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PERIPHYTIC OXYGEN PRODUCTION IN OUTDOOR EXPERIMENTAL CHANNELS

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Abstract—The contribution of periphytic oxygen was quantified in outdoor artificial streams. A factorial design was employed to determine the effect of stream velocity and light on periphytic growth, measured as chlorophyll *a*. Results showed that periphytic oxygen production can be estimated by the equation:

$$\frac{\text{mg O}_2\,\text{h}^{-1}}{\text{mg Chl } a} = 0.85 \times 10^{-4} \times \text{Light Intensity (ft-candles)} + 0.061$$
$$= 0.91 \times 10^{-3} \times \text{Light Intensity (lx)} + 0.061$$

for light intensities to 5000 ft-candles (53,800 lx). Stream velocity was found to be statistically insignificant in affecting oxygen production, but was a factor in periphyton accural and species composition. Gross oxygen production exceeded respiration by a factor of three.

Key words—periphyton, primary production, chlorophyll *a*, oxygen production, stream velocity

INTRODUCTION

It has been recognized that photosynthetic organisms can significantly influence the oxygen resources of lotic aquatic systems. Over the last 25 years, many studies have dealt with methods to quantify oxygen contribution by photosynthesis. Odum (1956) in his classic study, determined community productivity in Silver Springs from changes in dissolved oxygen concentration and employed correction factors for diffusion of oxygen through the surface. Similar techniques have been used by others to evaluate contributions from suspended algae (potamoplankton) and rooted aquatic vascular plants (Edwards, 1964; Edwards and Owens, 1960, 1962; Merritt *et al.*, 1968; Owens, 1965; Whitford, 1960). From these findings, researchers have developed a number of coefficients for modeling purposes that can be employed for oxygen production due to suspended algae and or aquatic plants.

The periphytic community is the dominant biological oxygen producer in autotrophic streams and little work has been done to assess its contribution (McConnell and Sigler, 1959). Variable results of oxygen production were obtained with the use of light and dark flow-through chambers. The dark chamber measured periphytic respiration as well as that attributed to the rest of the benthic community (O'Connell and Thomas, 1965; Thomas and O'Connell, 1966).

The objective of this research was to quantify oxygen production as a function of chlorophyll *a* (estimator of periphyton biomass) in outdoor experimental channels. Variables investigated included a range of light intensities and four current velocities. Physical reaeration rates for correcting overall oxygen increase were also determined.

MATERIALS AND METHODS

The channel used in this study consisted of repeating 1.3 m aluminum sections made waterproof by means of a 0.4 mm thick polyvinyl liner. The channel was modified from that described by Gannon *et al.* (1966). Two 110 m long channels were used, each having adjustable cross-section and slope. Each was divided longitudinally with 0.6 cm thick plexiglass, producing a total of four replicate channels with a width of 18.3 cm and a depth of 15.2 cm. These channels were designed to approximate a natural stream, while permitting closer control and greater ease of sampling.

Water for this study was supplied from the Huron River, near Ann Arbor, Michigan and stored in two 30 m^3 pools. Six pumps (capacity 440 l min^{-1}) were arranged so that water for experimental purposes could be supplied either from the storage reservoirs or directly from the river (Fig. 1).

Seventy-five randomly placed plexiglass substrata (3.0 × 31.0 × 0.6 cm) were used to estimate periphyton density in each channel. The exposed area of 186 cm^2 served for attachment of periphyton and it provided a relatively easy method for estimating biomass accrual.

EXPERIMENTAL PROCEDURE

Physical reaeration experiments were carried out initially over a range of oxygen deficits at each of the four designated velocities (7.6, 18.3, 27.4 and 42.9 cm s^{-1}). These experiments consisted of artificially inducing a large dissolved oxygen deficit and measuring the recovery of oxygen through the channels in the absence of biological activity. This involved pumping water from the river into the two storage reservoirs. During this process a known amount of sodium sulfite was added to the reservoirs to assure a deficit of dissolved oxygen. In addition, a pre-measured amount of bleach and copper sulfate was added to destroy both bacterial respiration and photosynthetic activity during the

