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BACTERIAL GRADIENTS AT THE SEDIMENT — WATER INTERFACE OF SHALLOW LAKES

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In Lake Balaton the number, biomass and production of the heterotrophic and total bacterioplankton have been investigated intensively from many points of view during the years of 1966–1971 (OLÁH, 1969 a, b; 1970; 1971 a, b, c; OLÁH and VÁSÁRHELYI, 1970 a). However, our knowledge about the bacteriobenthos of this lake is rather scanty. According to our short periodic investigation, in the constantly disturbed water of shallow Lake Balaton the sediment has a significant role in the formation of both the heterotrophic and total bacterioplankton. Therefore, the investigation of bacterial gradients is of special importance at the sediment — water interface, i.e. in the water layers above the bottom, the sediment — water interface taken in the literal sense as well as the deeper sediment layers. In this study we determined the quantitative distribution of the aerobic, anaerobic bacteria and that of the bacteria counted on the membrane filter at the sediment — water interface in three shallow lakes of different trophic levels.

Methods

In Lake Balaton the samples were taken in the Keszthely Bay the most eutrophicated part of the lake and in section "A" (in front of the Institute), which represents the less eutrophicated larger part of the lake. In the highly eutrophic Lake Belső the samples were taken in the deepest part of the lake. In Lake Velence between the state of eutrophy and "senescence", the samples were taken in the reeds-free open water (sampling station "C", OLÁH and VÁSÁRHELYI, 1970 a). Samples were taken in July, 1971 with a MILBRINK's microstatification sampler (1968) into sterile glass or Petri-dish and the determinations were carried out immediately after sampling or in the case of Lake Velence and Keszthely Bay not later than 5 hours. The anaerobic bacterial gradients were determined in January of 1973.

The quantity of bacteria counted on the membrane filter was determined according to KUZNETSOV and ROMANENKO (1963). The distribution of aerobic bacteria at the sediment — water interface was determined with the usual plating method. For plate pouring we have chosen the sodium caseinate agar (OLÁH and VÁSÁRHELYI, 1970 b). Burri-tubes were used to estimate the number of anaerobic bacteria. To ensure the anaerobic condition, besides using deep agar, the left-over oxygen in the closed tubes was absorbed with alkaline pyrogallol. The aerobic bacteria were cultured at 25° C and the anaerobic bacteria at 38° C. Two culture media were used to estimate the number of anaerobic bacteria. Nutrient II agar with a high organic content:

Beef extract (Difco)	3 g
Peptone (Difco)	5 g
Glucose	10 g
Difco agar	15 g
Distilled water	1000 ml

We used iron sulphite agar (Oxoid) with a lower organic content to count the anaerobic and sulphite-reducing bacteria. The colonies of sulphite-reducing bacteria are black in this medium owing to the iron sulphide precipitation. The agar column was pushed out of the tube, then cut into slices and examined under a microscope.

Results and discussion

Aerobic bacteria

At the end of the 1920s the quantity of bacteria on the sediment surface of the open water was below the value of $1 \cdot 10^3$ cell/g wet sediment (Zih, 1929) in Lake Balaton. After ten years there was no significant change. On the sediment surface of the open water Haranghy (1941) found about $1 \cdot 10^3$ cell/g wet sediment both on gelatine and Heyden agar. In this study the number of aerobic bacteria on the sediment surface of the open water reached the value of $1 \cdot 10^5$/g wet sediment *(Fig. 1)*. The comparison of data obtained during the 1920s and 1930s and in this study is reasonable. All these investigations were carried out in July and the same types of media occurred among the culture media which were used for plate pouring. Attention was paid to the selective effect of media (Haranghy, 1941; Oláh and Vásárhelyi, 1970 b). The comparison shows that during the first ten years of the period of forty years there was no significant change while in the course of the following thirty years the number of heterotrophic bacteria on the sediment surface increased by two order of magnitude. This very high increase is especially striking, because during the same period the quantity of aerobic bacterioplankton remained on the same order of magnitude (Oláh, 1969 b).

