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Generation time and utilization of energy by aquatic bacteria.

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By the researches of S.I. Kuznetszov (1954), M.I. Novozhilova (1955) and other authors it appears that the biomass of bacteria in lakes and other water-bodies can attain significant values. The huge production of bacteria is brought about by their great rate of reproduction. In a series of cases their biomass exceeds the biomass of phytoplankton. Therefore in a study of the biological productivity of water bodies it is necessary to calculate the biomass and production not only of the phyto- and zooplankton, but also of bacteria.

Bacteria are increasingly consumed by different aquatic animals, (A.G. Rodina, 1949; E.F. Manuilova 1953 and others) therefore the present biomass of bacteria is determined by the difference in the rates of the two processes - the reproduction of bacteria and their consumption by the zoo-plankton. It follows that for the determination of the productivity of water bodies it is insufficient only to know the total quantity of micro-organisms and their biomass, it is necessary also to calculate the rate of reproduction of bacteria and. the rate of consumption of them by the zoo-plankton.

An indicator of the rate of reproduction of bacteria appears to be the time of one generation, i.e. "the interval of time between two successive divisions or buddings of cells" (N.D. Ierusalimskii, 1949).

The generation time of aquatic bacteria is determined by three methods:
By the rate of growth of bacteria on glass slides (A.E. Kriss, 1952);
In isolated samples of water by the rate of increase of numbers of bacteria (A.S. Razumov, 1948; M.V. Ivanov, 1954; M.I. Novozhilova, 1955, 1957);
Directly in water bodies by the rate of absorbtion by bacteria of oxygen (S.I. Kuznetsov).

The method of determination of the time of generation by the rate of growth of bacteria on glass slides has significant drawbacks. By this method it is not possible to count all the bacteria as not all species have the ability to form periphyton. Besides, not all micro-organisms stay on the glass: Part of these are broken off and carried off by the current of water, and part are eaten. And of course the most important defect of this method lies in this, that conditions for the growth of bacteria on the surface of the glass significantly differ from the conditions of growth in the suspended state, and glass surfaces cannot serve for the determination of the time of generation of bacteria of plankton suspended in the water.

A broader application was obtained by the method of determination of generation time in isolated samples of filtered water by the increase of numbers of bacteria. The generation time of bacteria is calculated in this case by the following formula:

$$g = \frac{t \lg 2}{\lg V - \lg v} \qquad (1)$$

g- generation time in hours;
V- quantity of bacteria at the end of the experiment;
v- quantity of bacteria at the beginging of the experiment;
t— duration of the experiment in hours.

With the calculation of the generation time by this formula it is assumed that all bacteria, calculated by the method of direct counting,are alive.

The method of determining the time of generation of bacteria by observation, done directly in water bodies, was proposed by S.I. Kuznetsov (1954). The time of generation of bacteria he determined by rate of reduction of the content of oxygen in a determined interval of time in the hypolimnion of lake Gluboko. Taking the respiratory coefficient per unit, S.I. Kuznetsov calculated the rate of formation of carbon dioxide, which he completely took as an estimate of the respiration of the bacteria of the water, and took as total metabolism of bacteria. By determination of the rate of increase S.I. Kuznetsov found that "As shown by a series of authors, in connection with bacterial reproduction about 30% of total metabolism is involved with anabolism." The number of generations was calculated by means of dividing the quantity of carbon, going on anabolic metabolism of bacteria, by the carbon on bacterial biomass. With the calculation of the quantity of carbon in bacterial biomass the moisture content of the bacteria was taken as equal to 90% and the content of cabon in dry matter as 50%.

The increase of the biomass of bacteria (P) expressed in mg of carbon per litre, was calculated from the formulae:

$$P = \frac{\Delta O_2 \cdot 0.375 \cdot 30}{100}$$

where ΔO_2-reduction of concentration of oxygen, expressed in milligrammes of oxygen per litre, in the time t; 0.375- coefficient of the transition from a milligramme of oxygen to a milligramme of carbon.

The biomass of bacteria in milligrammes of carbon per litre, according to the indicated above assumption, is equal to:

$$B = \frac{\hat{n} \cdot v \cdot (100-90) \cdot 0.5}{100},$$

where
n- number of bacteria in one litre;
v- size of single bacterium in milligrammes.

The number of generations (Ng)in the time t according to S.I. Kuznetsov, can be represented by the following expression

$$N_g = \frac{P}{B} \qquad (2)$$

Hence the time on one generation in hours (g) is equal to;

$$g = t\frac{B}{P}, \qquad (3)$$

Where t- duration of experiment in hours.

However it is not possible to agree with this determination of total metabolism which is given by S.I. Kuznetsov, Taking as the total metabolism the rate of consumption of oxygen or the production of carbon dioxide, S.I. Kuznetsov in fact calculates only energetic metabolism, and not total. According to this value, i.e. according to the rate of energetic metabolism, it is possible to calculate the value of increase of biomass of bacteria in the determined period of time only in this case, if is known the relationship between energetic and constructive metabolism. This relationship can be expressed as a kind of coefficient, indicating the increase, received per unit of consumed and assimilated food substances. This coefficient subsequently we shall call the coefficient of utilization of energy. It matches the coefficient of the second order of V.I. Ivlev (cited by A.G. Vinberg, 1956). Note, that the quantity of consumed and assimilated food substances or the energy contained in them equals P + T, where T is the expenditure on energetic metabolism, giving:

$$K_p^g = \frac{P \cdot 100}{P + T} \qquad (4)$$

Calculations are simplified if not only the increase (P), but also the expenditure on energetic metabolism (T) is expressed in the equivalent of its quantity of oxygen. Established by means of observations in water bodies is the increase of consumption of oxygen (milligrammes of oxygen per litre) equal to the expenditure on energetic metabolism, i.e. $\Delta O_2 = T$.
Substituting in formula (4). ΔO_2 instead of T, we have

$$P = \frac{\Delta O_2 \cdot K}{100 - K} \qquad (5)$$

This value can be utilized for calculation of the number of generations by formulae (2) in this case if also the biomass of bacteria (B) is expressed in the same units.

