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WEEKLY CHANGES OF THE BACTERIO- AND PHYTOPLANKTON STANDING STOCK IN LAKE BALATON AND IN THE HIGHLY EUTROPHIC LAKE BELSŐ

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It was HENRICI (1938) who for the first time found a positive relationship between the seasonal changes of the bacterio- and phytoplankton of lakes. OVERBECK's results (OVERBECK and BABENZIEN, 1964; OVERBECK, 1965; 1968) also indicate a parallelism existing between the changes of bacterio- and phytoplankton. A similar relationship was observed between the primary production and the quantity and production of the bacterioplankton (SCHEGG, 1968; KUZNETSOV, 1968). Some authors on the other hand found no such relationships (ROMANENKO, 1966; GERLETTI and MELCHIORRI-SANTOLINI, 1968; GOLDMAN et al. 1968; GUNKEL, 1968) and I have also described negative and positive relationships (OLÁH, 1970; 1971).

Taking into account the few and contradictory data I have examined the seasonal changes in the quantity of the heterotrophic and total microbial plankton and the phytoplankton weekly during a period af one year in the highly eutrophic Lake Belső and in Lake Balaton.

Methods

The investigation was carried out in the open water of Lake Balaton in front of our Institute beside a buoy and in the centre of Lake Belső between 4th September, 1969. and 21st August, 1970. The samples were taken with a FRANCEV's sampler (KUZNETSOV, 1952) from a depth of 50 cm and from the bottom water. We determined the quantity of the heterotrophic microorganisms on sodium-caseinate agar and that of the total microbial plankton with the RAZUMOV's direct method (RAZUMOV, 1932).

Phytoplankton counting was done with an "Oxoid" membrane filter (pore size: 0.45 μ) using erythrozine staining. The μ-algae were stained and counted with the DE NOYELLES's method (1968). During the investigation the surface water temperature and the Secchi transparency were measured *(Fig. 1)*.

Results

In the green coloured Lake Belső with a very low Secchi transparency the phytoplankton maxima reached $3 \cdot 10^5$ cells/ml while in Lake Balaton the maxima were only about $8 \cdot 10^3$ cells/ml *(Fig. 2)*. In Lake Belső the bottom

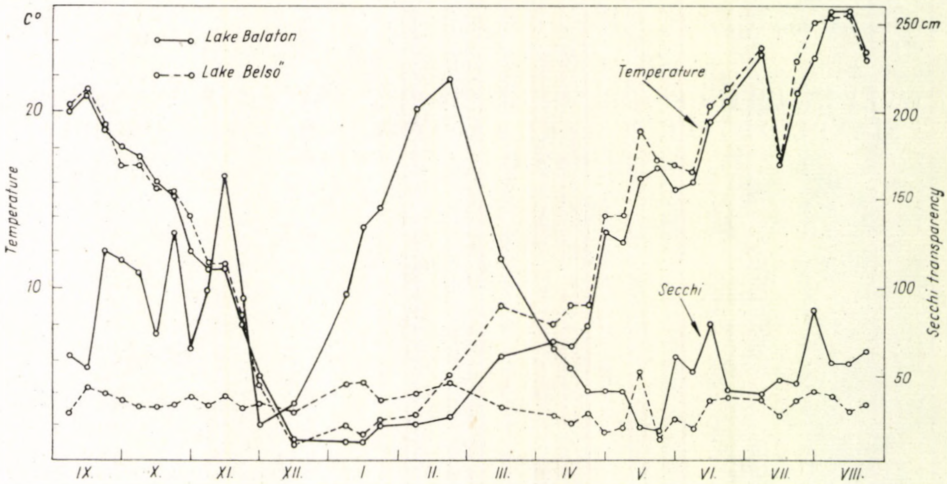

Fig. 1. Water temperature and Secchi transparency of the lakes in the period of the investigation