The gradient of aerobic heterotrophic bacteria at the sediment—water interface of Lake Balaton indicates the low number of cells in the water layer of 11—15 cm above the sediment surface *(Fig. 1)*. The number of aerobic heterotrophic bacteria decreased rapidly in the deeper sediment layers. However, their number even in the sediment layer of 9—11 cm was significant: reached the value of $1 \cdot 10^4$ cell/g. In the sediment of Keszthely Bay the accumulation of organic matter is higher than that in the other part of the lake (Ponyi et al., 1972). The input exceeds the output. This is reflected by the quantity of aerobic heterotrophic bacteria living on the sediment surface. Their number reach the value of $3.2 \cdot 10^5$ cell/g wet sediment. We have measured similar values in Lake Velence. In the highly eutrophic Lake Belső the quantity of aerobic heterotrophic bacteria reached the value of $2 \cdot 10^6$

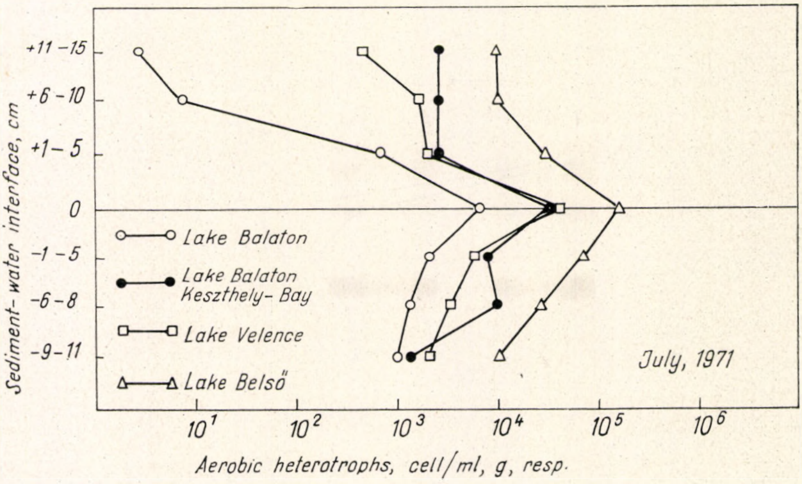

Fig. 1. The quantity of aerobic heterotrophic bacteria at the sediment—water interface of different lakes

cell/g wet sediment on the sediment surface and in the water layer of 11—15 cm above the sediment we have found more bacteria than on the sediment surface of Lake Balaton. In the lakes investigated the quantity of aerobic heterotrophic bacteria decreased rapidly in the deeper sediment layers except the sediment of Keszthely Bay which produced an increase again in the sediment layer of 6—8 cm.

Anaerobic bacteria

We investigated the distribution of anaerobic bacteria at the sediment—water interface only in section "A" of Lake Balaton. On the sediment surface the quantity of anaerobic bacteria counted on iron sulphite agar reached the value of $2 \cdot 10^4$ cell/g wet sediment *(Fig. 2)*. The same value on nutrient II agar was lower by one order of magnitude. During the last thirty years the quantity of anaerobic bacteria also increased on the sediment surface. In the open water sediment Haranghy (1941) found an average value of $1 \cdot 10^2$ and even in the littoral zone, in the sediment of the reeds his values were below the value of $1 \cdot 10^3$ cell/g. The anaerobic bacterial gradients differ from the gradient of aerobic heterotrophic bacteria. In the water layers we found no anaerobic bacteria except some cells in the water layer immediately above the sediment. The quantity of anaerobic bacteria counted on nutrient II agar was smaller in the oxidized sediment surface than in the reduced sediment layer of 1—5 cm. The distribution of sulphite reducing bacteria was similar. The anaerobic bacteria counted on iron sulphite agar occurred in a larger number on the sediment surface than in the deeper reduced sediment layers. This type of distribution may be explained by the higher proportion of facultative anaerobic bacteria and the anaerobic microenvironment.

