
A COMPARISON OF PHOTOSYNTHETIC YIELDS IN THE MAUMEE RIVER, STEIDTMANN'S POND, AND URSCHEL'S QUARRY UNDER NATURAL CONDITIONS[1]

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ABSTRACT

A study of photosynthetic rates under natural conditions in the Maumee River, Steidtmann's Pond, and Urschel's Quarry, computed from pH and O_2 measurements in the natural habitat at 4- to 6-hr intervals, revealed average rates of 1.4 to 20.9 μmol CO_2 absorbed per liter of water per hour, and 0.27 to 1.32 μmol CO_2 absorbed per μliter of plant matter per hour, with 0.1 to 35.0 μmol O_2 evolved per liter of water per hour, and about 0.012 to 2.22 μmol O_2 evolved per μliter of plant matter per hour. These values lie within the range of values for ponds, quarries, lakes, and streams reported in the literature. They are much lower than published values for clear flowing streams. It seems likely that poor light supplies resulting from suspended silt particles cancel any ecological advantage the turbulence of flowing water might provide. The ratios of O_2 production to CO_2 absorption were close to unity except during the spring flood period when ratios below 0.1 were observed, similar to ratios found in a shallow pond near Bowling Green.

This study, begun on October 6, 1961, represents a limnological investigation of a portion of the Maumee River near the town of Waterville, Ohio.

The study is concerned with photosynthetic yields computed for the river, using carbon dioxide, pH, and O_2 change during specified time intervals.

The photosynthetic yields determined for the Maumee River are compared to those of a shallow fresh water pond, a water-filled limestone quarry, and Lake Erie to show the differences encountered in these contrasting environments.

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METHODS

Samples were collected from several sampling areas, and the collection hours varied with the area. From October 6 to November 11, 1961, the samples were collected at 2200, 0600, 1000, 1400, 1800, and 2200. From November 17, 1961, to February 24, 1962, the samples were collected at 1800, 0700, 1250, and 1800, and from March 3, 1962, to May 13, 1962, the samples were collected at 0700, 1300, 1900, and 0700.

The samples taken during the period October 6 to February 24 were collected with a Kemmerer water sampler at a depth of 0.5 m, while the samples taken during the March 3 to May 13 period were collected with a sampler borrowed from the Waterville Water Treatment Plant. The samples were taken just above the bottom, where the depth varied from less than 0.1 m to over 2 m. The water collected was analyzed for pH with a Beckman Model G pH Meter. At each collection interval, CO_2 was determined by titrating a 100-ml sample to a phenolpthalein end-point, and O_2 was determined by the unmodified Winkler technique (Welch, 1948). Phytoplankton abundance was determined using a modification of the Kolkwitz method as described by Verduin (1959).

Carbon dioxide change was measured by relating pH values for each collection interval to a differential titration curve (Verduin, 1956). One set of differential titration data is shown in table 1. Each ml of NaOH added is multiplied by four

TABLE 1
An example of differential titration using water from the Maumee River

ml of 0.02 N NaOH added to 250 ml of Maumee River water	pH after each addition
0	7.17
1	7.50
2	7.80
3	8.00
4	8.11
5	8.20
6	8.30
7	8.39
8	8.49
9	8.57
10	8.64
11	8.70
12	8.76

to provide a value for a liter of water, thus each milliliter of NaOH added will change 20 μmoles of carbonate to bicarbonate (this is analogous to the removal of 20 μmoles by photosynthesis). The data obtained in the differential titration are then plotted on a graph to convert pH changes observed during photosynthesis or respiration to corresponding CO_2 changes per liter of water. For example: during a particular day the pH changed from 8.27 at 0700 hours to 8.41 at 1300 hours. This represents a pH change of 0.14 during that 6-hr period. By referring to the differential titration, one can see that the above values lie between 8.20 and 8.49 in the table. This 0.29 pH change is brought about by the addition of 3 ml of NaOH, thus it represents a CO_2 change of

$$\frac{(4 \times 20)}{0.29} = 822\ \mu\text{mol}$$

per liter per unit of pH change. The photosynthetic rate for the 6-hr period mentioned above would be computed as $822 \times 0.14 = 115$ μmol CO_2 absorbed per liter per 6-hr period or 19 μmol per liter per hour.

