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REGIONAL AND CIRCADIAN OXYGEN DETERMINATIONS IN LAKE BALATON CONCERNING THE EUTROPHICATION OF THE LAKE

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Eutrophication this-well known phenomenon in lakes surrounded by cultivated countryside is progressing in Lake Balaton. Attention has been called to this phenomenon repeatedly by SEBESTYÉN (SEBESTYÉN, 1952; 1973). The recent situation expressed as the changing rate of primary production was demonstrated by algal cell countings and by the ^{14}C methodics (HERODEK and OLÁH, 1973; HERODEK and TAMÁS, 1973; 1974; 1975). Similarly OLÁH conducted some measurements on primary production by oxygen determinations (OLÁH 1975; OLÁH 1976 – verb. comm.).

A wider application of this method seemed to be very meaningful because of its simplicity, fast performance and the possibility of the evaluation of the results on the spot (VOLLENWEIDER, 1969), to execute simultaneous or semi-simultaneous studies on wider lake areas in different biotopes, comparing the data immediately to each other and to obtain circadian data.

Purpose of the work was to clear whether extremely high oxygen saturation would appear during summer or autumn 1975, due to remarkable water bloom or water coloration (Vegetationsfärbung) indicating the possibility of a new winter fishkill. Another goal was to study the highly eutrophic south-western lake areas and to check more exactly their northern limits to state whether any expansion can be noticed for 1975 in comparison to the previous years.

Methods

Measurements have been carried out by the Dissolved Oxygen Meter Model 15A (Electronic Instruments Ltd. Richmond Surrey). Temperature and oxygen saturation values were recorded from the surface to the bottom at distances of 0.5 m each. By this way the absolute amounts of dissolved oxygen could be calculated for selected water layers and for the water column as a whole. From time to time control measurements have been conducted by the classical methods of WINKLER and MAUCHA (MAUCHA, 1945–47).

Regional measurements have been executed during windless periods following windy days. It is worth mentioning that in the open water of the lake on windy days the oxygen saturation of the whole water mass ranged around 100 per cent. This situation could be used as comparison for our results during windless periods.

In the lake section near Keszthely (Keszthelyi-öböl, Keszthely-basin, Bay of Keszthely) showing very high productivity (HERODEK and TAMÁS, 1975), some circadian measurements have been carried out. The amounts of dissolved oxygen lost by respiration processes were calculated from samples taken from any depth at night by calm weather under unstratified conditions and in the afternoon from the lower aphotic water layer during stratification. Stability values (S) in mkg/m² were calculated according to RUTTNER (RUTTNER, 1962).

Data of semi-synchronic measurements obtained in the late afternoon within a short time period in different lake areas seem to be well comparable to each other as far as results on fixed stations under similar conditions did not show remarkable variations. The values of oxygen productions calculated are underestimated because of loss of dissolved oxygen by diffusion, especially by high O_2 saturation (e.g. 150 – 200 %). This loss is not included in our calculations.

Though application of this method is restricted in the open water to calm, almost windless periods, its great advantage is to reach comparative results of the lake by one person in the cross-section of Lake Balaton within about a half hour and in its length within 2 to 3 hours.

Results and conclusions

1. *Circadian measurements*. Studies on temperature and oxygen saturation have been performed on 22 – 23th July and 13 – 14th August 1975, at a fixed station in the Bay of Keszthely, near the point marked since years as Station M_0 (SEBESTYÉN, 1960). Measurements were carried on at some occasions in the evening and at night but regularly at one hour intervals from dawn till afternoon *(Figs 1* and *2)*.

From the temperature data the mean values for the upper water layer (layer "A" between surface and 1.25 m depth) and the lower water layer (layer "B" between 1.25 and 2.50 m depths) could be calculated. Form these mean values the stability values (S) became available *(Tables I* and *II)*.

It was evident that during a windless night following the temperature decrease at the surface a reverse temperature stratification occurred. This kind of stratification induced according its negative stability naturally convection currents due to differences in specific gravity. Starting at daybreak (form about 4^{30} a.m. in July and 6^{00} a.m. in August) caused by the warming up of the surface water layers, the temperature instability decreased but still persisted for some time. At this stage the slightest breeze can mix the total water column. Further increase of the surface temperature during the next period leads to positive stratification and in the meantime to increased thermal stability.

