PRIMARY PRODUCTION BY DIURNAL VARIATION METHOD IN LAKE SUWA

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ABSTRACT

A high gross production of about 40 g $O_2.m^{-2}.d^{-1}$(15 g $C.m^{-2}.d^{-1}$) was recorded in an eutrophic lake in summer. It was calculated from the diurnal variations in dissolved oxygen and in total carbon dioxide content in the water column of Lake Suwa. The gross production estimated from in situ method was only 6.0 g $O_2.m^{-2}.d^{-1}$. The community enclosed in a bottle in eutrophic lakes gave an extremely low activity in comparison with the activity under the natural condition. The light utilization efficiency of phytoplankton was 2.6 % in Lake Suwa.

key words : Primary production, Diurnal variation, Light utilization, Lake Suwa

INTRODUCTION

A high gross production of about 40 g $O_2.m^{-2}.d^{-1}$(15 g $C.m^{-2}.d^{-1}$) was estimated in a eutrophic lake in summer. It was calculated from the diurnal variations in dissolved oxygen (DO) and in total inorganic carbon (TIC) in the water column at the lake center of Lake Suwa. This rate of phytoplankton production is about 2 times higher value than the common knowledge of the maximum rate of 6-10 g $C.m^{-2}.d^{-1}$ (Wetzel 1975; Talling 1975). And this is also over 2 times higher than the maximum value of 14.1 g $O_2.m^{-2}.d^{-1}$(5.3 g $C.m^{-2}.d^{-1}$) among the Japanese IBP data (Nakanishi, 1975). This is higher value than the gross production of 9.54 g $C.m^{-2}.d^{-1}$ (25.3 g $O_2.m^{-2}.d^{-1}$) in a hypertrophic Lake Kasumigaura in Japan (Takamura et al. 1987).

It is believed that the production rate of phytoplankton in aquatic environment is about one order lower than the terrestrial ecosystem (Wetzel 1975; Odum 1971; Kira 1975). However, the rate estimated from the diurnal variation in the environmental parameters may be the equal order to terrestrial communities.

In this paper the author describes an observation on an eutrophic lake Suwa in summer. The high rate of gross production was discussed in comparison with other observations on Lake Suwa. The production rate of this lake may be equal order of the terrestrial communities.

PRINCIPLE TO ESTIMATE PRODUCTION

The oxygen content in the surface water is sometimes in over saturated condition in eutrophic lakes in summer. Some amount of DO under this condition may escape from the water surface to the atmosphere. The estimation of this amount requires many assumptions. If the diffusion (escape) of oxygen from the surface to atmosphere is negligibly small, the production rate can be calculated with the stock difference in DO in the water column between the minimum and the maximum. This work is an attempt to estimate the production rate on this assumption.

The oxygen production by photosynthesis occurs under the sunshine. However, the respiration of the biological community goes on a whole day. And almost same diurnal variation is observed in every day in any lake. This means the net oxygen production during 24 hours in the water column is nearly equal zero. And the standing stock change of phytoplankton in the column is not easily detected within short days.

If the respiration rate in the daytime equals to the rate in the nighttime and if there is no significant gas exchange between the atmosphere and the water surface, the gross oxygen production (Pg) by photosynthetic organisms should be nearly equal to the total respiration (R) by biological community in the water column during 24 hours. These (Pg and R) should be equal to the double amount of the difference between the minimum DO content and the maximum DO content in the water column during 24 hours.

STUDY SITE AND METHOD

Lake Suwa is a shallow eutrophic lake located in the central part of Japan (36°03'N, 138°05'E). It is 759 m in altitude and has a maximum depth of 6.5 m, a mean depth of 4.1 m and a surface area of 14.45 km^2. Observation was done on fine and calm days of 24-25 August, 1982 (Table 1). The water at every meter depth was taken with a Van Dorn water sampler at the lake center. DO was determined by the Winkler method. Total inorganic carbon (TIC) was determined by the method of Satake et al. (1972). The diurnal variations of concentrations of DO and TIC in the water column were observed. Chlorophyll *a* was determined by the method of Lorenzen (1967). The primary production by the light-dark bottle method was measured by the 24 hours' *in situ* incubation.

The Secchi disk transparency was 73 cm. The mean chlorophyll concentration in the euphotic layer (0 m to 2 m) was 61 mg chl $a.m^{-3}$ (Figure 1). The amount of chlorophyll *a* from the surface (0 m) to the bottom (6m) was 227 mg chl $a.m^{2}$.

Table 1 Diurnal variation of water temperature (°C) in Lake Suwa.