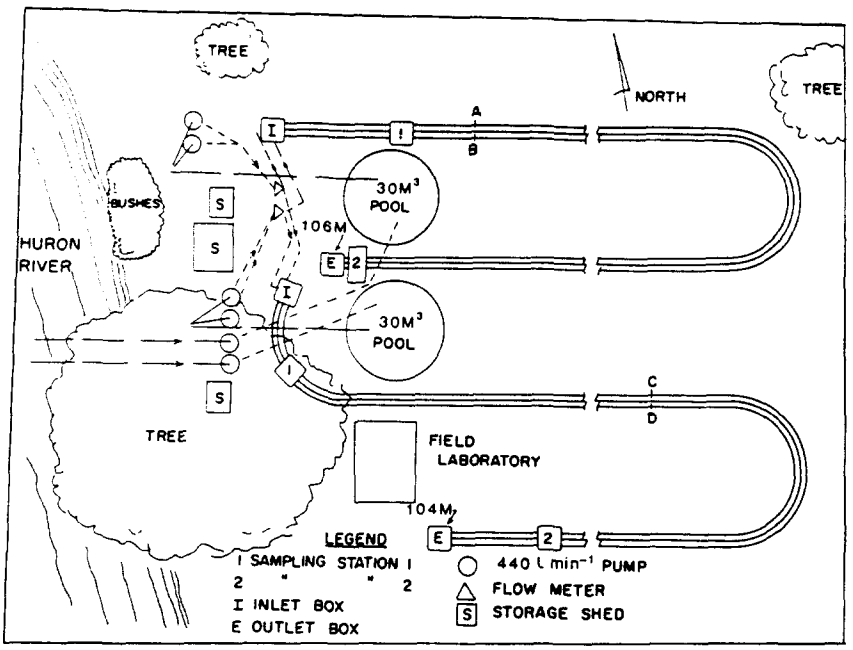

Fig. 1. Experimental site on the Huron River, Ann Arbor, Michigan.

experimental period. An additional 30 min were allowed to assure completion of the reaction and stabilization of the dissolved oxygen. During this period, time of passage was determined for each of the channels employing river water. A slug of sodium sulfite was added at Sta. 1 and detected at Sta. 2 with the deflection of a DO meter. As soon as that was accomplished, water was pumped from the reservoirs through each of the channels at the calibrated rate. The oxygen increase between Stas 1 and 2 was attributed to physical reaeration. This increase was determined from three replicate dissolved oxygen samples taken at 5 min intervals at both stations. Dissolved oxygen determinations were made according to the azide modification of the Winkler technique (APHA, 1981). Each of the channels was scrubbed clean between experiments to minimize error associated with attached and settled material.

Photosynthetic experiments were carried out in a similar fashion with some changes. First of all, river water was passed through each channel continuously over a 50-day period at a designated velocity to permit specific periphytic accural. During the experimental period, which would last no longer than one hour, pre-treated reservoir water with sodium sulfite for DO reduction was pumped through the channels at similar velocities. Time of passage was determined the same way as in earlier experiments. Three replicate DO samples were collected at Stas 1 and 2 at 5 min intervals. Air and water temperatures, pH, and surface light readings (G.E. ft-candle meter) were taken to coincide with the collection of DO samples. The increase of dissolved oxygen between Stas 1 and 2 was attributed to photosynthesis and physical reaeration. Immediately after the experiment, the water was pumped from the river. Three artificial substrata were randomly collected and replaced to minimize changes in physical-hydraulic conditions of the channels. Periphyton samples were packed in plastic bags and brought to the laboratory in ice chests. Each substratum was scraped and replicate analyses for dry weight, enumeration and identification and chlorophyll *a* were carried out (Richards and Thomson, 1952).

A factorial design was used to test the effects of periphyton biomass, light and the four stream velocities (7.6, 18.3, 27.4 and 42.9 cm s^{-1}) on photosynthetic oxygen production. As such, numerous experimental runs were made under different levels of these factors. Each channel was assigned a specific velocity which was used throughout the duration of the study. To minimize light inhibition, fiberglass screening was placed over the channels thus reducing ambient illumination by approx 50%.

The final objective of this study was to determine the amount of periphytic respiration coinciding with photosynthesis. These experiments were carried out similarly to the ones for photosynthesis except that the channels were covered with a 0.2 mm thick black polyethylene film to exclude light. Due to the uniform flow and smoothness of the channel bottom little accumulation of non-algal debris occurred. The water was at saturation levels at Sta. 1. The decrease in oxygen between Stas 1 and 2 was attributed to periphytic respiration.

RESULTS AND DISCUSSION

Eleven separate physical reaeration experiments were carried out at each of the four velocities over a range of oxygen deficits. Results were plotted and the correlation and reaeration coefficients (K_a) were calculated for each velocity (Fig. 2). Hence, biological reaeration (periphytic oxygen production) at a particular velocity was obtained by subtracting the appropriate value for physical reaeration from the overall dissolved oxygen increase in the water as it passed from Sta. 1 to 2.