Yet in the morning the increased stability values remained low till 8 a.m. on July 23rd and till 10 a.m. on August 14th, not surpassing the values of 0.04 to 0.08 mkg/m². This weak stability still does not interfere the mixing of the layers A and B by gentle water movements. Stability conditions pictured above are in favour to supply the lower water layers (B) with oxygen suitable for fish life and possibly to avoid the development of oxygen-free zones in Lake Balaton near the bottom even at calm periods of longer durations.

TABLE I

Temperature (mean values °C) in A and B and stability ($S = mkg/m^2$) in the Bay of Keszthely on 24th July 1975

Time	3	4	5	6	7	8	9	10	11^{30}	13	14	15	16h
A	22.20	22.04	22.34	22.52	23.01	23.18	23.70	24.08	24.19	24.57	24.42	25.45	25.33
B	22.36	22.20	22.56	22.60	22.65	22.54	22.66	22.84	22.77	22.43	22.38	22.91	22.81
S	−0.029	−0.027	0.041	0.014	0.072	0.040	0.192	0.233	0.267	0.405	0.384	0.498	0.492

A = Upper water layer between 0 and 1.25 m depths. B = lower water layer between 1.25 and 2.50 m

TABLE II

Temperature and stability values in the Bay of Keszthely on 13—14th August 1975

Time	17^{30}	6	8	9	10	11	14	15	15^{30}
A	23.34	21.48	21.70	21.28	21.72	22.42	23.76	23.52	22.68
B	23.38	21.50	21.60	21.18	21.32	21.62	21.76	21.86	21.78
S	−0.007	−0.003	0.017	0.017	0.069	0.141	0.363	0.302	0.343

Further explanation see *Table I*

The stability of the total water column increases during the following morning hours and early afternoon, forming a stratification strong enough to be disturbed only by wind speed above 2 to 4 m/sec ($S = 0.3$ to 0.5 mkg/m^2).

During these hours by calm weather layer A corresponds to the euphotic zone and differs basically from layer B, the aphotic zone *(Figs 1* and *2)*. The oxygen saturation grows gradually in layer A. Because the saturation values in question surmount 100 %, the only explanation are the assimilation processes. On the other hand in layer B, where due to the absence of the necessary light intensity assimilation is negligible or completely blocked, decreasing oxygen saturation could be registered.

Suitable time to measure the rate of respiration (dissimilation) was before dawn between 3 and 4 a.m. (DVIHALLY, 1975), when total circulation could be supposed. The amount of oxygen consumption by organisms was assessed to

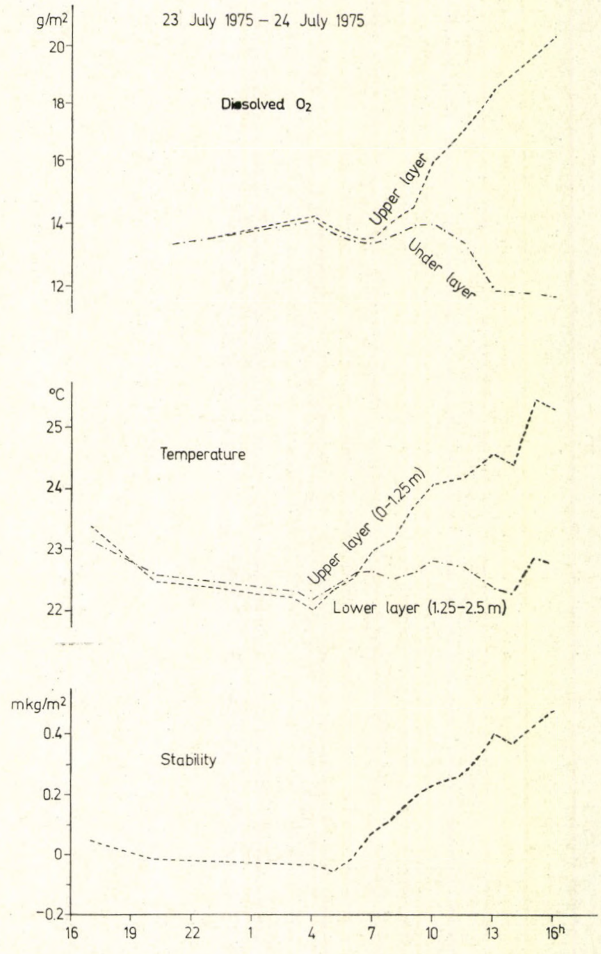

Fig. 1. Changes of temperature and dissolved oxygen in 2.5 m deep water in the upper and the lower water layers on 23—24th July 1975. Daily changes of thermal stability in the whole water column at the same time