Oxygen change was measured by computing the difference between the mg O_2/liter from one collection to the next and converting this value to μmol O_2 per liter. For example: during a particular day the mg O_2/liter at 0700 hours was 11.12 and at 1300 hours 15.84, a difference of 4.72 mg O_2/liter in 6 hr. The photosynthetic rate for the 6-hr period would be computed as

$$\frac{4.72 \times 1000}{32} = 147.5 \ \mu\text{mol } O_2$$

evolved per liter per 6-hr period or 24.6 μmol/liter/hr.

Photosynthetic yields were computed by using the maximal yield of CO_2 absorbed and O_2 evolved during a 6-hr interval, and dividing it by the plant volume observed during that period. For example: 19 μmol CO_2 absorbed per liter per hour with a plant volume of 12.8 μliters/liter would give a photosynthetic yield of about 1.5 μmol/μliter/hr while 24.6 μmol O_2 evolved per liter per hour with the same plant volume would give a photosynthetic yield of 1.9 μmol/μliter/hr. Thus, in this example, the ratio of O_2 evolved to CO_2 absorbed would be close to one, the expected ratio indicated in the general formula for photosynthesis.

RESULTS AND DISCUSSION

The average CO_2 and O_2 change per liter per hour is shown in table 2. The O_2/CO_2 ratio is also shown. The maximum photosynthetic rates compare favorably with those computed for Lake Erie (Verduin, 1960), Urschel's Quarry, and a

TABLE 2

*Average CO_2 and O_2 change in the Maumee River for each collection interval plus the corresponding O_2/CO_2 ratio**

Date and time	Change: μmol CO_2/liter/hr	Change: μmol O_2/liter/hr	O_2/CO_2
10/6/61 to 11/11/61			
2200–0600	4.4	−5.5	1.25
0600–1000	−1.7	1.6	0.94
1000–1400	−20.9	35.0	1.67
1400–1800	−5.0	4.7	0.94
1800–2200	17.8	−34.8	1.96
11/17/61 to 12/16/62			
1800–0700	1.7	−2.2	1.29
0700–1250	−5.4	6.9	1.28
1250–1800	3.4	−7.6	2.24
12/22/61 to 2/24/62			
1800–0700	0.7	−0.4	0.57
0700–1250	−1.4	0.7	0.50
1250–1800	−0.7	0.1	0.14
3/3/62 to 4/8/62			
1900–0700	3.4	−0.1	0.03
0700–1300	−6.5	−0.3	——
1300–1900	−2.7	0.1	0.04
4/14/62 to 5/13/62			
1900–0700	9.0	−4.4	0.49
0700–1300	−18.9	19.3	1.02
1300–1900	−11.6	−7.2	——

*Minus CO_2 represents photosynthesis; minus O_2 represents respiration.

number of other quarries and ponds around Bowling Green (Verduin, 1959), where rates of 1 to 25 μmol CO_2/liter/hr were found, and Sandusky Bay (McQuate, 1956), where an average of 17 μmol CO_2/liter/hr was found. The O_2 production values are higher than those found in the lower Missouri River (Berner, 1951) and the upper Mississippi River (Galtsoff, 1924), where it was noted that basic productivity was very low, but lower than those found by Odum (1956) and Hoskin (1959) for several clear southern streams, where values approaching 50 μmol O_2/liter/hr were reported. The higher O_2 production values found by Odum (1956) and Hoskin (1959) can be accounted for by the low turbidity of the waters they investigated. It can also be noted on table 2 that the maximal yields occur during the hours before 1400. This is consistent with the findings of Verduin (1960) and others.

The low oxygen production values for the period 12/22/61 to 2/24/62 are associated with the time during which the river was covered with ice. The ice cover plus the natural turbidity of the water combined to reduce light penetration to a minimum, thus reducing the photosynthetic activity of the phytoplankton.

