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THE EFFECT OF CURRENT ON PERIPHYTIC PRODUCTIVITY  
AS DETERMINED USING CARBON-14

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THE EFFECT OF CURRENT ON PERIPHYTIC PRODUCTIVITY  
AS DETERMINED USING CARBON-14<sup>1</sup>

*John H. Rodgers, Jr. and R. S. Harvey<sup>2</sup>*

ABSTRACT: Productivity measurements of organisms attached to artificial substrates ranged from 6.5-7.6 mg C/m<sup>2</sup>/hr and were 17-65% greater in flowing than under static conditions. Carbon-14 was used to determine the effect of current on the primary productivity of these organisms in six artificial streams and the parent stream at the Flowing Streams Laboratory on the Savannah River Plant (U.S. Energy Research and Development Administration, Aiken, South Carolina, U.S.A.). Seasonal changes in dominant organisms were monitored from June, 1973 to March, 1974. Estimates of productivity, accumulated biomass, and levels of chlorophyll *a* were compared for possible correlation. Production of chlorophyll *a* ranged from 50 to 381 mg/m<sup>2</sup>, and accumulated biomass ranged from 45 to 181 g/m<sup>2</sup> on the artificial substrates (glass microscope slides) during the period of study. Productivity of attached organisms was generally an order of magnitude greater

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than productivity of phytoplankton or tycho plankton. The consistently higher productivity in flowing systems than in static systems tends to cast some doubt on values obtained by other workers when lotic communities have been enclosed or isolated in chambers or bottles without inducing a current or stirring action.

(KEY TERMS: primary productivity; periphyton; phytoplankton; current effects; carbon-14; artificial substrates)

## INTRODUCTION

Assemblages of periphytic organisms have proven to be sensitive and reliable indicators of both chemical and physical stresses in aquatic environments. Techniques have been developed that utilize attached organisms as indicators of the relative "health" of aquatic systems (Patrick, 1962; Weber, 1973). Since Ruttner (1953) noted the apparent "physiological richness" of lotic systems, numerous studies of the metabolism and mineral exchange of indigenous organisms have initiated speculation on the effects of current velocity on productivity (McIntire, 1966; McIntire and Phinney, 1965; Westlake, 1967; Whitford and Schumacher, 1961; 1964; and others). Often the "upstream-downstream" dissolved oxygen technique of Odum (1956) and respirometers have been used to monitor changes in dissolved gases under artificial or natural situations (McIntire et al., 1964; Hoskin, 1959). Since the carbon-14 technique for measuring productivity was introduced by Steemann Nielsen (1951, 1962), studies utilizing this technique

have focused for the most part on lenitic situations. Very little information is available on the effects of currents on the reliability of productivity measurements that were determined by using isolation incubation techniques. It has been demonstrated that current velocity can have a pronounced effect upon respiration rates of both segregated organisms and assemblages of organisms (Whitford and Schumacher, 1964; McIntire and Phinney, 1965). It follows that carbon assimilation rates would also be affected. The objective of this study was to determine the effect of current on the productivity of attached organisms (on glass slides) in a natural stream and in artificial streams by using carbon-14.

## MATERIALS AND METHODS

### *Experimental Streams*

The effect of current on periphyton productivity was studied in artificial streams of the Flowing Streams Laboratory (Harvey, 1975) on Upper Three Runs Creek. These streams differ from other artificial streams because: 1) the study channels are inside a greenhouse and receive natural illumination with the same diurnal and seasonal patterns of sunlight as the parent stream (Upper Three Runs Creek); 2) organisms are "seeded" naturally on substrates in the study channels by a 189 liters/min once-through flow of creek water through each stream; and 3) all materials utilized in construction of the streams are plastic (polyvinyl chloride) or stainless steel to reduce the possibilities of heavy metal contamination.

### *Artificial Substrates*

The periphyton in the experimental streams was collected on standard glass microscope slides (25 × 75 mm) which were mounted in "diatometers" or slide racks similar to those of Patrick et al. (1954). Two modified diatometers holding six slides each were placed in each of the six artificial streams and in the parent stream. Diatometers in the laboratory streams modified by the removal of styrofoam floats and splash plates, were held in proper position to the current by plastic legs inserted into the substrate. After a colonization period of about three weeks, the periphyton slides were carefully removed from the racks in the streams.