be 0.4 g O_2/m^2/hour in each water layer (A and B). This value could not be determined separately in the two layers in the early morning hours because of vertical water movements of different intensity. Under well stratified conditions in the afternoon the respiration value could be determined again but only in the lower water layer (B) without assimilation. The result was the same as at night i.e. 0.4 g O_2/m^2/hour. Thus at the period studied and under conditions in question the estimated respiration values of the whole water column were round 0.8 g O_2/m^2/hour. Using this value as correction, beside the measured net oxygen production values of the gross production could be estimated.

The values of dissolved oxygen were increasing overday in the upper water layers as expected. There was only a slight but gradual increment between 4 and 7 a.m. followed by a rapid increase between 8 and 11 a.m. Afterwards the increase of oxygen saturation slowed down or ceased and even loss of oxygen could be stated. (Comp. DVIHALLY, 1975). A new increment was present in the afternoon. The same tendency appeared summing up the values of layers A and B together *(Tables III* and *IV)*.

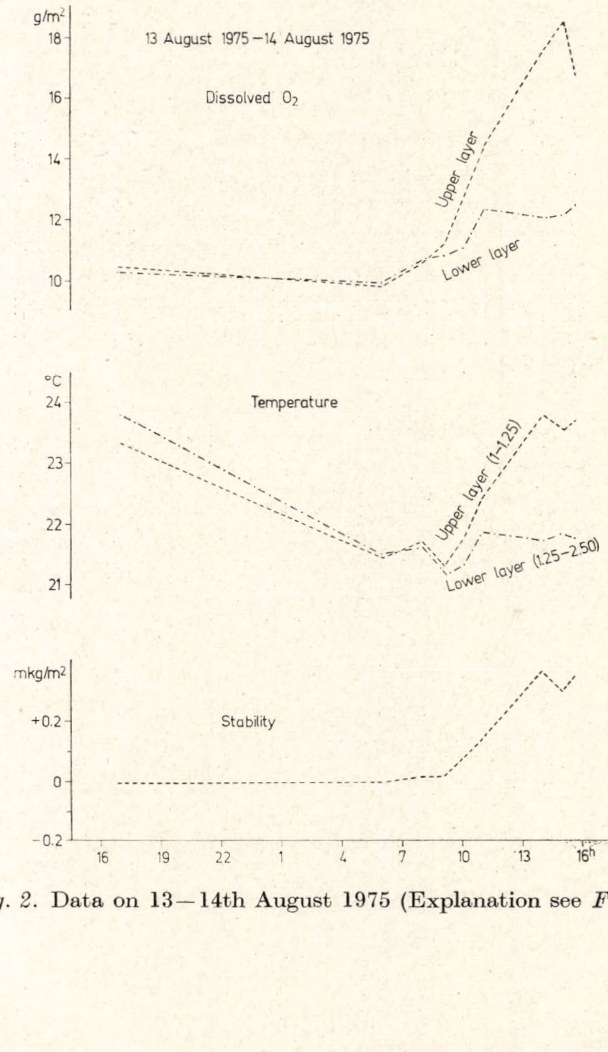

Fig. 2. Data on 13–14th August 1975 (Explanation see *Fig. 1*)

TABLE III

Dissolved oxygen values in the Bay of Keszthely on 24th July 1975 ($O_2 mg/l$).