Depth (m)	24 AUG 06:00	14:40	20:30	25 AUG 06:30
0	24.0	26.0	24.4	24.7
1	24.1	25.6	24.3	24.7
2	24.2	24.1	24.1	24.7
3	23.1	22.9	24.0	22.6
4	20.4	22.2	21.6	19.9
5	19.6	19.7	20.0	19.2
6	19.3	19.4	19.5	19.1

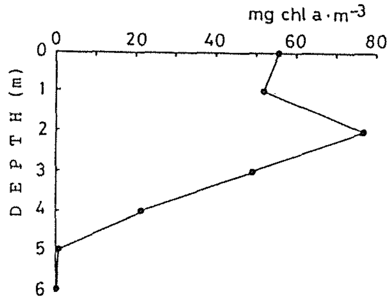

Figure 1 Vertical profile of chlorophyll a at the lake center.

RESULTS

DIURNAL VARIATION IN DO IN THE WATER COLUMN

DO concentration in early morning was homogenous from the surface to 2 m depth. It was about 140 % saturation (Figure 2). It increased by photosynthesis and reached over 200 % saturation in the surface water in the afternoon. DO concentration in 3-4 m depth increased in the daytime.

DO stock difference in the column between the stock at 06:00 on 24 August and the stock at 14:40 was 14.2 g $O_2.m^{-2}$ (Table 1). And the stock difference of this maximum from the minimum in the following morning was 17.9 g $O_2.m^{-2}$. The average was 16.1 g $O_2.m^{-2}$. The rates of the gross production and the respiration a day became 32.2 g $O_2.m^{-2}.d^{-1}$ on the basis of the above assumption.

DIURNAL VARIATION IN TIC IN THE WATER COLUMN

The low concentration of TIC in the surface water was 9.5 g $CO_2.m^{-3}$ at 14:40 on 24 August (Table 2). The high concentrations in the surface water were 18.7 g $CO_2.m^{-3}$ at 06:30 on 24 August and 15.5 g $CO_2.m^{-3}$ at 06:30 on 25 August. The difference of the maximum standing stock of TIC at 06:30 on 24 August from the minimum at 14:40 was 29.3 g $CO_2.m^{-2}$. And the difference of this maximum from the minimum in the following morning was 34.1 g $CO_2.m^{-2}$. The average was 31.7 g $CO_2.m^{-2}$. The rate of the gross assimilation became 63.4 g $CO_2.m^{-2}.d^{-1}$ on the basis of the above assumption. This could be converted to 46.0 g $O_2.m^{-2}.d^{-1}$ as the photosynthetic quotient, PQ was 1.0 (Strickland 1960). This production rate calculated by TIC change was higher than the rate calculated by DO change.

Table 2 Diurnal variation in DO ($mg\ O_2.l^{-1}$) and DO standing stock ($g\ O_2.m^{-2}$) in the water column in Lake Suwa.

Depth (m)	24 AUG 06:00	14:40	20:30	25 AUG 06:30
0	10.42	15.21	10.54	10.82
1	10.43	14.49	10.39	10.76
2	10.66	13.28	10.21	10.53
3	8.91	9.52	9.86	7.64
4	5.13	8.27	7.77	5.00
5	3.79	4.44	4.39	1.89
6	2.52	3.06	3.28	0.75
stock	45.41	59.55	49.55	41.62

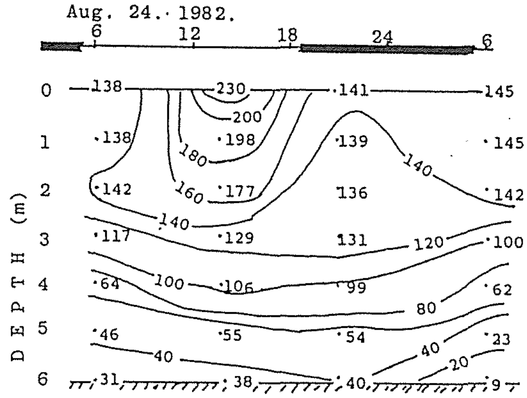

Figure 2 Depth-time distribution of oxygen saturation(%) at the lake center.

Table 3 Diurnal variation in TIC ($mg\ CO_2.l^{-1}$) and TIC standing stock ($g\ CO_2.m^{-2}$) in the water column in Lake Suwa.

Depth (m)	24 AUG 06:00	14:40	20:30	25 AUG 06:30
0	18.7	9.5	18.7	15.5
1	15.5	9.5	16.0	15.0
2	15.5	11.0	16.0	15.0
3	21.0	17.5	18.7	22.0
4	28.0	19.2	23.0	27.5
5	32.0	30.0	30.5	35.5
6	34.6	35.2	34.5	41.5
stock	138.7	109.4	130.8	143.5

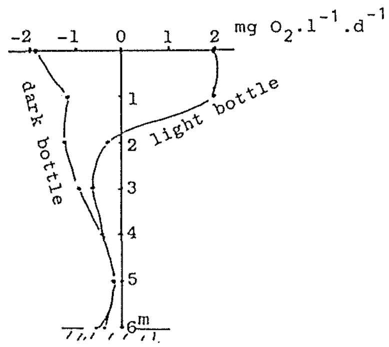

Figure 3 Oxygen change in both light and dark bottles during an in situ incubation of 24 hours.