### *Sample Analyses*

Chlorophyll a and biomass (dry weight) were determined according to APHA Standards Methods (1971). Slides were examined to determine the density and dominance (area covered) of the organisms present which were identified using standard techniques and taxonomic references (Smith, 1950; Patrick and Reimer, 1966; Whitford and Schumacher, 1973). Slides with attached organisms were used to estimate productivity using a modified flowing-water carbon-14 technique (APHA Standard Methods, 1971).

### *Carbon<sup>14</sup> Productivity*

Three *Plexiglas* (Trademark of Du Pont Co.) chambers (figure 1) were constructed to hold four 500 ml screw-capped bottles. Four slides in a *Plexiglas* rack were placed in each of the light

and dark bottles (dark bottles were painted and wrapped with opaque tape). Two slides from the inlet and two slides from the outlet from each of the six artificial streams were utilized on each date. The bottles were filled with water from the respective streams and injected through a port with one ml of sodium bicarbonate- $^{14}\text{C}$  (New England Nuclear, 1  $\mu\text{Ci/ml}$ , specific activity: 10  $\mu\text{g}/\mu\text{Ci}$ ). The bottles were incubated for four hours in the chambers with circulating water maintaining ambient temperatures of each stream. A current approximating that of the stream (0.335 m/sec) was induced in the experimental bottles using calibrated magnetic stirrers under the chambers. The stirrers were calibrated using vegetable dye and flecks of styrofoam in the manner of Westlake (1967). Light and dark bottles that were not stirred were used as a static situation, and additional stirred bottles were used to determine the relative contribution of phytoplankton to primary productivity in the streams. After four hours, the bottles were collected, injected with one ml of formalin to stop biological activity, and placed on ice in coolers for transportation to the laboratory. Samples were processed and analyzed in a laboratory located at Clemson University, Clemson, South Carolina. Approximately three hours elapsed from the time the samples were collected until they were processed in the laboratory.

### *Sample Preparation*

Periphyton was scraped from the slides and filtered using 0.45  $\mu$  pore size Gelman membrane filters and less than three-tenths atmosphere vacuum. Phytoplankton was filtered in the same manner, and the filters were exposed to fumes of hydrochloric acid to remove any inorganic carbon-14 as recommended by Wetzel (1965). After desiccation, the algae on the filters were weighed and oxidized using a Packard Model 305 *Tri-Carb Oxidizer* (Trademark of Hewlett Packard Company) and counted in a Packard Model 3320 Liquid Scintillation Spectrometer (Trademark of Hewlett Packard Company). Determinations of water quality and environmental parameters were based on those in APHA Standard Methods (1971).

## RESULTS AND DISCUSSION

### *Primary Productivity*

Mean productivity (mg C/m<sup>2</sup>/hr) of attached organisms on the glass slides was 17 to 65% greater in the flowing systems than in the static systems during the period of measurement. Variability of productivity measurements was not great over the months that determinations were made; the coefficients of variation was 18.5%. Mean productivity ranged from 6.5 to 7.6 mg C/m<sup>2</sup>/hr in flowing systems. Phytoplankton or tychoplankton productivity ranged from 0.65 to 1.0 mg C/m<sup>2</sup>/hr with the low in January and a peak in the period from November to December, probably the result of input of nutrients from autumnal leaf fall

(figure 2). There were no significant differences (at  $P = 0.05$ ) in productivities among simulated streams or between the simulated streams and the parent stream. Unless otherwise noted, Student's t-test was used to determine significant differences at the 0.05 level hereafter. Water quality parameters (table 1) varied seasonally with no significant daily fluctuations.

#### *Chlorophyll a and Biomass*

Seasonally, chlorophyll a concentrations were erratic, ranging from  $50 \text{ mg/m}^2$  in December to  $381 \text{ mg/m}^2$  in March (figure 3). Accumulated biomass (dry weight) ranged from  $45 \text{ g/m}^2$  in June to  $181 \text{ g/m}^2$  in March (figure 4). Weber (1973) discussed the relationship between biomass and chlorophyll a and noted that chlorophyll a is usually 1 to 2% of the dry weight of organic matter of algae. From this relationship, the Autotrophic Index (AI) or the ratio of biomass (ash-free dry weight) to chlorophyll a was derived. The fact that the presence of detritus and heterotrophic organisms increased the values obtained for this index was also mentioned. In his study of a sewage outfall on the Ohio River, Weber (1973) reported an average AI value of 177 for organisms attached to glass slides at the station above the discharge, while the average value below the discharge was 1019. The average biomass to chlorophyll a ratios in the artificial streams ranged from 129 to 2950 with a coefficient of variation of 105%, and average chlorophyll a values ranged from 0.04% to 0.8% of the biomass of organisms attached to the glass slides.