The period of 3/3/62 to 4/8/62 also represents a time of little O_2 change. However, the CO_2 data show that photosynthesis was taking place during the day. This low O_2/CO_2 ratio was also found in a study of a small fresh-water pond. Table 3 presents the data from Steidtmann's Pond pertinent to this study. The

TABLE 3

*Average CO_2 and O_2 change in Steidtmann's Pond for each collection interval plus the corresponding O_2/CO_2 ratio**

	Change		
Date and time	μmol CO_2/liter/hr	μmol O_2/liter/hr	O_2/CO_2
3/3/61 to 5/13/61			
1800–0600	6.1	−1.5	0.25
1000–1400	−9.7	3.9	0.40
1400–1800	−5.3	−0.42	——

*Minus CO_2 represents photosynthesis; minus O_2 represents respiration.

CO_2 in both cases, Steidtmann's Pond and the 3/3/62 to 4/8/62 period of the Maumee River, behaves normally; this is, it decreases during the day and increases at night. The O_2, however, shows very little change, thus resulting in a low O_2/CO_2 ratio. An interesting sidelight to the Steidtmann Pond study occurred when an attempt was made to transfer the pond water into the laboratory to study the causes of the low O_2/CO_2 ratio. When the pond water was transferred to an aquarium, the O_2/CO_2 ratio returned to the expected ratio of nearly one. This experience, in itself, presented a good argument for studying O_2 and CO_2 changes under completely natural conditions rather than under an artificial environment. It also tended to indicate that the low O_2/CO_2 ratio was probably due to the detritus on the bottom of this shallow pond, because this was a factor not included in our aquarium. The detritus would be undergoing decay, thus releasing CO_2 into the pond. However, bottom detritus cannot be responsible for the low O_2/CO_2 ratio encountered in the river. Because the 3/3/62 to 4/8/62 period was a high-water period, it might be proposed that detritus brought into suspension under high water conditions created an environment similar to that in the pond. It should be noted, however, that no such phenomena occurred in Urschel's Quarry during this time period. Table 4 shows that, although the O_2/CO_2 ratio does not approach one, neither does it show the phenomena occurring for the 1300 to 1400 period in the Maumee River nor the 1400 to 1800 period in Steidtmann's Pond.

Since bottom detritus would not contribute greatly to the O_2 and CO_2 in the upper 0.5 m of water in the Quarry, this enhances the possibility of detritus being a factor in shallow water.

TABLE 4

*Average CO_2 and O_2 changes in Urschel's Quarry for each collection interval plus the corresponding O_2/CO_2 ratio**

Date and time	Change µmol CO_2/liter/hr	µmol O_2/liter/hr	O_2/CO_2
3/3/61 to 5/13/61			
1800–0600	25.5	−10.1	0.40
1000–1400	−15.2	4.8	0.32
1400–1800	−4.0	1.9	0.47

*Minus CO_2 represents photosynthesis; minus O_2 represents respiration.

The high O_2 production values for the periods 10/6/61 to 11/11/61 and 4/14/62 to 5/13/62 are associated with periods of oxygen supersaturation. Table 5 shows the average maximum O_2 evolution rate in µmol/liter/hr, the average percentage of saturation and the average pH for specific time intervals. In each case, with the exception of one time interval, an increase in O_2 evolution corresponded with an increased percentage of saturation. It can also be noted that high O_2 evolution corresponded with high pH values. This would be logical because CO_2 would be removed from the water during photosynthesis, thus shifting the carbonate-bicarbonate equilibrium toward the carbonate side.

TABLE 5

*Average O_2 evolution rate, per cent saturation, and pH in the Maumee River for specific time intervals**

Time interval	O_2 evolution µmol/liter/hr	Per cent saturation	pH
10/6/61 to 11/11/61	35.0	179	7.80
11/17/61 to 12/16/61	6.9	118	7.63
12/22/61 to 2/24/62	0.7	83	7.36
3/ 3/62 to 4/ 8/62	0.1	90	7.71
4/14/62 to 5/13/62	19.3	148	8.32

*The O_2 values represent the maxima observed during the daytime intervals, while the per cent saturation and pH values represent those associated with the maximum O_2 concentration in the water.

