above, the production of biomass of bacteria increases nearly four times in 24 h. when compared with its initial amount. In the autumn period (November 20), although the total number of bacteria augments, the intensity of reproduction is considerably lower (74,7 hours). Biomass production amounts to 400 mg/m³, scarcely 0,38 of the actual biomass.

When comparing the obtained results concerning the intensity of reproduction of bacteria in the Rajgród lakes, which are different types, reproduction of bacteria takes place in the Białe lake, which is similar in type to oligotrophic lakes (97,6 h.). It must be remembered that Ivanov (1955) as a results of his investigations stated that in the oligotrophic Baikal lake (water temperature 7,50) the time necessary for doubling the amount is 218 hours, whereas it is 78 hours in the mesotrophic Glubokoe lake. Belackaja (1959) in her report states that in Narocz lake (which, as far as primary production and transparency are concerned, resembles most the Białe lake) the time when the number of bacteria doubled varied within the limits of 61,2 to 103,4 hours. (The present author observed in the Białe lake 40,2 to 121,5 hours). These results are therefore very similar. In the Rajgrodzkie lake, a reservoir more productive than the Białe lake, the intensity of bacteria reproduction in the summer period is greater (45—62 h.). Bacteria reproduce themselves with the greatest intensity in the mesotrophic Dręstwo lake and in the dystrophic Ślepe lake. In the Krzywe lake, however, in which phytoplankton is very abundant (Czeczuga 1958, 1959, 1959 a) the intensity of reproduction of bacteria is rather low, being smaller than in the mesotrophic Rajgrodzkie lake. This migth be connected with the fact that the principal component of phytoplankton in the Krzywe lake are the bluegreen algae (*Oscillatoria planctonica* Wołosz.) which, according to some authors (Razumov 1948, Novožylova 1957, Manuilova 1959) inhibit the intensity of reproduction bacteria.

The obtained results indicate that in the autumn period (November) indices of the intensity of reproduction of bacteria are similar for all the lakes. In lakes like Białe and Rajgrodzkie develop in autumn with a much greater intensity than in August, in spite of the lower temperature of the water. This could prove that the role of temperature is not decisive in the process of reproduction of bacteria. It would seem, from the data obtained, that the principal factor is the amount of organic substance, as in the degree of succession of the reservoir and the increase of organic substance the intensity of reproduction of bacteria is higher. (The Krzywe lake is an exception).

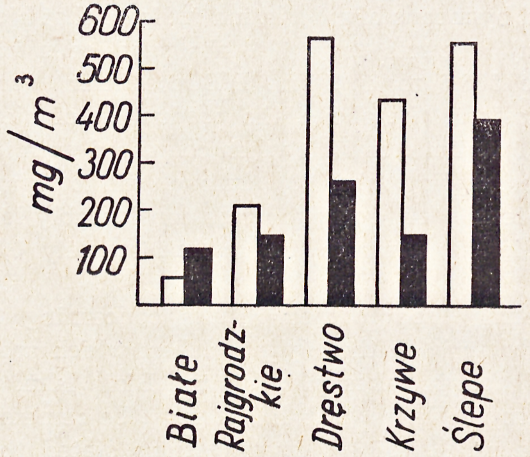

Fig. 2. 24 hours production of some Rajgród lakes
summer period; autumn period;

When comparing the biomass production of phytoplankton (Fig. 2) in the investigated lakes it way be seen that, with the exception of the Krzywe lake and beginning with the Białe lake (similar to the oligotrophic type) and ending with the Ślepe lake, bacterioplankton biomass production increases both in August and in November.

Mineralisation of organic substance by bacterioplankton

In all water reservoirs part of the organic substance formed by producers and also some of the organic substance carried by inflowing water settles on the bottom of the water reservoir in the form of a bottom sediment. Bacteria play a dominant role in the mineralisation of organic substance. Thus S t a r m a c h (1959) is quite right when stating that the principal role on the stage of metabolism in a water reservoir belongs only to producers binding light energy in organic compounds and to reducers liberating this energy. In connection with this, the amount of organic substance in the investigated lakes which, as a result of bacterioplankton activity, undergoes a complete mineralisation, should be computed. The calculations presented above do not include the amount of organic substance subject to mineralisation by bacteria of which the periphyton is partly composed, nor those that remain in the surface layer of the bottom sediment. It is probable that the activity of the latter is much greater than that of bacterioplankton. One of the causes of water reservoirs, that is of succession leading to the disappearance of lakes, is the lack of balance between producers and reducers. As far as the production of organic substances and also their transport from the terrain surrounding the given reservoir is greater than the amount of organic substance subject to mineralisation by bacteria, so is the process of ageing of the reservoir more rapid. This process undoubtedly depends also on numerous other factors not mentioned here.