### *Respiration Rates*

Whitford and Schumacher (1964) reported increases in respiration rates of 40.5 to 57.1% for lotic species of algae in flowing versus static situations and increases in phosphorus-32 uptake of 160 to 510% under the same circumstances. Odum and Hoskin (1957) found 33 to 380 mg/m<sup>2</sup> chlorophyll a in their laboratory stream microcosms, which agreed well with values found in this study. Biomass values were comparable to those reported by McIntire and Phinney (1965) for their laboratory streams. Attempts to determine predictive correlations between productivity, biomass, and chlorophyll a were ineffectual (figures 3 and 4), and reliable (P = 0.10) predictive equations for productivity could not be determined using these parameters.

### *Interstream Comparisons*

Four genera of algae, *Vaucheria*, *Tabellaria*, *Oscillatoria*, and *Spirogyra*, were present during most of the sampling periods (table 2). *Tabellaria* was the dominant genus considering all sampling periods, but *Vaucheria* was seasonally dominant in June and late January. *Oscillatoria* and *Spirogyra* were chosen for observation in future temperature elevation studies. Community structure, productivity, chlorophyll a, biomass, and physical and chemical parameters did not show significant seasonal differences among the simulated streams and between the simulated streams and the parent stream. The taxonomic composition of the attached communities did not differ significantly among the six artificial streams on the individual sampling dates. However, with the

exception of January 23, 1974, the biomass and chlorophyll a values were significantly different among streams on all other sampling dates. Biomass and chlorophyll a values were also significantly different between replicate slides among six artificial streams on these dates, while the taxonomic composition or diversity did not differ significantly.

#### SUMMARY

The use of Carbon-14 to measure current and stirring action enhancement of aquatic primary productivity agrees with the data of Whitford and Schumacher (1961, 1964), Odum and Hoskin (1957), Owens and Maris (1964), McIntire (1966), Westlake (1967), and others. Consistently higher productivity in flowing systems as compared to static systems would tend to cast some doubt on values presented from studies of streams, rivers, estuaries, tidal areas, or discharges where aquatic plants are enclosed or isolated without inducing a current or stirring action. Also, the necessity for maintaining a constant current or rate of flow should be emphasized when attempting to determine effects of changes in environmental parameters on lotic systems, particularly when simulated streams are used. With carbon-14, turnover times and photosynthetic efficiency may be inaccurately estimated when a static system is used to represent a lotic situation. Since tychoplankton in flowing systems is transient, attached organisms and aquatic vascular plants are usually more indicative of ambient conditions at a given point in the system. In this study, phytoplankton contributed relatively little to

the total productivity of the system when compared to the attached organisms. If current had been excluded as a variable, periphyton productivity would have been significantly underestimated.

When attempting to assess the effect of altering an environmental parameter, such as increasing temperature, it is necessary to monitor the most consistent components to obtain the most useful information. Considering the inherent variability of biomass and chlorophyll a among streams, those parameters which were less variable, namely component community structure and productivity, would provide better comparisons. In future studies of the effects of increased temperatures on organisms inhabiting the artificial streams, the less varying parameters will have to be utilized to sort out real effects from natural biological variability. More research is needed to elucidate the proportional influence of current on estimates of impact of environmental perturbations on productivity.

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TABLE 1  
 Monthly Averages<sup>a</sup> of Physical and Chemical Characteristics of Upper Three Runs Creek (Source of Water for Artificial Streams), June 1973 - February 1974.