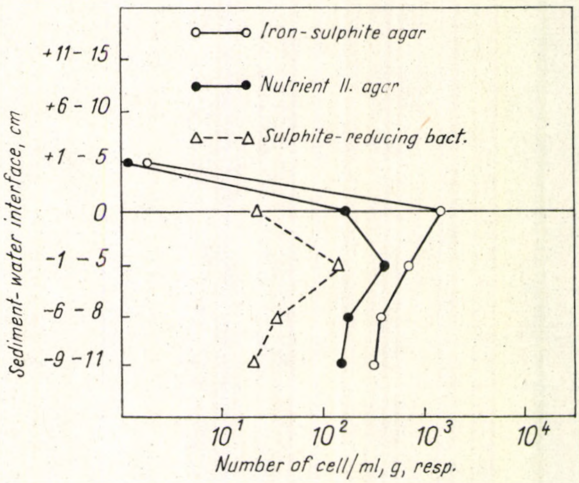

Fig. 2. The quantity of anaerobic heterotrophic bacteria at the sediment—water interface of Lake Balaton

Bacteria counted on membrane filter

A membrane filter variety of the original VINOGRADSKY's method is used more often to estimate the total number of bacteria living in the sediment (KUZNETSOV and ROMANENKO, 1963). According to our present data the quantity of bacteria on the sediment surface of open water in Lake Balaton is lower in July than in the mesotrophic lakes *(Fig. 3)*. The values of $3 \cdot 10^8$ cell/g wet sediment is lower than the values of $0.5-1.5 \cdot 10^9$ cell/g characterizing the mesotrophic lakes (ROMANENKO and ROMANENKO, 1971). How-

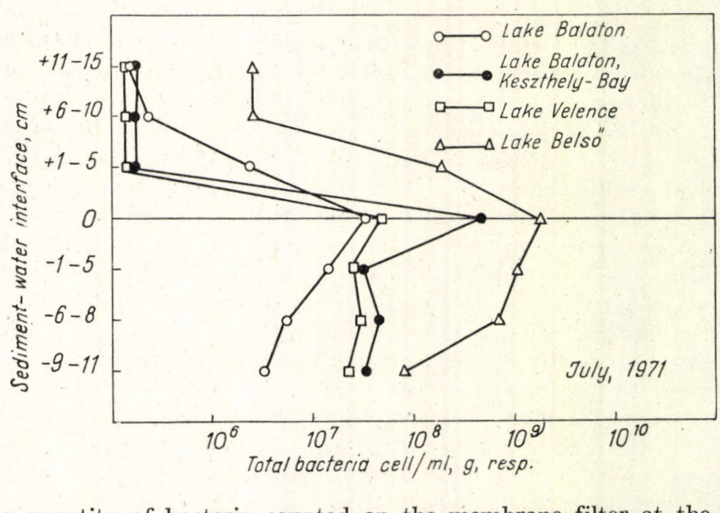

Fig. 3. The quantity of bacteria counted on the membrane filter at the sediment—water interface of different lakes

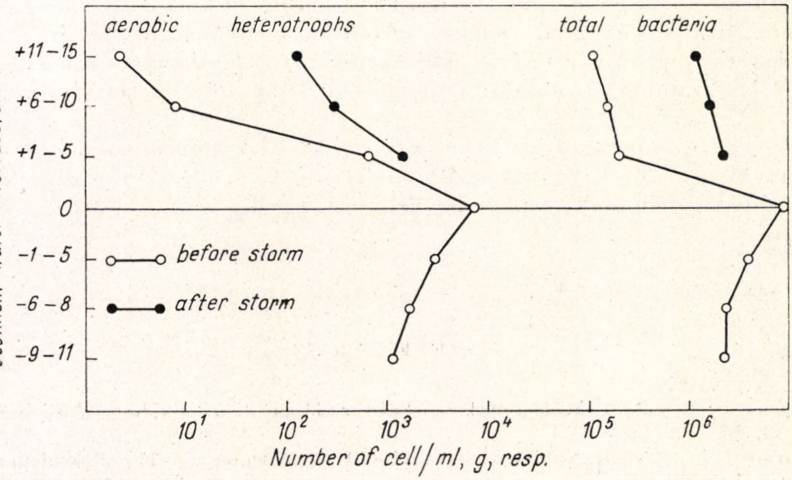

Fig. 4. Storm effect on the quantity of aerobic heterotrophic bacteria and bacteria counted on the membrane filter in the bottom water layers