Time Depth m	4	5	6	7	8	9	10	11^{30}	13	14	15	16h
0.0	11.47	11.42	10.97	11.18	11.00	11.60	11.13	11.16	14.75	15.48	12.80	16.90
0.5	11.43	11.04	10.89	10.80	11.58	11.91	12.82	15.52	15.73	13.76	17.84	17.18
1.0	11.22	10.91	10.80	10.76	11.15	11.34	13.43	13.26	13.88	11.37	15.02	14.85
1.5	11.22	10.91	10.89	10.62	11.46	11.38	11.59	11.23	9.81	10.33	10.09	10.34
2.0	11.22	10.89	10.89	10.72	10.47	10.89	11.02	10.80	9.34	9.35	9.11	8.64
2.5	11.22	10.89	10.47	10.80	10.58	10.80	10.63	9.56	8.93	8.35	8.63	8.32

Dissolved oxygen in g/m^2 on 24th July 1975 (mean values)

Time	3	4	5	6	7	8	9	10	11^{30}	13	14	15	16h
A	14.59	14.19	13.83	13.59	13.58	14.12	14.53	15.91	16.98	18.94	16.41	19.63	20.24
B	14.43	14.03	13.62	13.51	13.37	13.61	13.84	13.96	13.41	11.81	11.92	11.76	11.57
A+B	29.02	28.22	27.45	27.10	26.95	27.73	28.36	29.87	30.39	30.21	28.33	31.39	31.81

A = upper layer; B = lower layer; A + B = total water column

TABLE IV

Dissolved oxygen in mg/l in the Bay of Keszthely on 14th August 1975

Time / Depth m	6	8	9	10	11	14	15	15^{30}
0.0	7.89	8.49	8.84	10.31	11.67	13.71	15.51	13.84
0.5	7.88	8.49	8.90	10.60	11.67	13.86	15.63	13.86
1.0	7.92	8.45	9.04	9.52	11.46	14.36	13.74	12.74
1.5	7.96	8.50	8.78	9.30	10.56	10.75	11.48	11.43
2.0	7.96	8.59	8.65	8.69	9.80	9.02	8.58	9.35
2.5	8.01	8.55	8.54	8.30	8.35	8.59	8.44	8.35
Dissolved oxygen in g/m² on 14th August 1975 (mean values)								
A	9.87	10.59	11.18	12.64	14.48	17.54	18.56	16.76
B	9.96	10.68	10.85	11.07	12.27	12.03	12.14	12.48
A+B	19.83	21.27	22.03	23.71	26.75	29.57	30.70	29.24

Further explanation see *Table III*

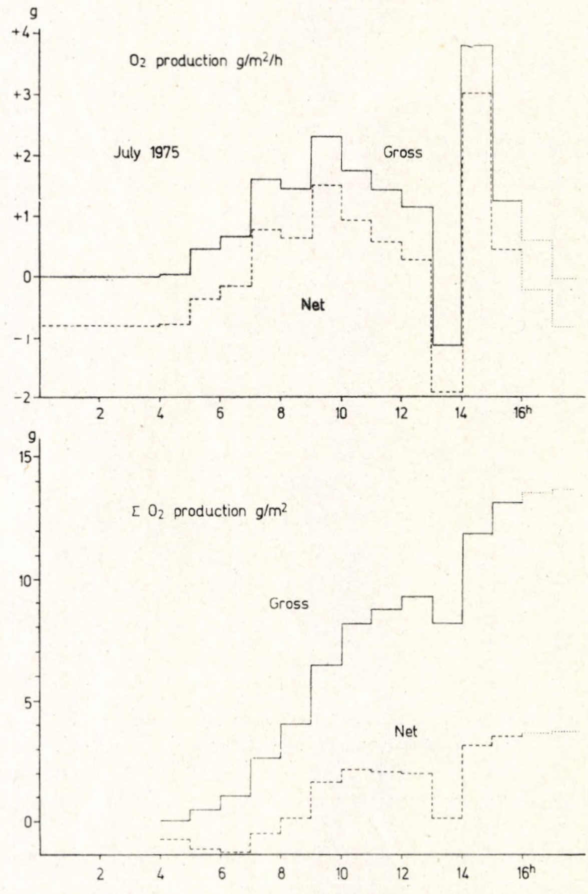

Fig. 3. Net and gross oxygen production in g/m²/hour in the Bay of Keszthely (Keszthely-Basin of Lake Balaton) — upper part. Summarized production from morning till afternoon on 24th July 1975 — lower part