For the first series of photosynthesis experiments carried out in the fall, the periphyton community was established in all channels at a velocity of 17.6 cm s^{-1}. It was with this community that the rate of oxygen production was compared to the ambient light conditions (Fig. 3). The preliminary results of 50 experiments showed that optimum light conditions were met at 1900 ft-candles (20,400 lx). No inhibition was observed at 4200 ft-candles (45,200 lx), which was the

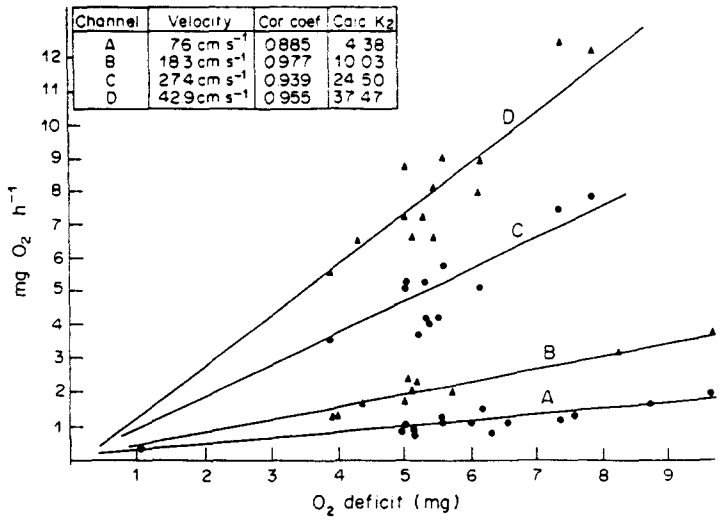

Fig. 2. Oxygen contribution from physical reaeration under varying velocities and oxygen deficits.

maximum level measured during that experimental period.

For the second series of experiments during the spring of the following year, all channels were covered with fiberglass screening. This procedure reduced the incident light by approximately one half and hence permitted experiments to be run in the plateau range from 1900 to 5000 ft-candles (20,400–53,800 lx). Through this technique, an attempt was made to factor out "light" as a variable. Hence, periphyton was permitted to accrue at a particular velocity (Channel A—7.6 cm s^{-1}; Channel B—18.3 cm s^{-1}; Channel C—27.4 cm s^{-1}; and Channel D—42.9 cm s^{-1}). Although there was some difference in the rate of colonization over the first 3 weeks for the four velocities, the mean standing crop over the last 19 experiments was similar (Table 1). Periphytic accrual in Channel A was much slower.

Table 1. Effect of velocity on periphytic biomass accrual measured as Chlorophyll *a*

Channel	Velocity (cm s^{-1})	Number of observations	Mean (mg m^{-2})	SD
A	7.6	19	12.76	2.47
B	18.3	19	10.50	1.19
C	27.4	19	12.61	2.04
D	42.9	19	11.05	2.54

Species composition varied inversely with channel velocity (Table 2). At 7.6 and 18.3 cm s^{-1}, 52 and 49 taxa were identified. No particular genus showed dominance. In the higher velocity channels, the diversity was reduced to 41 and 39 species. However, over 50% of the total number of cells counted at the higher velocities (27.4 and 42.8 cm s^{-1}) were represented by two species of *Cocconeis*. The dorso-ventral flattening of their shape must have been an advantage in their ability to dominate.

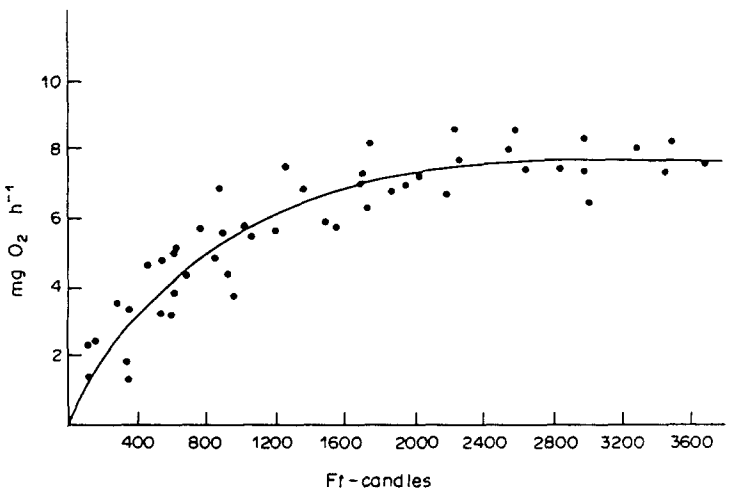

Fig. 3. Periphytic oxygen production under varying light intensities.