Month	Air Temp. (°C)	Water Temp. (°C)	Dissolved Oxygen (mg/l)	BOD (mg/l)	pH	Alkalinity (mg/l CaCO <sub>3</sub> )	Turbidity (JTU)	Conductivity (µmho/cm)	NO <sub>3</sub> -N (mg/l)	NH <sub>3</sub> -N (mg/l)	Ortho-PO <sub>4</sub> (mg/l)
Jun	21.7	20.6	6.8	5.4	6.3	1.5	4.5	24.7	0.3	0.02	0.01
Jul	22.0	22.1	6.7	5.8	6.3	3.0	4.1	22.9	0.3	0.02	0.02
Aug	20.9	23.2	7.0	5.8	6.4	2.8	2.4	23.8	0.2	0.03	0.03
Sep	20.5	20.8	7.2	6.2	6.5	6.2	3.3	26.2	0.2	0.01	0.02
Oct	11.5	17.7	8.2	6.4	6.6	6.9	2.5	25.5	0.2	0.01	0.01
Nov	8.6	14.9	8.3	6.5	6.7	5.5	2.3	26.5	0.1	0.02	0.01
Dec	4.5	11.4	9.4	7.5	6.5	2.7	2.6	26.6	0.3	0.01	0.03
Jan	9.7	14.5	8.6	5.9	6.4	3.7	3.2	27.3	0.2	0.01	0.02
Feb	2.5	11.8	9.1	6.1	6.2	3.1	4.5	25.9	0.3	0.01	0.01

<sup>a</sup>. Mean values of approximately 21 samples per month.

TABLE 2

Changes in Density and Dominance of Dominant Periphytic Organisms, 25 June 73 - 6 Mar 74

Date	<i>Vaucheria</i>		<i>Tabellaria</i>		<i>Oscillatoria</i>		<i>Spirogyra</i>		Average <sup>a</sup> Temperature (°C)
	relative density (%)	relative dominance (%)	relative density (%)	relative dominance (%)	relative density (%)	relative dominance (%)	relative density (%)	relative dominance (%)	
25 Jun	31.1	37.6	16.3	13.7	22.4	19.8	0.5	0.9	20.6 (18.5 - 22.0)
16 Jul	23.7	28.1	26.8	21.2	18.8	16.9	b	-	22.1 (17.0 - 21.0)
5 Aug	11.4	15.8	19.7	14.3	0.6	0.4	-	-	22.1 (17.0 - 22.0)
27 Aug	23.1	27.2	46.7	39.2	0.9	0.6	-	-	21.2 (17.0 - 22.0)
18 Sep	21.7	30.1	59.6	51.3	4.7	3.1	-	-	20.8 (20.0 - 22.0)
9 Oct	4.6	7.2	89.4	77.8	-	-	-	-	17.6 (14.0 - 22.0)
30 Oct	-	-	6.1	4.9	-	-	78.2	81.7	17.6 (13.0 - 21.0)
27 Nov	3.1	4.6	68.4	54.9	6.7	4.8	19.6	22.1	14.9 (10.0 - 18.5)
14 Dec	-	-	74.0	71.5	20.3	22.7	-	-	11.4 (7.2 - 16.0)
3 Jan	4.3	6.1	67.3	64.1	0.9	1.2	0.7	1.9	11.2 (7.0 - 16.0)
23 Jan	31.9	38.2	41.1	37.6	0.4	0.6	11.3	17.1	14.5 (10.0 - 17.0)
13 Feb	-	-	67.7	61.2	7.3	8.6	6.2	9.8	11.8 (7.9 - 15.8)
6 Mar	3.7	5.1	64.3	59.8	22.2	23.1	4.2	6.9	13.2 (8.7 - 16.5)

a. Range in parentheses.