Based on these data the net values of oxygen production could be calculated for time units (hours) and these values could be summed up from dawn till afternoon *(Figs 3* and *4; Tables V* and *VI).* It became evident that after a strong oxygen consumption at night, there followed after daybreak a decrease of the net value of oxygen consumption in the upper water layer (A), which

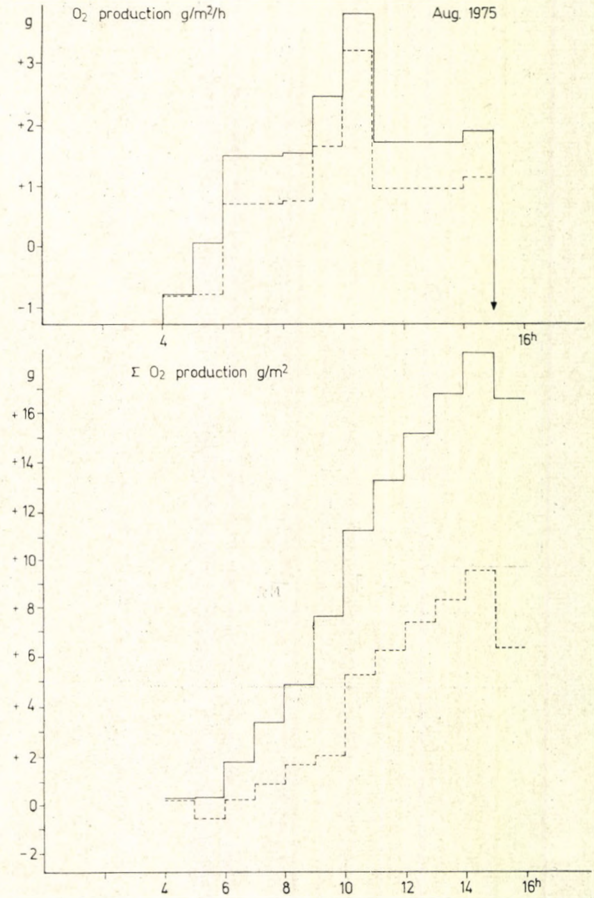

Fig. 4. Oxygen production on 14th August 1975 (Explanation see *Fig. 3*)

affected layer B in a similar way through vertical currents. The stability values (S) increased gradually. As soon as S equalled 0.1 mkg/m², the mixing of layers A and B stopped by calm weather *(Figs 1* and *2).* Finally the sum of oxygen accumulated from daybreak till afternoon reached in the layer A about 8 to 11 g O_2/m² *(Figs 3* and *4).*

To study the conditions in a different way, the total water column was divided into three layers (0 to 1; 1 to 2; 2 to 3 m). The course of the oxygen curves based on these three layers are represented in *Fig. 5.* Accordingly there is during midday a remarkable decrease of the oxygen content in the uppermost

TABLE V

Values of oxygen production in g/m² on 24th July in the Bay of Keszthely

Time	3—4	4—5	5—6	6—7	7—8	8—9	9—10	$10—11^{30}$	$11^{30}—13$	13—15	15—16
Net	−0.80	−0.77	−.035	−0.15	+0.78	+0.64	+1.50	+0.52	−0.09	+1.09*	+0.43
Gross	0.00	+0.03	0.45	0.65	1.58	1.44	2.30	1.32	0.71	1.89*	1.23
Sum Net	−0.80	−1.57	−1.92	−2.07	−1.29	−0.65	+0.85	+1.37	+1.28	+2.37*	+2.80
Sum Gross	0.00	+0.03	0.48	1.13	2.71	4.15	6.45	7.77	8.48	10.37*	11.60

* Mean values from measurements at 13, 14 and 15 hours

TABLE VI

Data on 14th August 1975 (See Table V)

Time	6—7	7—8	8—9	9—10	10—11	11—12	12—13	13—14	14—15	15—16
Net	0.72	0.72	0.76	1.68	3.02	0.94**	0.94**	0.94**	1.13	−2.92***
Gross	1.52	1.52	1.56	2.48	3.82	1.74**	1.74**	1.74**	1.93	−2.12***
Sum Net	0.72	1.44	2.20	3.88	6.90	7.84**	8.78**	9.72**	10.85	7.93***
Sum Gross	1.52	3.04	4.60	7.08	10.90	12.64**	14.38**	16.12**	18.05	15.93***

** Interpolations. *** Extrapolations

water layer, apparently caused by superoptimal light intensities (light inhibition). The oxygen content of the same layer shows increasing tendency in the afternoon. The conditions are different in 1 to 2 m depths where the morning maximum is followed by a gradual diminution till evening. Within 2 to 3 m depth assimilation is not probable, consequently overday only a slight fluctuation of the oxygen values can be expected. This example shows in which important manner circumstances for life can differ in shallow water caused by stratified light and temperature conditions even in huge water masses.