ever, according to our earlier autumnal investigation the quantity of bacteria on the sediment surface reaches the values of mesotrophic lakes (PONYI et al., 1972). In the Keszthely Bay with a higher trophic level, the quantity of bacteria reached the value of $5 \cdot 10^9$ cell/g characterizing the eutrophic lakes. During our earlier investigation in autumn we found no such a large difference between the Keszthely Bay and the other part of the lake.

The number of bacteria living on the sediment surface of the highly eutrophic Lake Belső exceeded the value of $1 \cdot 10^{10}$ cell/g wet sediment.

In the lakes Balaton and Belső the quantity of bacteria counted on membrane filter decreased with depth. In the sediment of Lake Velence and Keszthely Bay the number of bacteria was lower in the deeper sediment layers, however, their number showed no decrease up to the sediment layer of 10 cm. The number of bacteria in the water layers immediately above the bottom decreased rapidly in all three of the investigated lakes. After a storm the number of heterotrophic bacteria increased by two order of magnitude and that of the bacteria counted on membrane filter by one order of magnitude in the water layers immediately above the bottom *(Fig. 4)*. According to our short periodic investigation the storm or strong wind effect may be detectable even in the surface water layers (OLÁH, 1970).

Summary

1. During the last forty years the number of aerobic heterotrophic bacteria on the sediment surface of Lake Balaton increased from a value of $1 \cdot 10^3$ cell/g wet sediment to a value of $1 \cdot 10^5$. During the same period the quantity of the heterotrophic bacterioplankton showed no significant change. Most bacteria occurred in the upper 1 cm layer of the sediment. In the deeper sediment layers and in the water layers above the bottom their number decreased rapidly.

2. During the last thirty years the number of anaerobic bacteria on the sediment surface increased at least by one order of magnitude. In the bottom water layers there was no anaerobic bacteria. In the deeper, reduced sediment layers their number increased or decreased depending on the different media used.

3. The quantity of bacteria counted on the membrane filter increased from a value of $3 \cdot 10^8$/g wet sediment (Lake Balaton) to a value of $1 \cdot 10^{10}$ in lakes with different trophic levels.

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BAKTÉRIUM GRADIENSEK A SEKÉLY TAVAK VÍZ-ÜLEDÉK HATÁRÁN

Oláh János

Összefoglalás

1. Az elmúlt negyven év során a Balaton üledékfelületén élő aerob heterotróf baktériumok mennyisége $1 \cdot 10^3$ sejt/g-ról $1 \cdot 10^5$ sejt/g-ra emelkedett. Ugyanezen periódus alatt az aerob heterotróf bakterioplankton mennyisége nagyságrendileg nem változott. Legtöbb baktérium az üledék felső 1 cm-es rétegében volt. Az üledékmélységgel, de különösen az üledékfeletti vízrétegben számuk gyorsan csökkent.

2. Az elmúlt harminc év során a Balaton üledékfelületén élő anaerob baktériumok mennyisége legalább egy nagyságrenddel nőtt. Közvetlenül az üledékfeletti vízrétegben nem találtunk anaerob baktériumot. A mélyebb, redukált üledékrétegekben számuk csökkent vagy nőtt az alkalmazott táptalajtól függően.

3. A membránszűrőn számolt baktériumok mennyisége a vizsgált különböző trofitású tavakban $3 \cdot 10^8$ sejt/g nedves üledékről (Balaton) $1 \cdot 10^{10}$ sejt/g nedves üledékre nőtt (Belső tó).