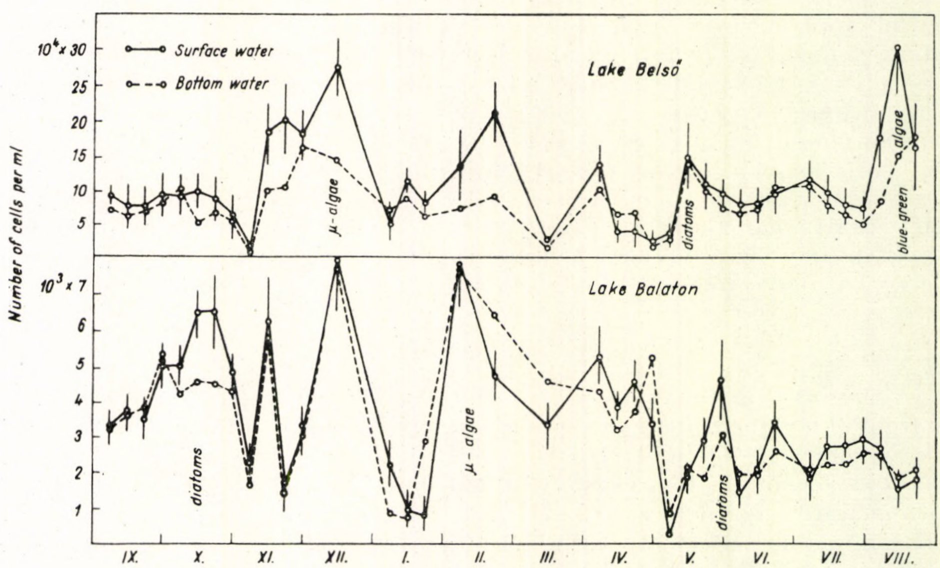

Fig. 2. Seasonal fluctuation in the number of phytoplankton

water contained a smaller number of algae comparing with that in the surface water especially in winter, under ice and in August during the water bloom of the blue-green algae. In Lake Balaton the bottom water contained a higher number of algae in winter. It is striking that the greater changes in the quantity of the phytoplankton was observed almost simultaneously in both lakes. Generally, a sudden decrease in the number of algae was accompanied by a change of the dominant species. During September and October there was no significant change in Lake Belső. In Lake Balaton Diatoms developed in the middle of October. In the winter months the μ-algae stained by the DE NOYELLES's method were found in a higher number in both lakes. In the Lake Belső they appeared in large numbers already in December and in a smaller number they were present in various forms during the whole investigation period. In the bottom water of the Lake Belső the number of the photosynthetic bacteria *(Thiopedia rosea, Thiocystis sp.)* was also significant in the winter months. In Lake Balaton the μ-algae appeared at the beginning of February and mainly the whole standing stock consisted of a small (1—4 μ) "coccus"-form colouring blue with the DE NOYELLE's staining. At the end of April in Lake Belső the number of algae decreased with the disappearance of winter dominant species. In Lake Balaton this process took place at the beginning of May. In May a significant development of Diatoms was observed following the decrease in the number of algae in both lakes. During the summer months only slight changes were observed in the quantity of the phytoplankton except in Lake Belső, where in August a quite rapid bloom of *Microcystis* developed. During the period of the investigation nc blue-green algal water bloom was observed in Lake Balaton. It was absent even in Keszthely-Bay. In both lakes the number of phytoplankton was surprisingly high during the winter months due to the μ-algae.

In this one-year period the quantity of the heterotrophic microbial plankton in the bottom water of Lake Belső was somewhat higher than in the surface water except in the first half of June, when the number of heterotrophs increased *(Fig. 3)* in the surface water owing to the mineralization of the large biomass of Diatoms. During the whole period of investigation this was the highest value for heterotrophic microbial plankton. Throughout the summer months, following this high spring value, the number of heterotrophs was very low even at the time of the blue-green algal water bloom.

