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By CORNELIUS I. WEBER

INTRODUCTION

Many methods (1) have been employed to measure the organic production of phytoplankton communities in natural waters. These methods include measurements of, (a) the ash-free weight of seston, (b) the chlorophyll content of the water, (c) phytoplankton abundance, (d) plant volume, (e) oxygen evolution, and (f) the assimilation of carbon-14. The introduction (3) of a simple technique for the application of carbon-14 to production studies has opened the way for a more direct approach to the problem. Because the significance of data obtained by the use of indirect methods is necessarily obscure, production studies frequently employ two or more methods. Although the carbon-14 method is considered to give a direct measurement of production, it was decided that a more comprehensive picture of production factors would be obtained by measuring both oxygen evolution and carbon-14 assimilation. The data reported were collected in June, July, and August of 1957, during the initial phase of a project organized in June 1957 by Dr. K. D. Carlander, Department of Zoology and Entomology, and Dr. J. D. Dodd, Department of Botany and Plant Pathology, for the purpose of measuring primary production in some Iowa lakes.

MATERIAL AND METHODS

Light and Dark Bottle Method

The oxygen method involves the use of light and dark bottles. Water taken from a given level is used to fill a clear glass bottle, and a similar bottle which is placed in a dark container. The water is analyzed for its initial oxygen content. Both bottles are suspended at the level from which the water is taken. At the end of the exposure period the bottles are analyzed for oxygen content. Differences in the oxygen concentration between the light and dark bottles are interpreted as gross production. Differences in the oxygen concentration between the light bottles and the samples at time zero are interpreted as net production.

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Carbon-14 Method

A known amount of C^{14} activity, in the form of $Na_2C^{14}O_3$, is added to a water sample. The sample is suspended in the lake in a clear glass bottle for a selected period of time (with the light and dark bottle). Upon removal, the sample is filtered, and the residue is acidified to remove inorganic C^{14}, dried, and counted on the filter. The activity of the residue is an index of the quantity of carbon assimilated.

Field Procedures

One sampling station was established in each of the following areas; 1. Miller's Bay, 2. West Okoboji, 3. East Okoboji. The depth of the water at these stations was 6 meters, 17 meters, and 5 meters respectively.

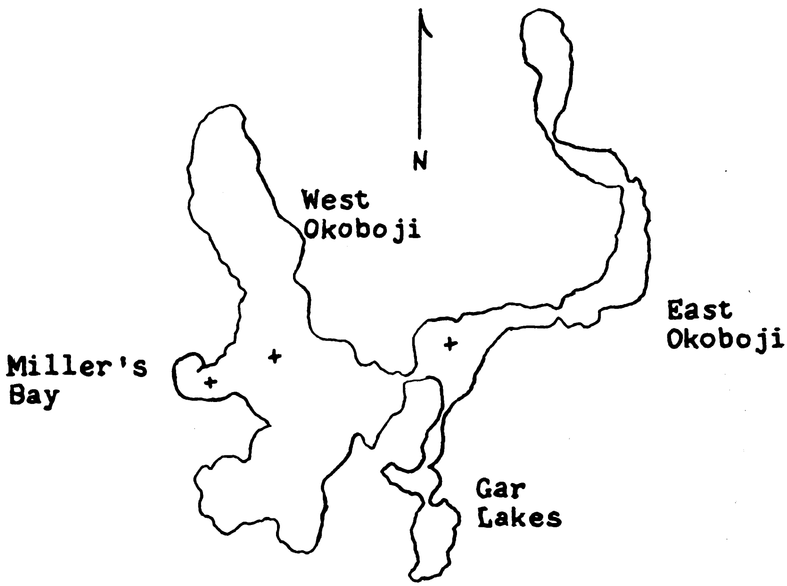

Figure 1. Sampling stations.

Samples were taken with a 3-liter Kemmerer sampler. One sample volume was utilized as five 300 ml-subsamples in the following manner; (a) for carbonate and bicarbonate determination, (b) for determination of initial dissolved oxygen, (3) in a clear bottle, (4) in a darkened bottle, and (5) in a clear bottle to which carbon-14 was added. The capacity of the sampler permitted the overflow of 300 ml for each subsample. Clear, glass-stoppered, B.O.D. bottles were used. The carbon-14 was dispensed with a hypodermic syringe bearing a 5-inch needle. The light bottle and carbon-14 bottle were suspended in wire holders. The dark bottle was placed in a closed metal container. The bottles were usually left in the lake from sunrise to sunset. When removed from the lake at the end of the exposure period, bottles to be analyzed for oxygen content were given immediate preliminary treatment. Bottles containing carbon-14 were placed in closed metal containers.