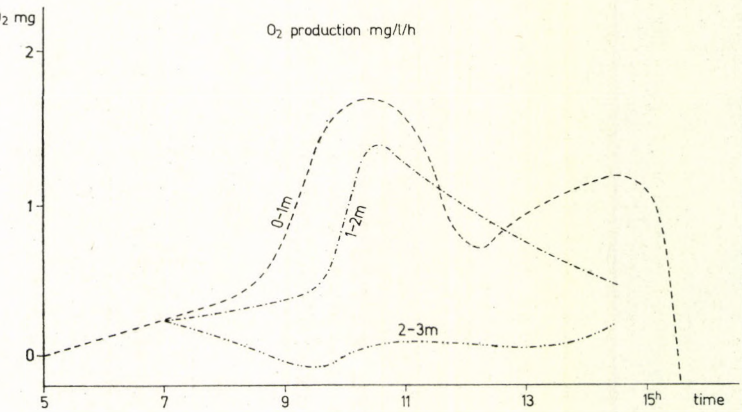

Fig. 5. Oxygen production in the Bay of Keszthely on 24th July 1975. Separately calculated values of the water layers 0 to 1m, 1 to 2m and 2 to 3m

Results of September and October are different from those of the summer months, showing in daytime on calm days only very slight differences in O_2 saturation unsuitable to be evaluated by the method in question.

Comparing the results of the present and the previous years, the recent data seemed to be definitely lower, making autumn or winter alga invasions accompanied by fishkill unprobable. This expectation was confirmed by observations and the fact that noticeable fishkill did not happen during the winter half year 1975–76.

2. *Horizontal studies.* Numerous determinations taking place in the Bay of Keszthely (to be published later) showed that the method discussed is suitable at any time for measurements in wind-protected areas. Semi-synchronic determinations at nearby open water stations (distances not over 200–300 m) showed valuable differences, consequently detailed circadian studies should be carried out at fixed stations.

Surprising low O_2 saturation values were achieved in River Zala, just above its estuary (42–46 %). On the contrary in the open water of the lake at a distance of a few hundred meters from the station mentioned above, already high saturation could be observed at the same time (e.g. 169 % on 14/8/1975).

The actual underwater river flow of the River Zala could be followed besides the well-known determinations of conductivity or Ca^{++} content, by the oxygen conditions. Quite different values could be obtained in the littoral zone, among dense macrophytic underwater vegetation, amidst reed stands etc. These conditions should be studied in the future in details.

The highest O_2 saturation recorded was 220 %. This value indicated together with the moderate green coloration of the water no further eutrophication of the area in 1975.

The differences within the open-water in the Bay of Keszthely, except the areas under the immediate influence of the River Zala, were much smaller than those of the data of the semi-synchronic collections between Keszthely and Tihany *(Fig. 6, Tables VII* and *VIII)*. From these tables – as expected

TABLE VII

Dissolved oxygen in mg/l between Keszthely and Tihany on 23rd July 1975 between 16h and 19h

Station Depth m	M_0	Györök	Szigliget	Badacsony	Szepezd	Udvari	Tihany
0.0	16.90	12.56	11.69	10.40	10.39	10.69	10.97
0.5	17.18	12.26	11.79	10.80	10.92	10.69	11.18
1.0	14.85	12.94	11.52	10.78	10.85	10.69	11.18
1.5	10.34	13.03	11.74	10.69	10.86	10.53	10.83
2.0	8.62	12.90	11.59	10.83	10.25	10.57	10.15
2.5	8.32	12.30	11.72	10.00	10.12	10.09	9.91
3.0		11.27	11.04	10.05	9.81	9.69	9.63
3.5			9.71		8.52	7.99	9.02
Dissolved oxygen in g/m² at the same station and time							
0 – 1.25	20.24	15.74	14.58	13.39	13.49	13.37	13.93
1.25 – 2.5	11.56	16.04	14.60	13.26	13.09	13.08	12.97
0 – 2.5	31.80	31.78	29.18	26.65	26.58	26.45	26.90