b. Did not occur

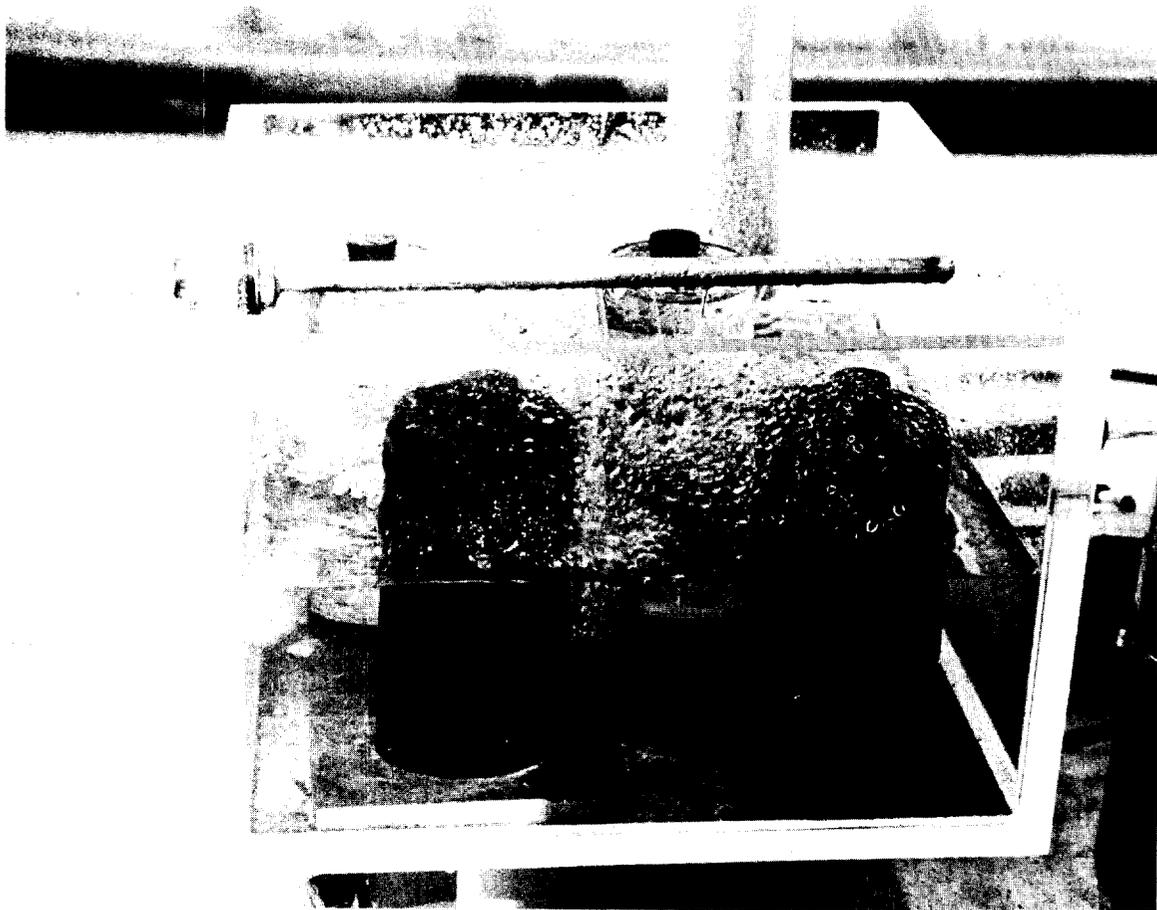


Figure 1. Incubation chamber with light and dark bottles (flowing and static).