Laboratory Procedures

Standard methods (6) were used to analyze subsamples. Oxygen determinations were made with the Winkler method. Phenolphthalein and methyl orange were used as indicators for the determination of carbonate and bicarbonate. Oxygen data were converted to mg. of carbon fixed per liter per day by making the assumption that one mole of oxygen was released for each mole of carbon fixed. The true values of the photosynthetic quotients of the phytoplankton communities studied were not known. The values shift as environmental conditions change. Measured values of this ratio usually approximate 1.0, but higher values have been suggested (2).

A $BaCO_3$ self-absorption curve was determined using the dilution method. The activity of an aliquot of $Na_2C^{14}O_3$ solution was determined at zero plate thickness. Aliquots of the subsamples containing carbon-14 were filtered on analytical paper. Algae plates were of less than 0.1 mg per cm^2 thickness and were considered to have zero thickness. All plates were counted with the same geometry. The carbonate and bicarbonate content of the lake water was used as a measure of the total inorganic carbon available for photosynthesis. The ratio of total carbon to carbon-14 was expressed as mg of total carbon per microcurie of carbon-14. The C^{14} activity of the algae was converted to mg of carbon fixed by comparing the counting rate with the activity of a labelled barium carbonate precipitate having zero thickness, and by considering the specific activity of the inorganic carbon assimilated. A factor of 1.064 was used to correct for the isotope effect. There is some evidence that respiratory carbon dioxide, and some respiratory intermediates are recycled into the photosynthesis pathway during the photoperiod. Under those conditions the loss of assimilated carbon-14 would be negligible. It is generally agreed that the carbon-14 method measures net photosynthesis.

Results and Discussion

Production rates assume more meaning when expressed as carbon fixed per square meter of surface area. However, the sampling intervals used in the preliminary studies do not permit conversion to these units (exception noted later). Values reported are only for the photoperiod. It is generally recognized that variations in the photosynthetic yield among individual samples are large. The mag-

Table 1
Primary Production of West Okoboji Lake in mg of Carbon/liter/day

Depth / Method	1 Meter Oxygen			5 Meters Oxygen			9 Meters Oxygen		
	Gross	Net	C^{14}	Gross	Net	C^{14}	Gross	Net	C^{14}
Date									
6/28	0.24	0.20	0.052	0.30	0.13	0.046	0.25	0.00	0.017
7/8	.21	.015	.029	.22	.00	.029	.00	.00	.0072
7/16	.12	.045	.021	.068	.0075	.013	.030	.00	.010
7/17	.045	.045	.015	.091	.045	.0087	.015	.015	.0057

nitude of error of the data collected by either method is not known.

West Okoboji Lake and Miller's Bay

West Okoboji does not support a large plankton population. The lake is usually sharply stratified by early July and the epilimnion extends to a depth of 10-12 meters. Because the transparency of the water is high the entire epilimnion is undoubtedly included in the photic zone. Classification of the lake on the basis of its production rate (Table 1) would place it intermediate between oligotrophic and eutrophic. The significance of the higher production rates at the 5 meter level is not known. They may result from photoinhibition of surface algae. Production rates in some natural communities have been found (1, 4) to reach a maximum at the depth where the illumination was 25-50% of full sunlight.

The production rates of Miller's Bay (Table 2) were found to be similar to those of the lake proper. Rates, however, declined more rapidly with depth.

Table 2

Primary Production of Miller's Bay in mg of Carbon/liter/day

Depth Method	1 Meter Oxygen		C^{14}	3 Meters Oxygen		C^{14}
	Gross	Net		Gross	Net	
Date						
7/17/57	0.26	0.014	0.020	0.17	0.075	0.018
7/23	.17	.16	.015	.13	.098	.016
7/30	.16	.015	.021	.17	.053	.024
7/30*	.27	.098	.036	.21	.11	.051

*Sum of two 7-hour periods.

East Okoboji Lake

East Okoboji supports a high plankton population. The production rates (Table 3) are much higher than those of West Okoboji or Miller's Bay. Blooms of the blue-green algae, *Aphanizomenon* and *Microcystis,* were observed, in that order, in July and August. On calm nights the algae concentrate in the surface waters. Samples taken near the surface at day-break have extremely high populations and show high production rates. After day-break the mixing action of the wind brings about a more uniform distribution of the plankton.

The morning of July 24, 1957 was calm. A large surface accumulation of algae was observed. Subsamples were exposed for varying periods of time to determine the differences in observed production rates. It was found that the total production of a series of short term exposures was less than the production obtained when the exposure period was long. Plankton communities with uniform populations show the opposite tendency. The data in Table 4 are presented to illustrate the variation encountered in production studies.