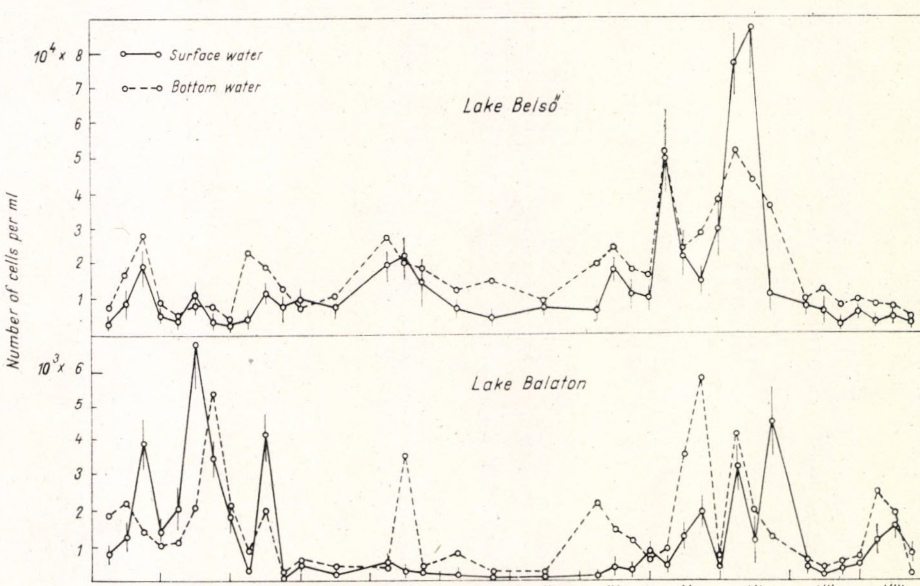

Fig. 3. Seasonal fluctuation in the number of heterotrophic microbial plankton

In the Lake Belső the heterotrophs were present in a significant number in the winter months, too. In the surface water we have found no correlation at all between the quantitative changes of the heterotrophs and algae ($r = -0.001$).

In Lake Balaton the quantity of the heterotrophs determined on sodium-caseinate agar was smaller by one order of magnitude and decreased to a very low level during the winter months. Like Lake Belső, after the spring maximum the number of heterotrophs decreased but in autumn it was high again. In the surface water of Lake Balaton there was not any correlation between the quantitative changes of the heterotrophs and algae ($r = 0.02$).

In the Lake Belső great seasonal changes were measured in the quantity of the total microbial plankton. Generally, it was above $3 \cdot 10^6$ cells/ml and the maxima reached the $17.7 \cdot 10^6$ cells/ml. After a decrease in the beginning of November the quantity of the total microbial plankton grew, especially in the bottom water *(Fig. 4)*. After the decrease in January—February we measured a rise again simulataneously with the increasing water temperature. The spring maximum consisting of several peaks was also followed by a significant decrease, like in the phytoplankton and the heterotrophs. In the surface water a very strong negative correlation was found between the quantitative changes of the phytoplankton and the total microbial plankton ($r = -0.913$) with a large significance ($P \ll 0.001$).

In Lake Balaton the quantity of the total microbial plankton was very low, generally below $1 \cdot 10^5$ cells/ml. The autumn and spring maxima reached $1.5 \cdot 10^5$ cells/ml. Atfer the autumn maximum we measured a decrease and in the winter months, under ice the quantity of the total microbial plankton

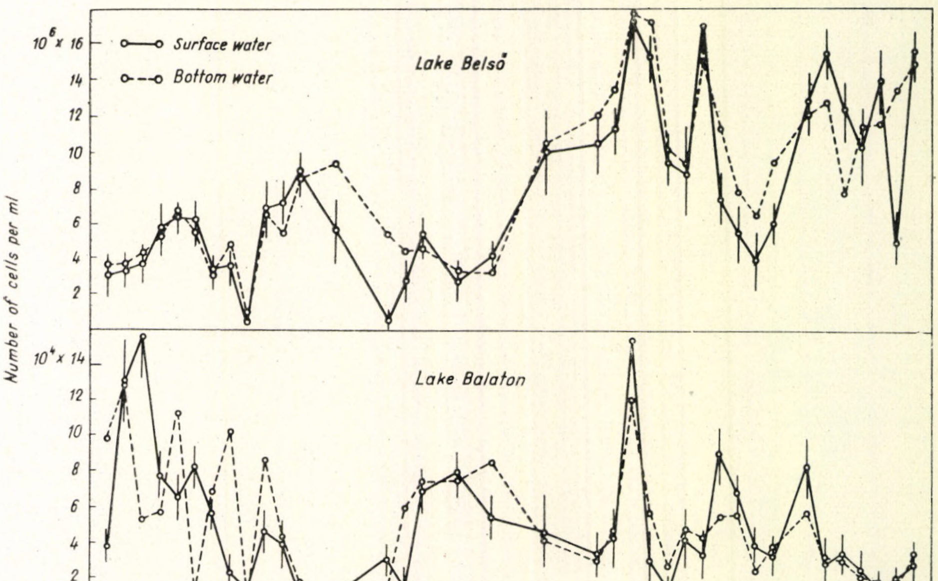

Fig. 4. Seasonal fluctuation in the number of total microbial plankton

rose parallel with that of the μ-algae. In the second half of July and in August the number of the total microbial plankton was very low in Lake Balaton, contrary to Lake Belső, where the standing stock of the total microbial plankton consisted of several various forms, in Lake Balaton cocci with about 1 μ diameter were the dominant forms in this period. In the surface water no correlation was found between the quantitative changes of the phytoplankton and the total microbial plankton ($r = 0.02$).