If it is agreed with S.I. Kuznetsov and other authors that in dry weight bacteria are 50% carbon and the dry weight comprises 10% of the wet weight then 1 milligramme wet weight bacteria contains 0.05 milligrammes carbon; this quantity of carbon with the respiratory coefficient in similar units is equivalent to 0.1333 milligrammes of oxygen necessary for full oxidation of carbon. Therefore in order that the biomass of bacteria is expressed in milligrammes of oxygen per litre, it is sufficient to multiply the wet weight of bacteria (in milligrammes per litre) by 0.1333. In calculation for small periods of exposure it is possible with a small error to take the mean arithmetic biomass of the bacteria at the beginning and at the end of the experiment.

Substituting in formula (2) the value P from formula (5), we have

$$N_g = \frac{\Delta O_2 \cdot K}{(100 - K) \cdot B} \qquad (6)$$

or the time of one generation in hours (g) is equal to:

$$g = \frac{(100 - K) \cdot B}{\Delta O_2 \cdot K}$$

By formula (7) it is possible to calculate the time of one generation, if the coefficient of utilization of energy is known, or the coefficient of utilization of energy if the time of a generation is known.

For a comparison of the. different methods of determining the times of generation of aquatic bacteria research was conducted by us (from 24 to 31 August 1956) on lakes Batorin (eutrophic) and Naroch (mesotrophic), lying in the North west part of the Belorussian S.S.E. The time of generation was determined in parallel by two methods,: In isolated samples of water by the rate of increase in numbers of bacteria and by the rate of consumption of *oxygen* by bacteria according to formulae (3) and (7).

The experiments were laid down in the surface layers of the water of the lake by. the method developed by A.S. Razumov (1948) and M.V. Ivanov (1955). Times of exposure were different (6, 8, 12, 16 and 24 Hours).

In the determination of the biomass of bacteria the volume of bacterial cells was calculated on the basis of the mean dimensions of broad-shaped and coccoid forms. The mean volume of single bacterial cell for Lake Batorin was equal to 1.399μ3, for lake Naroch - 0.887μ3. It follows that the biomass of . bacteria expressed in milligrammes of oxygen per litre in Lake Batorin constitutes n.o.l865.10^{-9} and in Lake Naroch - n.o.1182.$l0^{-9}$

Data on the times of generation of bacteria in the water of lakes, found by different methods, are presented in table 1. The time of generation (g) was determined by formulae (l) and (3), and the coefficient of the utilization of energy (K) was calculated by formula (7).

Table 1.

Comparison of time of one generation of the bacteria, determined by different methods, in the water of Lake Batorin.

Time of exposure in hours	Water Temp. °C	Oxygen consumption mg/l	No. of bacteria in thous. per cm³		g by formula (1)	K in %	g by formula (3)	K in %	g by formula (7), with K = 60%
			Start	end					
6	16,0	0,075	3724	4508	21,7	73,9	204,7	23,6	40,9
8	15,5	0,160	3626	4083	46,7	43,5	119,8	23,1	23,9
12	16,0	0,125	3724	4303	57,5	55,5	239,6	25,6	47,9
16	15,7	0,140	3553	4386	52,6	61,6	282,0	23,0	56,4
24	16,0	0,190	3335	4489	55,9	62,3	307,1	23,1	61,5
Среднее 13,2 Mean	15,8	0,138	3592	4354	47,5	59,9	236,6	29,9	47,9

From the table it is evident, that the time of one generation of bacteria is isolated samples of water of lake Batorin is equal to 21.7-57.5 hours with a coefficient of utilization of energy of 43.5-73.9%. From these data are very clearly distinguished the rate of reproduction of bacteria, determined by the method of S.I. Kuznetsov; the time of generation varies within limits from 119.8 to 307.3 hours and the coefficient of utilization of energy comprises in all only 23-25%.

Comparing the generation time of aquatic bacteria by different methods and comparing the obtained coefficient of utilization of energy, we see, that the coefficients of utilization of energy appear more practicable, calculated with isolated water samples. Therefore with the determined time of generation of bacteria by formula (7) we took the coefficient of utilization of energy equal to 60%, obtaining in this way much better conformity of the mean values or the generation time calculated by formulae (3) and (7) and equal accordingly to 47.5 and 47.2 hours.

The coefficient of utilization of energy of aquatic bacteria in mesotrophic Lake Naroch. calculated from two series of observations appeared very low (10.4%). It is possible that the value of the coefficient of utilization of energy of aquatic bacteria depends on the type of water body. However the materials from Lake Naroch, in view of the low number of observations, demand further verification.

Thus a comparison of different methods of determination of the generation time of aquatic bacteria leads to the conclusion, that observations on the rate in increase in numbers of bacteria in isolated samples of filtered water, present a simple and adequately precise method of determining this value. The rate of consumption of oxygen even in this case can be used for calculation of the time of generation of bacteria, when the value of the coefficient of utilization of energy is known. Observations on the consumption of oxygen and the reproduction of bacteria in water of the eutrophic Lake Batorin show that the coefficient of utilization of energy of aquatic bacteria in the given case was near to 60%.

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Notice

Please note that these translations were produced to assist the scientific staff of the FBA (Freshwater Biological Association) in their research. These translations were done by scientific staff with relevant language skills and not by professional translators.