Table 3

Primary Production of East Okoboji Lake in mg of Carbon/liter/day

Depth	1 Meter			3 Meters		
Method	Oxygen		C^{14}	Oxygen		C^{14}
	Gross	Net		Gross	Net	
Date						
7/3	1.08	0.89	0.38	0.00	0.00	0.012
7/9	3.41	3.10	1.12	.030	.00	.0093
7/23	1.93	1.63	.56	.17	.00	.036
7/24	1.95	1.56	.19	.218	.030	.016
8/12	1.62	1.22	.54	.13	.00	.19

Table 4

Primary Production of East Okoboji Lake, July 24, 1957, in mg of Carbon/liter

Depth	1 Meter		3 Meters	
Method	Oxygen (Net)	C^{14}	Oxygen (Net)	C^{14}
Exposure				
600AM-1030AM	0.46	0.045	0.00	0.010
1030AM-300PM	.90	.11	.030	.0052
300PM-730PM	.20	.031	.00	.0013
Totals	1.56	0.186	0.030	0.0165
6:00AM-7:30PM	3.00	0.39	0.00	0.0054

Table 5

Primary Production of East Okoboji Lake, August 12, 1957, in Grams of Carbon/m²/day.

Method	Oxygen		C^{14}
	Gross	Net	
Depth			
Surface	6.16	5.80	1.22
1 M	1.46	1.02	.70
2 M	.090	.00	.44
3 M	.13	.00	.19

A production profile of East Okoboji Lake is shown in Figure 2. If the curve is assumed to be exponential (it probably follows the absorption curve of light), the integrated net production rate for August 12, was 3.23 grams of carbon per square meter of surface area per day. The integrated gross production for the first three meters was 4.22 grams of carbon per square meter per day. Production was largely confined to the first two meters.

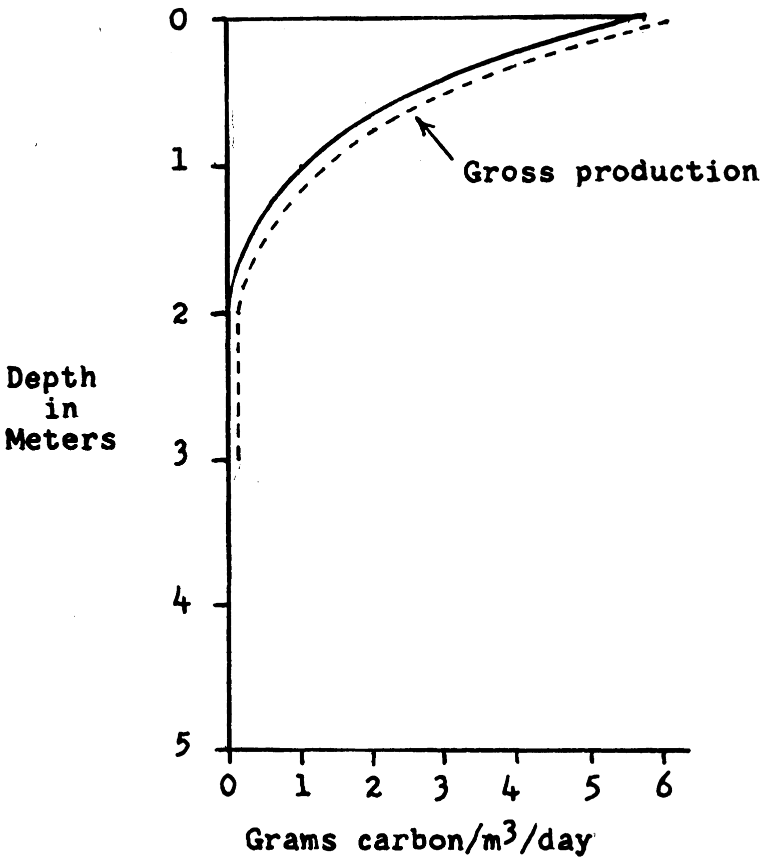

Figure 2. Net primary production of East Okoboji Lake, August 12, 1957, in grams of carbon/m²/day.

Summary

Measurements of primary production were made with the light and dark bottle method and carbon-14. The rates determined by the oxygen method were generally higher than those obtained by use of carbon-14, and on occasion were ten or more times as great. The integrated gross and net production rates of East Okoboji Lake, August 12, 1957, were 4.22 and 3.23 grams of carbon per square meter per day respectively.

Acknowledgments

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