Table 2. Periphyton species encountered

	Channel A	B	C	D
	Velocity (cm s^{-1}) 7.6	18.3	27.4	42.8
Achanthes lanceolata	×	×	×	×
Amphora ovalis	×	×	×	×
Anacystis sp.	×			
Closterium sp.	×	×		
Chroococus varians			×	
Cocconeis klamathensis	×	×	×	×
Cocconeis pediculus	×	×	×	×
Cocconeis placentula	×	×	×	×
Cyclotella bodanica		×	×	
Cyclotella catenata	×	×	×	×
Cyclotella comta	×	×		×
Cymatopleura solea var. *regula*	×			
Cymatopleura solea	×	×	×	×
Cymatopleura sp.	×			
Cymbella sinuata	×	×	×	
Cymbella ventricosa	×	×	×	×
Cymbella spp	×	×	×	×
Diatoma tenue	×	×	×	×
Diatoma vulgare	×	×	×	×
Epithemia sorex		×		
Fragilaria brevistriata	×	×	×	×
Fragilaria crotonensis	×	×	×	×
Fragilaria lepidostauron	×	×		
Gomphonema augur			×	×
Gomphonema sp.			×	×
Gyrosigma attenuatum	×	×	×	×
Melosira ambigua	×	×	×	×
Melosira granulata	×	×	×	×
Melosira varians	×	×	×	×
Melosira spp	×	×	×	
Meridian circulare	×	×	×	×
Navicula capitata	×	×		×
Navicula integra	×			
Navicula tripunctata	×	×	×	×
Navicula spp	×	×	×	×
Nitzschia dissipata	×	×	×	×
Nitzschia palea	×	×	×	×
Nitzschia sigmoidea	×	×		×
Nitzschia vermicularis	×	×	×	×
Opephora martyi	×	×	×	×
Oscillatoria angustissima	×	×	×	×
Oscillatoria tenuis	×	×	×	×
Pediastrum duplex		×		
Pleurosigma sp.	×		×	
Pinnularia sp.		×		
Rhoicosphenia curvata	×	×	×	×
Rhopalodia gibba		×	×	×
Rhopalodia gibberula	×			
Scenedesmus abundance	×		×	×
Scenedesmus quadricauda	×	×	×	×
Stauastrum parodoxum	×			
Stephonodiscus niagarae	×	×		×
Stigeoclonium sp.	×	×	×	
Surirella elegans	×	×	×	
Surirella sp.	×	×		×
Synedra ulna var. *oxyrhynchus*	×	×	×	×
Synedra ulna	×	×	×	×
Synedra sp.	×	×		
Tabellaria fenestrata	×	×	×	×

Periphytic oxygen production was directly related to light for all velocities, although experiments were run on the plateau (Fig. 4a–d). Interestingly, the

Table 3. Comparisons of slopes obtained from different velocities (DO mg h^{-1}/mg Chl *a* vs light)

Channel	Velocity (cm s^{-1})	Correlation coefficient	Slope	Number of observations
A	7.6	0.752	0.774	40
B	18.3	0.735	0.898	40
C	27.4	0.806	0.977	40
D	42.9	0.375	0.546	40