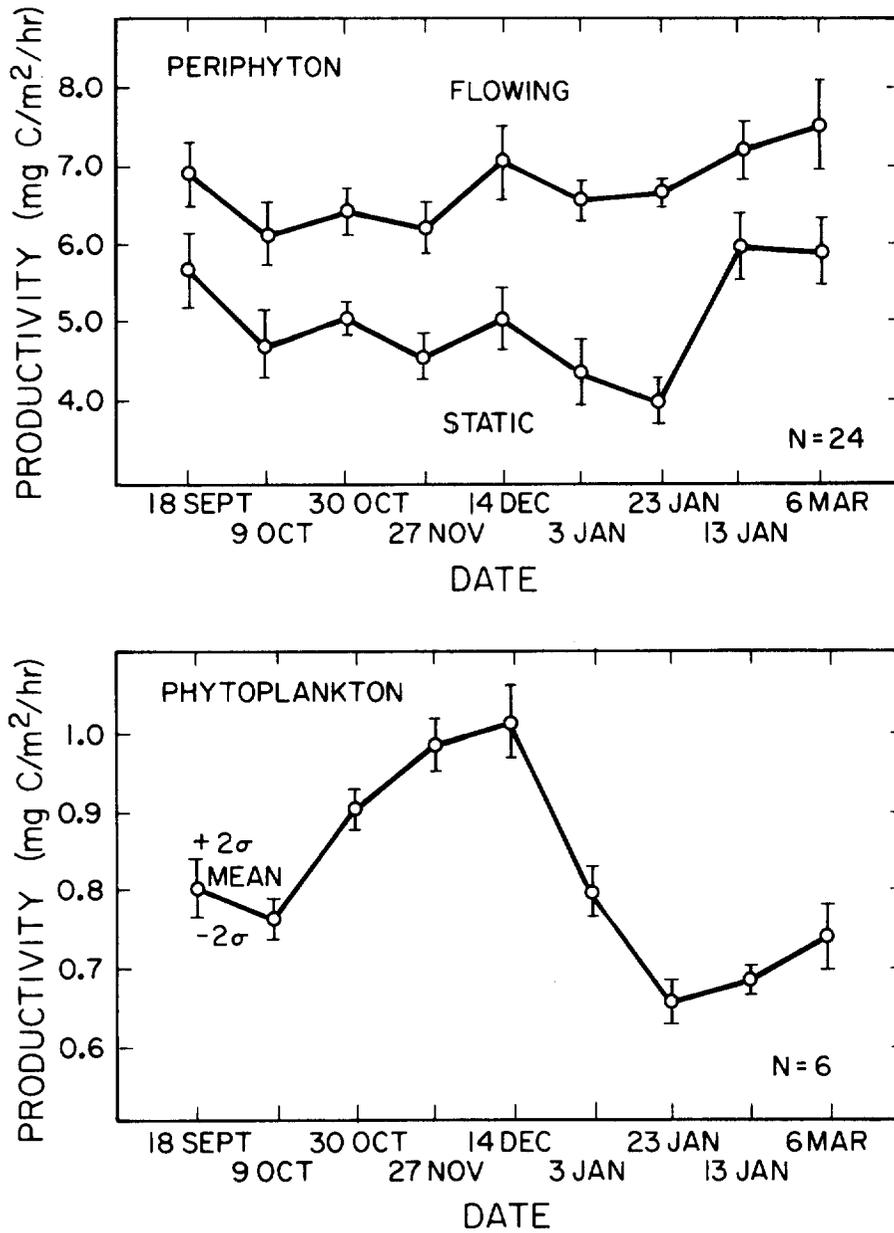


FIGURE 2. Periphyton and phytoplankton productivity in flowing and static systems, 1973-1974. Vertical lines represent two standard errors on each side of the mean.

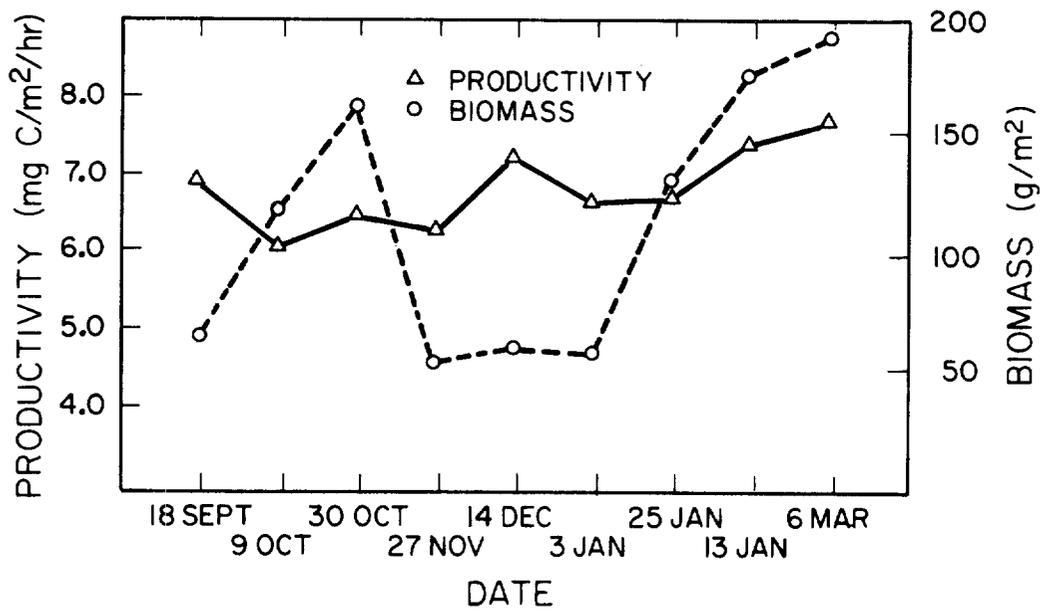
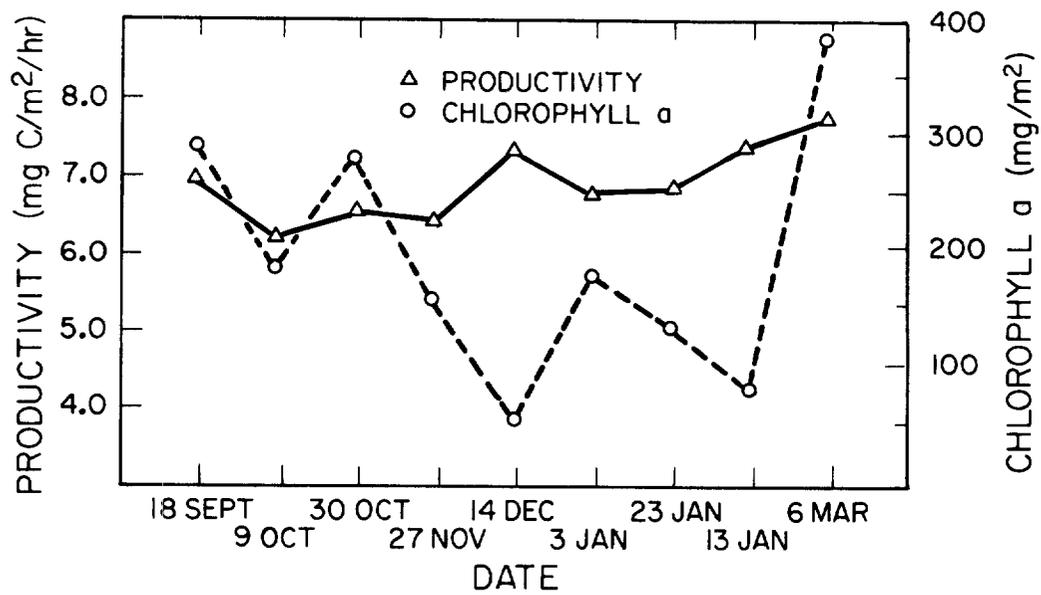