The amount o fdry organic substance mineralised by bacterioplankton in the Rajgród lakes is presented on Tab. VI.

Tab. VI

Orientative amount of organic substance mineralised by bacterioplankton in the photic zone of investigated lakes (in mg/m^3)

Lake	Dry mass of bacterioplankton mg/m^3		Amount of mineralised dry organic matter	
	August	November	August	November
Białe	25	10	27,5	15,2
Rajgrodzkie	35	18	78,4	32,2
Dręstwo	20	36	147,0	97,0
Krzywe	61	29	175,0	39,0
Ślepe	37	57	440,3	93,5

In the Białe lake, in August as well as in November, the amount of mineralised substance is the smallest in relation to the other Rajgród lakes. In August the amount of mineralised organic substance increases in the measure of succession of the lake and attains its highest index in the dystrophic Ślepe lake (440 mg of dry organic substance per 24 h./m^3). In November, however, mineralisation of organic substance is greatest in the Dręstwo and Ślepe lakes.

Assuming that the month of August the amount of organic substance in the surface stratum of the Rajgrodzkie lake was the same as in 1957 and that the loss after roasting represents the amount of organic substance in this stratum, 1 m^3 of water contains 80 g on the average. The amount of mineralised organic substance in the Rajgrodzkie lake is about 0,1% of the actual state.

A similar percentage of organic matter is subject to mineralisation in the photic zone of the Black Sea, where the amount of organic substance is 7 g/m^3 (K r i s s 1959):

It results from the above that the share of bacterioplankton in the mineralisation of organic substance is very small.

The observations made demonstrate that a study of bacterioplankton, restricted to the summer months, cannot give a complete picture of numerical relations. The greatest amount of bacteria in the Rajgród lakes was found in the winter period. Investigations on bacterioplankton should be carried out not only as to quantity since the rate of reproduction and the production of biomass are also very important factors. The amount of bacteria in a water volume unit may be very small while the intensity of their reproduction is very great and vice versa. Not only the amount of organic matter in the form of bacterial cells, of which the food of invertebrates consists, in of importance — the problem concerning the liberation of nutritional salts for producers of organic matter is more important. Some authors (H a y e s 1955, R i g l e r 1956. H a r r i s 1957, H a y e s and P h i l l i p s 1958) are of the opinion that the function of bacteria in phosphorus rotation in a water reservoir is of great importance. H a y e s and A n t h o n y (1959) even propose that classification of lake productivity should be made on the basis of the numerical relations of bacteria in the bottom sediments of these water reservoirs. Undoubtedly microscopical studies will make possible a better definition of metabolism in a water reservoir and will thus help in establishing a classification of the lakes. When comparing the amount of bacterioplankton biomass production in different water reservoirs attention should be paid to the volume of bacteria cells, as their dimensions are apt to differ and can change even when the amount of bacterioplankton in the same. If this problem is oberlooked, great differences in the size of the produced bacterioplankton biomass and the amount of mineralised organic substance may arise.

STRESZCZENIE

Autor badał stosunki ilościowe oraz intensywność rozmnażania się, a także produkcję biomasy bakterioplanktonu jezior Rajgrodzkich w różnych porach 1959 roku. Ilość bakterioplanktonu obliczano na sączkach membranowych nr 3 metodą R a z u m o v a (1932), a przy obliczaniu intensywności rozmnażania się bakterioplanktonu zastosowano metodę opracowaną również przez R a z u m o v a (1948). Produkcję biomasy bakterioplanktonu w ciągu doby obliczano wg metody I v a n o v a (1955).

W wyniku badań stwierdzono:

1) W Jeziorze Białym ilość bakterii wahała się od 361 tys/ml wody do 1789,9 tys/ml wody. Największą ilość bakterii stwierdzono na wszystkich głębokościach jeziora Białego w lutym oraz w sierpniu w hypolimnionie. W Jeziorze Rajgrodzkim ogólna ilość bakterii wahała się od 714,4 (jesień) do 2782,8 tys/ml wody w okresie zimowym.