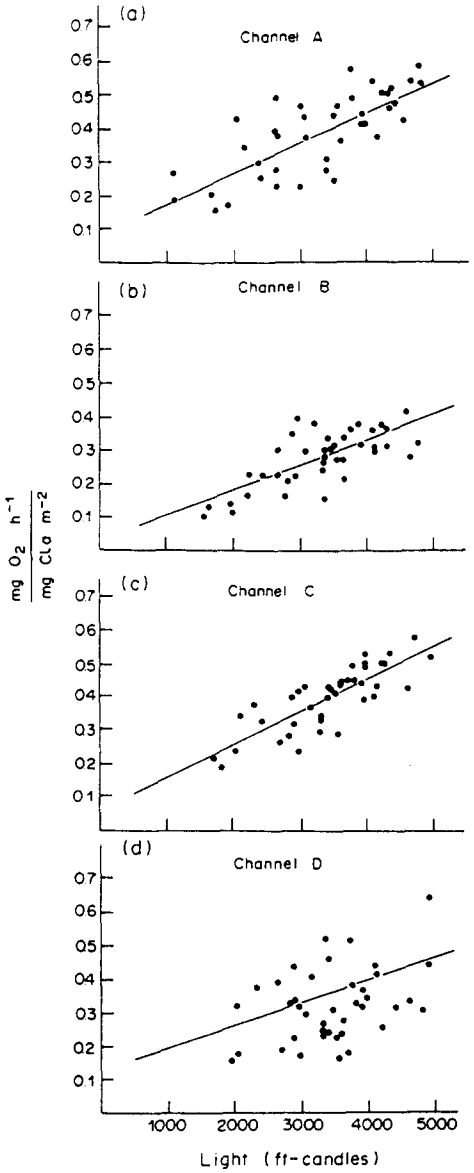

Fig. 4. Periphyton oxygen production as a function of light intensities for different velocities: (a) Channel A = 7.6 cm s^{-1}; (b) Channel B = 18.3 cm s^{-1}; (c) Channel C = 27.4 cm s^{-1}; (d) Channel D = 42.9 cm s^{-1}.

calculated lines were not statistically different, despite varying velocities and species composition in each channel (Table 3). This would imply that periphytic oxygen production can be predicted from chlorophyll *a* density and light intensity. Therefore, all experimental results from the four velocities were plotted on the same graph (Fig. 5). The best fit description of the relationship obtained is:

$$\frac{\text{mg O}_2\ \text{h}^{-1}}{\text{mg Chl } a} = 0.85 \times 10^{-4} \times \text{Light Intensity (ft-candles)} + 0.061$$

$$= 0.91 \times 10^{-3} \times \text{Light Intensity (lx)} + 0.061.$$

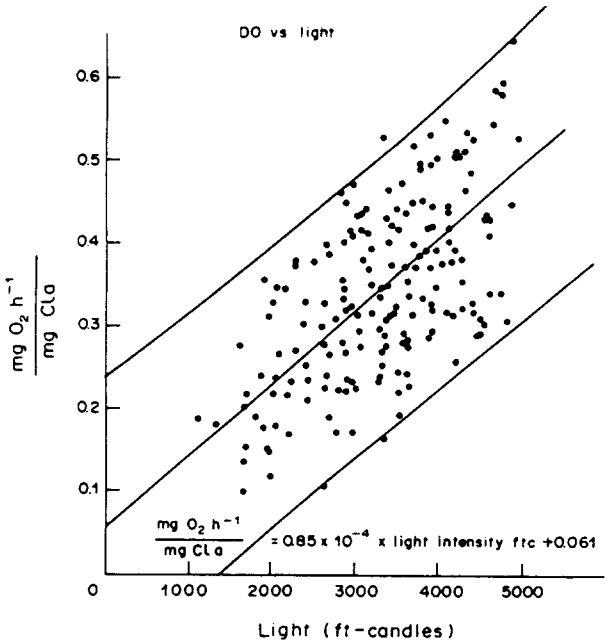

Fig. 5. Observed oxygen production per mg of Chlorophyll *a* for velocities from 7.6 to 42.9 cm s^{-1} and varying light intensities (upper and lower limit represents 95% confidence range).

Finally, a series of experiments were carried out to determine the relationship between periphytic photosynthesis and respiration under dynamic conditions. The time of passage was too fast in Channels C and D and hence, the decrease of dissolved oxygen between Stas 1 and 2 could not be accurately measured. However, results of 12 separate experiments for Channels A and B are presented in Table 4. Although variations in respiration between channel A and B were observed, they were not significantly different. According to these data, net dissolved oxygen production for each channel was quite similar and gross oxygen production exceeded respiration by a factor of 3:1. Since these experiments were run under optimal light conditions, the lower than expected ratio was attributed to heterotrophic components such as bacteria, fungi, protozoans and minute invertebrates.

CONCLUSION

It can be seen from this investigation, that although growth rate and species composition vary with current velocity, periphytic oxygen production is similar. It can be predicted under natural conditions from chlorophyll *a* concentration per unit area and ambient light intensities to at least 5000 ft-candles (53,800 lx) and possibly higher. Respiration due to periphyton can be estimated to be approximately one third of the gross photosynthetic oxygen production.

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Table 4. Relationship between photosynthesis and respiration

Channel	Velocity (cm s^{-1})	mg DO h^{-1} / mg Chl *a*	Mean net DO production h^{-1} / mg Chl *a*	Mean gross DO production h^{-1} / mg Chl *a*
A	7.6	0.23 ± 0.06*	0.40 + 0.13	0.63 ± 0.18
B	18.3	0.15 ± 0.03	0.32 ± 0.07	0.47 ± 0.10
C	27.4		0.32 ± 0.08	
D	42.8		0.32 ± 0.09	

*1 SD.

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