Discussion

In the Lakes Balaton and Belső the seasonal changes in the quantity of the phytoplankton and the microbial plankton has never been simultaneously investigated. The majority of the algological studies is also floristic or taxonomic. Quantitative algological work extending over the whole year in Lake Belső was carried out by JACZÓ and MANN (1940) and that in Lake Balaton by ENTZ et al. (1937) and TAMÁS (1954). The comparison on equal bases is not quite justified owing to the different methods employed by earlier investigators and by us, nevertheless, it can safely be said that since 1932 in Lake Balaton and since 1938 in Lake Belső the quantity of the phytoplankton increased immensely.

In February, 1969 the standing stock of the μ-algae was represented by a *Chlamydomonas* sp. with a number of $18-19 \cdot 10^3$ cells/ml in the bottom water (OLÁH, 1970). In the present investigation the February standing stock of μ-algae consisted of a "coccus" form of various size (1—4 μ) with a number of $7.8 \cdot 10^3$/ml also in the bottom water. All these prove the very important role of the winter μ-algae in Lake Balaton. In Lake Belső no homogeneous standing stock of μ-algae was formed like in Lake Balaton. In winter, besides the Flagellates and Diatoms even some species of photosynthetic bacteria were observed in the bottom water of Lake Belső. In the open water of Lake Balaton no phytosynthetic bacteria were found.

In Lake Belső a smaller number of active algae was regularly in the bottom water; this phenomenon is due to the unsuitable light condition prevalent there. In the bottom water of Lake Balaton the strong development of μ-algae was initiated among others by the favourable light condition in winter months.

During our earlier investigations (OLÁH and VÁSÁRHELYI, 1970) we have stated that in the shallow lakes Balaton and Velence with large surface areas the low quantity of the total microbial plankton did not reflect the real trophic state of these lakes and in Lake Belső the relation between the quantity of the total microbial plankton and the trophic state corresponds to the data in the literature. This statement is supported by the present investigation, too.

In Lake Belső the quantity of the total microbial plankton was very high throughout the year corresponding to the highly eutrophic state of this lake. The highest values were recorded in spring but in July and August we observed a summer maximum, too. In Lake Balaton a similar summer maximum was measured only in the Keszthely-Bay (OLÁH, 1969b).

In Lake Balaton the quantity of the total microbial plankton was surprisingly low during this investigation, too. The values were even smaller than those measured in 1966—67 and followed the characteristics of earlier seasonal changes of shallow lakes like Balaton and Velence: 1. spring maximum formed during the rising temperature of the water, 2. summer minimum, 3. autumn and winter maximum. In the present investigation the winter maximum accompanying the mass-development of the μ-algae compared to the 1969 winter maximum was smaller. It seems that in the winter of 1969 the mass-development of the *Chlamydomonas* sp. produced a more suitable environment for the proliferation of the total microbial plankton than the coccus-form in the present investigation.

In Lake Balaton the seasonal changes in the quantity of the heterotrophs was the same as was observed earlier in other parts of the lake with a lower trophic level (OLÁH, 1969b; 1970). Spring—autumn maxima and summer—winter minima. In the Lake Belső the high spring values and the low summer minimum were the most conspicuous. The summer minimum may be explained by the constant green colour of the water owing to the algae. I described a similar phenomenon during the bacteriological study of a water bloom in River Zala (OLÁH, 1971).

It was very surprising that the tendencies of the changes in the quantity of the heterotrophic and total microbial plankton and the phytoplankton were nearly the same in both lakes. Considering that the lakes are absolutely isolated from each other this similarity in the quantitative changes may only be explained by climatic conditions which emphasizes that the weather plays a more important part in the plankton life of these lakes than in deep, stratified lakes.

The correlation coefficients in this study has revealed a significant connection in the surface water of Lake Belső, only between algae and the total microbial plankton. In the other cases, after the proliferation of algae the quantity of the microbial plankton decreased or increased depending partly on the type of algae present and thus the counting during to the whole period did not reveal any correlation whatsoever. The interrelation between the algae and bacteria is quite complicated. From this point of view numerous experimental results prove the importance of the stimulatory and inhibitory extracellular substances excreted by algae (GOCKE, 1970; WEIMANN, 1970). The changing pH and rH_2 during the activity of the algae and bacteria (MAKSIMOVA, 1966) and the bacterial CO_2 production (KUENTZEL, 1969) further enlarge the number of factors operating in an inverse direction. We must take into account also the different effects of the active and dead plankton, too (GUSEVA, 1952).