PRODUCTION BY *in situ* METHOD

The result of *in situ* light-dark bottle method of 24 hours' incubation is shown in Figure 3. The net increase in the bottles was only marked at 0 m and at 1 m. The dark bottle was marked the minus value at any depth. The high respiration rate was observed in the dark bottles in the upper layer. The gross production rate, the respiration rate and the net production rate in the water column were 6.0 g $O_2.m^{-2}.d^{-1}$, 5.2 g $O_2.m^{-2}.d^{-1}$ and 0.8 g $O_2.m^{-2}.d^{-1}$, respectively.

DISCUSSION

DATA DIFFERENCE BETWEEN DIURNAL VARIATION METHOD AND *in situ* METHOD

The highest respiration rate at 0 m was observed only 1.89 g $O_2.m^{-3}$

$\cdot d^{-1}$ by *in situ* incubation. However, the decrease of DO concentration in the actual surface water (0 m) was 4.59 g $O_2.m^{-3}$ during the half day (Table 1). It means the community enclosed in a bottle gives an extremely low activity in comparison with the activity under the natural condition. The gross production rate of 6.0 g $O_2.m^{-2}.d^{-1}$ observed *in situ* method was extremely low activity in comparison with the rates estimated from DO and TIC variation in the water column. The rates of 32.2 g $O_2.m^{-2}.d^{-1}$ calculated by DO variation and 46.0 g $O_2.m^{-2}.d^{-1}$ calculated by TIC variation may show the real activity. The production rate estimated by the diurnal variations of DO and TIC were marked 5 and 8 times higher than the rate by the 24 hours' *in situ* method.

The surface water was an extremely over saturated condition in DO in the afternoon on this observation. And it was very low concentration in TIC. DO concentration in the surface water even in the early morning was over-saturated condition. This calculation was done on the assumption of that the diffusion (escape) of oxygen from the surface to atmosphere was negligibly small. However, there was some possibility to escapee the oxygen from the surface to the atmosphere. Therefore, the real production rate should be higher than this rate estimated from the apparent variation without this correction.

ON THE PRODUCTION RATE BY THE DIURNAL VARIATION METHOD MEASURED BY OTHER AUTHORS IN LAKE SUWA

Maruyama et al. (1969) observed the diurnal DO variation at every 2 hours at 4 m depth site on 18 July, 1968. The minimum standing stock in the water column was recorded at 7:00 in the morning and the maximum standing stock was recorded at 17:00 in the evening. The gross production per day could be calculated to 28.18 g $O_2.m^{-2}.d^{-1}$.

Koyama et al. (1972) measured the diurnal variation of TIC in the water column on 3-4 August, 1968 and reported 7.2 g $C.m^{-2}$ of the net production during the daytime. This value was equivalent to 19.2 g $O_2.m^{-2}$. When the net production per day was zero, the gross production should be 38.4 g $O_2.m^{-2}.d^{-1}$.

Okino et al. (1969) observed the diurnal DO variation in the water column on the same day of Koyama's observation. They did not calculate the production from this diurnal variation. But the produc-tion rate was measured by the *in situ* method of 24 hours' incubation on the following day. The DO standing stock in the water column was estimated from their figure. The minimum standing stock of 32.62 g $O_2.m^{-2}$ in the water column was recorded at 6:30 and the maximum standing stock of 52.0 g $O_2.m^{-2}$ was recorded at 17:00. The difference was 19.4 g $O_2.m^{-2}$ and the gross production per day was 38.8 g $O_2.m^{-2}.d^{-1}$. This rate coincided to the rate reported by Koyama et al. 1972. However the gross production, the respiration and the net production measured by *in situ* method on the following day were 2.79, 2.54 and 0.25 g $O_2.m^{-2}.d^{-1}$, respectively. The Suwa group of the JIBP adopted these low rates measured by the dark-light bottle method as an actual activity (Sakamoto et al. 1975).

The enclosure experiment was done on 1 August 1972. The diurnal variation in DO in the water column at the outside of the enclosure was measured to evaluate the change of the environmental condition (Kurasawa et al. 1972). The maximum standing stock of DO_2 in the column was 33.8 g $O_2.m^{-2}$ and the minimum was 21.6 g $O_2.m^{-2}$. From these values, the gross production was calculated to 24.4 g $O_2.m^{-2}.d^{-1}$. However the low activities were reported by *in situ* method on the following day. The gross production, the respiration and the net production were 13.8, 8.97 and 4.85 g $O_2.m^{-2}.d^{-1}$, respectively.