W Jeziorze Dręstwo ilość bakterii zmieniała się od 572,0 do 1727 tys/ml wody. O wiele większą ilość bakterii stwierdzono w Jeziorze Krzywym. Najmniejszą ilość bakterii (1028,8 tys/ml wody) stwierdzono w Jeziorze Krzywym w okresie jesiennym, największą (2653,4 tys/ml wody) zimą. W Jeziorze Ślepym ilość bakterii w jednym ml wody wahała się od 910,6 tys. (latem) do 2818,2 tys. (zimą).

2) Analizując pionowe rozmieszczenie bakterii i fitoplanktonu na poszczególnych głębokościach badanych jezior zaobserwowano, że nie występuje prosta zależność między ilością chlorofilu w badanych jeziorach, a ilością fitoplanktonu. Małej

ilości chlorofilu w danym okresie (ma się rozumieć fitoplanktonu) nie odpowiadała mała ilość bakterii i odwrotnie. Natomiast obserwowano, że ten stosunek ilości bakterii i fitoplanktonu, jaki wytworzył się w danym sezonie, ulega zmianom na poszczególnych głębokościach tak, że w miarę zwiększania się ilości fitoplanktonu zwiększa się ilość bakterii w danym poziomie wód jeziora i odwrotnie. Autor przypuszcza, że ilość bakterii w zbiorniku wodnym uzależniona jest od ilości substancji organicznej obecnej w danym zbiorniku wodnym. Substancja organiczna, pochodząca z fitoplanktonu, stanowi różny odsetek w różnych zbiornikach wodnych, a nawet w tym samym zbiorniku wodnym w różnych porach roku. Utrudnia to stwierdzenie ilościowej zależności między fitoplanktonem z jednej strony, a bakterioplanktonem z drugiej.

3) Najintensywniej rozmnażają się bakterie w okresie letnim w Jeziorze Ślepym. Czas podwojenia się liczby bakterii w powierzchniowej warstwie Jeziora Ślepego w okresie letnim wynosił 5,9 godz. Najwolniej rozmnażają się bakterie w okresie letnim w Jeziorze Białym. Czas podwojenia się ilości bakterii wynosił 97,6 godz., w okresie jesiennym (listopad) najintensywniej rozmnażały się bakterie w Jeziorze Rajgrodzkim (czas podwojenia się ilości bakterii wynosił 30,4 godz.), najwolniej w Jeziorze Krzywym i Jeziorze Ślepym (czas podwojenia się ilości bakterii wynosił w nich 74,8 godz.).

4) Dobowa produkcja biomasy bakterioplanktonu w Jeziorze Białym wynosi: w okresie letnim 58,7 mg/m^3, co stanowi 25% ogólnej biomasy: jesienią 12,8 mg/m^3, czyli 34% ogólnej biomasy.

W Jeziorze Rajgrodzkim dobowa produkcja biomasy bakterioplanktonu wynosiła 211,5 mg/m^3, tj. 58% ogólnej biomasy, jesienią natomiast tylko 153,4 mg/m^3, czyli 43%. O wiele większa produkcja biomasy była w Jeziorze Dręstwo. Latem w ciągu doby produkcja biomasy stanowi 570 mg/m^3 (228% ogólnej biomasy), jesienią 268,8 mg/m^3 czyli 73% ogólnej biomasy. W Jeziorze Krzywym dobowa produkcja biomasy stanowi w sierpniu 79% ogólnej biomasy, czyli 442 mg/m^3, w okresie jesiennym 28%, czyli 156 mg/m^3. Natomiast w Jeziorze Ślepym produkcja dobowa biomasy w trzeciej dekadzie sierpnia wynosiła 563,5 mg/m^3 (380% ogólnej biomasy), oraz w listopadzie 400,6 mg/m^3, czyli 38% ogólnej biomasy.

5) W wyniku działalności bakterioplanktonu, w trzeciej dekadzie sierpnia najmniejsza ilość suchej substancji organicznej ulega mineralizacji w Jeziorze Białym (27,5 mg/m^3), a największa w Jeziorze Ślepym (440,3 mg/m^3). W okresie jesiennym najmniejsza ilość substancji organicznej ulega mineralizacji w Jeziorze Białym (15,2 mg/m^3), największa natomiast w Jeziorze Dręstwo (97 mg/m^3) i w Jeziorze Ślepym (93,5 mg/m^3 suchej substancji organicznej).

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Adres autora — Author's address

dr Bazyli Czeczuga

Zakład Biologii Akademii Medycznej, Białystok, ul. Kilińskiego 1