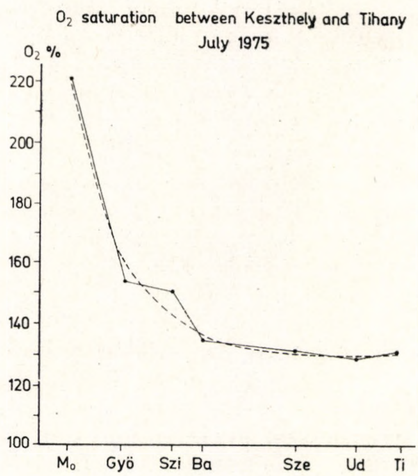

Fig. 6. Data on 24th July 1975 of stations arranged according to their distance from the SW end of Lake Balaton. (M_0 = Keszthely-Basin; Gyö = Balatongyörök; Sz = Szigliget; Ba = Badacsony; Sze = Balatonszepezd; Ud = Balatonudvari; Ti = Tihany). ———— actual values, — — — — ideal curve

TABLE VIII

Dissolved oxygen in g/m² between Keszthely and Tihany on 14th August 1975 between 16h and 19h

Station Depth m	M_0	Berény	Györök	Ederics	Szig-liget	Bada-csony-lábdi	Bada-csony-tomaj	Zánka	Tihany
0 – 1.25	16.76	15.64	15.22	13.81	13.80	11.59	11.57	11.29	10.92
1.25 – 2.5	12.50	10.25	11.13	11.06	11.27	10.31	10.28	10.50	10.94
0 – 2.5	29.26	25.89	26.35	24.87	25.07	21.90	21.85	21.79	21.86

from previous investigations by authors quoted above – it is evident that the oxygen saturation and naturally the rate of primary production in the upper water layer is the highest at the south-western end of the lake, the Bay of Keszthely. There was a gradual decrease of these values during our studies from Keszthely until Badacsony. From there almost uniform results could be achieved till Tihany or based on measurements at other occasions, up to the north-eastern end of Lake Balaton *(Fig. 6)*.

In the meantime there were the lowest saturation values in the lower water layers around Keszthely and Balatonberény. A slight increase could be demonstrated within the area of Balatongyörök and Szigliget followed by newly decreasing values towards NE. Though these decreased values benorth of Szigliget remained always higher than those of the deep water in the Bay of Keszthely.

All previous data on primary production from Tihany in 1972–73 (HERODEK and TAMÁS, 1974), the Bay of Keszthely in 1973–74 together with those of the Szigliget area in 1974–75 (HERODEK and TAMÁS, 1975; HERODEK and TAMÁS, unpublished data), further on the 1974 phosphorus distribution data by TÓTH (TÓTH, 1975), indicate that the highest eutrophy in Lake Balaton is present near Keszthely in the Bay of Keszthely, decreasing from here till the Badacsony area from where on the trophity is at a lower but fairly even level all over the rest of the lake. It could be concluded that there was a definite borderline between the even but less eutrophic lake section to the north and the south-western part of the lake with its gradually increasing eutrophy towards Keszthely. This borderline was situated between Badacsony and Fonyód. It was understood, that there was no remarkable change in the location of this line during the year in question as compared to previous records. That means there was no expansion on behalf of the strongly eutrophic water into the "clear water section" of Lake Balaton in 1975.

Summary

1. The method to determine the productivity of different sections of Lake Balaton by oxygen measurements is suitable due to its simplicity, fastness and valuation in situ by semi-synchronic studies.

2. The thermal stability of Lake Balaton has been studied for the first time. It could be stated that by calm weather due to surface cooling down at night, the thermal stability conditions changed basically in summer-time in the shallow lake, causing vertical mixing of the whole water column. This

process is in particular promoting a suitable oxygen supply of the deeper water layers and is in spite of its short duration an important limnological factor. As soon as the thermal stability (S) surpasses by calm weather overday 0.1 mkg/m^2, the vertical water movements are blocked and microstratification appears. This stratification can be only dissolved by wave action at a windspeed of 2 to 4 m/sec.