Among the seasonal changes in the relation of the microbial and phytoplankton it was possible to observe three types for Lake Balaton and Lake Belső considering our earlier investigations, too.

1. The quantity of the microbial plankton increases with the increasing number of algae. In February, 1969 (OLÁH, 1970) and in the present investigation the quantity of the total microbial plankton increased with the mass-development of μ-algae. In Lake Balaton the autumn phytoplankton standing stock consisting mainly of Diatoms was accompanied with a total microbial plankton maximum.

2. The quantity of the microbial plankton decreases with the increasing number of algae. In Lake Belső the abrupt appearance of the blue-green algae was accompanied with a significant decrease in the quantity of the total microbial

plankton standing stock. In 1966, during the blue-green algal water bloom the quantity of the total microbial plankton was very low in the Keszthely-Bay (OLÁH, 1969a). At the time of the water bloom in River Zala especially the number of the heterotrophic microorganisms was very low.

3. The quantity of the microbial plankton increases only after a definite delay following the phytoplankton maximum. In Lake Balaton at the end of April we observed a development of microbial plankton after the maximum of the winter standing stock of μ-algae. In the Lake Belső the large spring biomass of algae was accompanied by the maximum of the total microbial plankton with some delay. After the water bloom in River Zala a very high number of the heterotrophic microorganisms was measured.

Summary

1. In Lake Balaton the maxima of the phytoplankton were about $8 \cdot 10^3$ cells/ml and those in the Lake Belső $3 \cdot 10^5$ cells/ml. In both lakes there was a significant spring and winter maximum and in Lake Belső a maximum of blue-green algae in August. In Lake Balaton the standing stock of the winter μ-algae consisted of one species ($1-4\ \mu$ coccus) while in Lake Belső of several species. There was a significant number of photosynthetic bacteria in Lake Belső.

2. In Lake Balaton the maxima of the heterotrophs were reached in spring and autumn and the minima in summer and winter. In Lake Belső the spring maximum and the summer minimum were the most prominent. In Lake Belső the quantity of the total microbial plankton was above $3 \cdot 10^6$ cells/ml and the maxima reached $17.7 \cdot 10^6$ cells/ml, while in the Lake Balaton generally below $1 \cdot 10^5$ cells/ml and autumn and spring maxima about $1.5 \cdot 10^5$ cells/ml. Contrary to Lake Balaton, in Lake Belső the quantity of the total microbial plankton was high in summer months, too.

3. The correlation coefficients revealed significant connection ($r = -0.913$; $P \leqslant 0.001$) in the surface water of Lake Belső only between the total microbial plankton and the phytoplankton.

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A BAKTERIO- ÉS FITOPLANKTON ÁLLOMÁNY HETENKÉNTI VÁLTOZÁSAI A BALATONBAN ÉS AZ ERŐSEN EUTRÓF BELSŐ-TÓBAN

Oláh János

Összefoglalás

1. Az egyéves hetenkénti vizsgálatok során a fitoplankton maximumok a Balatonban megközelítették a $8 \cdot 10^3$/ml-t, a Belsó-tóban pedig elérték a $3 \cdot 10^5$/ml-t. Az évszakos mennyiségi változásokban mindkét tóban legszembetűnőbb a téli és tavaszi maximum. Jelentős a Belső-tóban augusztusban kialakult kékalga tömegprodukció is. A téli μ- alga állományt a Balatonban egyetlen, $1-4\,\mu$-os „kokkusz" forma, a Belső tóban pedig több

faj populációi alkották. A Belső-tó téli planktonjában jelentős volt a fotoszintetizáló baktériumok száma is (*Thiopedia rosea, Thiocystis* sp.).

2. A heterotrófok mennyiségének évszakos változásai a Balatonban: tavaszi, őszi maximum és nyári, téli minimum. A Belső-tóban legszembetűnőbb a tavaszi maximum és a nyári minimum. A Belső-tóban a teljes mikrobiális plankton mennyisége $3 \cdot 10^6$/ml fölött volt és a maximum elérte az $17.7 \cdot 10^6$/ml-t. A Balatonra jellemző nyári minimummal szemben a Belső-tóban nyáron is magas volt a teljes mikrobiális plankton száma.

3. A heterotróf, a teljes mikrobiális plankton és a fitoplankton mennyiségének évszakos változásai között a számítások gyenge korrelációt mutattak. Egyedül a Belső-tó felszíni vízében a teljes mikrobiális plankton és az algák között találtunk erős negatív korrelációt ($r = -0{,}913$), nagy szignifikanciával ($p \ll 0{,}001$).