In table 6, the major components observed during specified time intervals are presented, with average volume of each component and average phytoplankton volume in µliters/liter. A major component is defined as one which comprises at least 20 per cent of the plant volume in the community (Verduin, 1960). Because this table provides an ecologic rather than a taxonomic classification of the phytoplankton, only the genera are listed. The presence of the flagellate, *Chlamydomonas*, during the winter months, is a feature observed in Lake Erie (Verduin, 1960), and in Urschel's Quarry (Verduin, 1959). The blue-green filament, *Aphanizomenon*, seemed to be a major component until the March 31 to May 13 period, when it became insignificant. Blooms of *Oscillatoria* appeared during this period; however, the variety of organisms was so great that no one organism represented a major component. *Melosira*, *Asterionella*, *Tabellaria*, and *Oscillatoria*

TABLE 6

Major components of phytoplankton in the Maumee River in μliters/liter during the period of October 6, 1961, to May 13, 1962

Time interval	Major components	Average volume of species in μliters/liter	Average total plant volume in μliters/liter
Oct. 6–Nov. 11	Aphanizomenon	6.78	15.84
	Melosira	3.67	
	Chlamydomonas	3.41	
Nov. 18–Dec. 16	Aphanizomenon	2.86	5.81
	Chlamydomonas	1.47	
	Scenedesmus	1.23	
Dec. 23–Feb. 24	Aphanizomenon	3.23	5.14
	Chlamydomonas	1.56	
Mar. 3–Mar. 24	Aphanizomenon	2.67	4.76
Mar. 31–May 13	———	——	25.70

represented about 3/5 of the total volume, with about ten other organisms representing the remaining 2/5.

In computing photosynthetic yields per unit of plant volume, it was found by Verduin (1960), McQuate (1956), and others that an inverse relationship existed between population density and photosynthetic yield per unit of plant volume. This was also found to be true in my study of the small fresh-water pond (see table 7).

TABLE 7

*Photosynthetic rates in Steidtmann Pond**

Time interval	Plant volume μliters/liter	CO_2 absorption	
		μmol/liter/hr	μmol/μliter/hr
10/10/60 to 10/11/60	80.15	36.0	0.45
11/ 3/60 to 11/26/60	9.57	10.0	1.05

*Rates per unit water volume and per unit plant volume are shown. These rates are average values of the most productive daytime interval.

No such relationship is clearly evident in the Maumee River data. Table 8 presents these data for specific time intervals. This table shows that the highest yields per microliter of plant volume are not associated with low population density, but with the intermediate density of 16 μliters/liter, and the lowest yield is associated with the lowest population density. During the 12/22/61 to 2/24/62 period the river was covered with ice; thus, light was probably a limiting factor and responsible for this low photosynthetic yield per microliter of plant volume.

The highest photosynthetic yields reported in table 8 do not reach the values reported for Lake Erie (Verduin, 1960), where values of 4 μmol/μliter/hr have been reported. The lowest photosynthetic yields for Lake Erie (0.28 μmol/μliter/hr) were similar to the low levels exhibited by the Maumee River during the 12/22/62 to 2/24/62 period, when only 0.27 μmol CO_2/μliter/hr and 0.14 μmol O_2/μliter/hr were reported. These low yields in the Maumee River were not associated with dense phytoplankton crops, as was the case in Lake Erie, but were probably influenced by low light supply in the turbid waters. Moreover, the densest phytoplankton crops observed in this study were considerably below the maximal densities reported in the literature (100 μliters/liter). Consequently, the inverse relationship between phytoplankton crop and photosynthetic yield per microliter of algae may have been masked by the influence of limiting light supply. This factor probably also accounts for the failure to detect any beneficial influence on productivity from the stirring action of flowing waters in the Maumee River.

TABLE 8

*Photosynthetic rates and phytoplankton volumes observed in the Maumee River**

Time interval	Plant volume μliters/liter	CO_2 absorption μm/μliter/hr	O_2 evolution μm/μliter/hr
10/ 6/61 to 11/11/61	15.8	1.32	2.22
11/17/61 to 12/16/61	5.8	0.93	1.2
12/22/61 to 2/24/62	5.1	0.27	0.14
3/ 3/62 to 4/ 8/62	8.5	0.76	0.012
4/14/62 to 5/13/62	29.6	0.639	0.652

*Rates per unit water volume and per unit plant volume are shown. These rates are average values of the most productive daytime interval.

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