Mashiko (1975) observed the diurnal variation in TIC in the column at the lake center on 3-4 September, 1972. It was calculated from his table that the minimum standing stock of TIC in the column was 28.2 g $C.m^{-2}$ in the daytime and the maximum was 34.2 g $C.m^{-2}$. The apparent difference of 6.0 g $C.m^{-2}$ (16 g $O_2.m^{-2}$) was due to the net photosynthesis during the daytime. This rate was equivalent to 32.0 g $O_2.m^{-2}.d^{-1}$ as the gross production and the respiration per day.

However the production data by in situ method was adopted as the formal one on Lake Suwa for JIBP-PF group (Sakamoto et al. 1973 and 1975). The maximum gross production rate was 14.1 g $O_2.m^{-2}.d^{-1}$ (5.3 g $C.m^{-2}.d^{-1}$) in summer of 1971. This rate was extremely low rate in comparison with the average of 34.3 g $O_2.m^{-2}.d^{-1}$ (12.9 g $C.m^{-2}.d^{-1}$) estimated from the diurnal variation (Table 4).

Table 4 Comparison of gross production rate (g $O_2.m^{-2}.d^{-1}$) estimated by diurnal variation in Lake Suwa.

Original data reported by	Rate (Pg)	parameter
Maruyama et al. 1969	28.2	O_2
Koyama et al. 1972	38.4	CO_2
Okino et al. 1969	38.8	O_2
Kurasawa et al. 1972	24.4	O_2
Mashiko 1975	32.0	CO_2
This study	32.2	O_2
This study	46.0	CO_2
average	34.3	

CONCLUSION

Ordinary measurements performed on isolated samples of natural communities are usually called the light-dark bottle method (so-called in situ measurement). In this case, certain environmental factors, as light and temperature will be almost the same in both the isolated and non-isolated communities; whereas, other factors, such as turbulence, nutrient replenishment, grazing, etc., may more or less differ in the isolated samples from natural conditions (Vollenweider 1969). When natural phytoplankton communities are enclosed into the glass bottle, it is usually observed that the phytoplankton sinks and flocks at the bottom of a bottle. The measurement for the primary production is performed under above condition without any caution and the result by the light-dark bottle method is adopted as the actual activity. The natural phytoplankton communities are given a shock by the enclosing into a bottle and the communities are in the special condition. Therefore the activity in a bottle under above condition may be low activity in comparison with the actual activity under natural environment.

The activity estimated directly from non-isolated communities in the natural environment represents the apparent actual activity. If the amount of the gas exchange between the atmosphere and the water surface is a negligible quantity and if the water mass does not move, this apparent activity in the water column may coincide to the actual activity. However, the condition of the water surface on a calm day in summer is always over saturated of DO. If the apparent activity estimated from the diurnal variation is corrected by the amount of DO escaped, the actual activity may be higher value than the calculation without the correction.

The average activity of the gross production in Lake Suwa in summer is 34.3 g $O_2.m^{-2}.d^{-1}$ (12.9 g $C.m^{-2}.d^{-1}$). Talling (1975) reported that technically satisfactory estimations exceeded 10 g $C.m^{-2}.d^{-1}$ were extremely rare, even in densely populated habitats. However, Talling et al. (1973) reported 57 g $O_2.m^{-2}.d^{-1}$ (21.4 g $C.m^{-2}.d^{-1}$) estimated from the diurnal variation in an Ethiopian soda lake as the upper limit productivity. The high productivity in this report may be one of the highest production rates in eutrophic environments.

The solar radiation measured at Suwa hydrobiological station was 5,371 $Kcal.m^{-2}.d^{-1}$ on the observation day and 4,946 $Kcal.m^{-2}.d^{-1}$ on the previous day. The average gross production was 39.1 g $O_2.m^{-2}.d^{-1}$ in this report. One mole of oxygen evolution by photosynthetic process represents 112.3 Kcal. The phytoplankton required 137.2 $Kcal.m^{-2}.d^{-1}$ by photosynthesis. The efficiency of light utilization in Lake Suwa was about 2.6 per cent. It is well-known that the efficiency of utilization of light energy by phytoplankton in aquatic systems is generally much lower than photosynthetic efficiency of terrestrial systems. Nearly all of the efficiencies are less than 1 per cent (Brylinsky and Mann 1973; Wetzel 1975). It might be presupposed that the aquatic environment is much less green. However, almost all data compiled in texts are the data taken by the light-dark bottle method. The efficiency of light utilization in an eutrophic lake as Lake Suwa may be the same level of the efficiency (2.0-3.0 per cent) of forests (Kira 1975). If the activity in an aquatic environment is measured by the diurnal variation method, the efficiency of light utilization will be the same order as the terrestrial systems.

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