3. The value of thermal stability in the open water was at night occasionally negative (−0.029 mkg/m^2 was measured in July and −0.007 mkg/m^2 in August). During daytime by calm weather the stability values increased gradually up to 0.5 mkg/m^2 in a water column not deeper than 250 cm.

4. The amount of dissolved oxygen reached in July 10.8−16.0 mg/l at a temperature of 22.0−25.5 °C. The corresponding values were in August 8 − 15.5 mg/l at 21.5 to 23.8 °C.

5. It is worth mentioning how important life effecting differences (microstratification) can develop within a few hours in shallow (2 to 3 m deep) calm water due to temperature and light conditions in huge water masses.

6. The oxygen saturation values were low in autumn 1975 indicating no alga invasions accompanied by fishkill in the winter half year 1975−76. This hypothesis was assured in time.

7. The rate of oxygen production was decreasing gradually from the Keszthely area till the line between Badacsonytomaj and Fonyód. From thereon even and relatively low values could be noticed up to the NE end of the lake. It could be concluded that there was no further expansion of the highly eutrophic lake section in 1975 as compared with previous years.

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A BALATON OXIGÉNVISZONYAINAK REGIONÁLIS ÉS NAPSZAKOS KUTATÁSA, FIGYELEMMEL A TÓ EUTROFIZÁLÓDÁSÁRA (GYORSMÓDSZER ALKALMAZÁSA)

Entz Béla

Összefoglalás

1. Az oxigénmeghatározáson alapuló módszer egyszerűsége, gyorsasága és helyszíni értékelhetősége révén alkalmas hullámzásmentes vízben a Balaton különböző vízterületei termelési értékeinek összehasonlító vizsgálatára, különösen rövid időn belül végzett „szinkron" vizsgálatokkal.

2. A Balaton hőstabilitási viszonyait eddig nem tanulmányozták. A sekély vizű tóban a nyári időszakban a felszíni éjjeli lehűlés a hőstabilitási viszonyok alapvető megváltoztatása révén konvekciós vízáramlásokat, vagyis vízkeveredést idéz elő. Ez jelentősen hozzájárul a tó mélyebb vízrétegei kedvező oxigénellátásához és mint ilyen, tavi limnológiai szerepe rövid időtartama ellenére is jelentős. Nappal, amikor a stabilitás értéke (S) megnő és meghaladja a 0,1 mkg/m²-t, csendes időben mikrorétegzettség keletkezik, melyet csak 2—4 m/sec-os szél okozta hullámzás képes feloldani.

3. Éjjel a nyílt vízben a hőstabilitás értéke néha negatív lehet (júliusban — 0,029, augusztusban pedig — 0,07 mkg/m²-t mértünk). Nappal szélmentes időben a stabilitás értéke fokozatosan megnő, így a 2,5 m-nél nem mélyebb vízoszlopban 0,5 mkg/m²-es értéket is mértünk.

4. Az oldott oxigén mennyisége júliusban 20,0, ill. 23,5 °C mellett 10,8, illetőleg 16,0 mg/l volt. Az augusztusi hasonló értékek 8,0 és 15,5 mg/l, illetőleg 21,5 és 23,8 °C voltak.

5. Érdekes, hogy milyen említésre méltó, limnológiai jelentőségű mikrorétegzettség alakulhat ki néhány órán belül egy sekély (2—3 m mély) tó nyílt vizében csendes időben a hőmérséklet és a fényviszonyok hatására.

6. Az őszi oxigéntelítettségi értékek 1975-ben alacsonyak voltak, ami egy újabb, az előző évihez hasonló téli algainvázıót, illetőleg halpusztulást nem tett valószínűvé. A tények a feltevést igazolták.

7. Az oxigéntermelés nettó értéke Keszthely térségétől Badacsonytomaj—Fonyód vonaláig egyenletesen csökkent és onnan szinte változatlan volt a tó északkeleti végéig. Eszerint 1975. év folyamán az előző évhez viszonyítva nem növekedett az erősen eutróf tófelület nagysága.