Figure 3. Productivity, chlorophyll a, and biomass (dry weight) in artificial streams, 1973-1974.

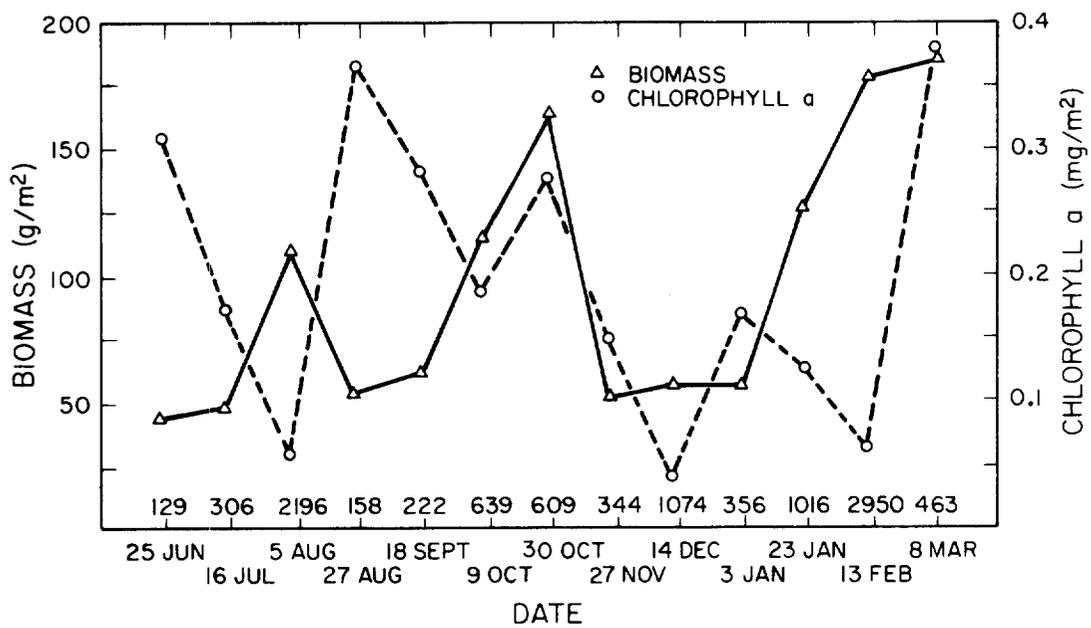


Figure 4. Accumulated biomass (dry weight) and chlorophyll a in artificial streams, 1973-1974. Biomass ( $\text{g/m}^2$ ) to chlorophyll a ( $\text{g/m}^2$ ) ratios are shown above each date.