

AN ABSTRACT OF THE THESIS OF

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(Name) (Degree) (Major)

Date thesis is presented May 12, 1965

Title METABOLISM OF PERIPHYTON COMMUNITIES IN TWO

SMALL STREAMS

Abstract approved

Redacted for Privacy

(Major professor)

A technique for estimating gross primary production and respiration of periphyton communities, in situ, in small turbulent streams was developed using a photosynthesis-respiration chamber in a modified "light and dark bottle" method. Trays containing portions of the substrate bearing the benthic community were embedded in the stream, level with the bottom. A clear plexiglas cover could be clamped to a tray to make it part of a closed system in which the water was mixed, circulated, and exchanged to facilitate measurement of changes in the concentration of dissolved oxygen.

The rates of gross primary production and respiration of the periphyton communities in two coastal streams in Oregon were estimated periodically during the six months from July through December 1964 by hourly determinations of the changes in concentration of dissolved oxygen in the chamber. The rates so determined were used to demonstrate seasonal trends in both processes

and to obtain quantitative relationships between these processes and the environmental parameters known to control them. These relationships were determined by formulating multiple regression equations for both components of community metabolism using light intensity, water temperature, and plant biomass as the independent variables for gross production and the latter two plus the wet weight of the animal fraction of the community for respiration computations. Respective R^2 values of 0.971 and 0.800 for each stream indicated that most of the variability in the gross production process was accounted for and that the relationships involved were not the same in both streams. A single R^2 value of 0.821 was obtained from the measurements of community respiration since differences in the variability between streams were not statistically significant. The resulting equations were also used to predict production and respiration on a monthly basis.

A portable illumination totalizer was used to measure incident solar radiation striking the streams in gram-calories per cm^2 . The influence of the canopy and surrounding topography in determining available light was found to be significant and varied for each stream. Approximately 75 to 95 percent of the total light energy was absorbed and reflected and did not reach the communities in the streams.

The predicted range of gross production

(0.34-1.28 g O₂/m²/day) was substantially lower than results reported from other in situ investigations using the oxygen method. The most apparent reasons for these low levels were low light availability and instability of the bottom substrate.

An asymptotic gross photosynthesis-light intensity curve was obtained by plotting actual dissolved oxygen changes against observed light intensities. The shape of the curve was similar to that obtained in a laboratory community.

Predicted rates of respiration (0.22-1.60 g O₂/m²/day) were consistently higher than equivalent estimates of gross production until November, when the animal fraction of the community was reduced. For most of the season both streams were heterotrophic, obtaining a significant amount of their energy from the surrounding watershed.

METABOLISM OF PERIPHYTON COMMUNITIES
IN TWO SMALL STREAMS

by

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A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1965

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Date thesis is presented

May 12, 1965

Typed by Lola Brocksen

ACKNOWLEDGMENTS

I wish to gratefully acknowledge the help received from Dr. James D. Hall in the planning and application of this research program and in the interpretation of the results. I also wish to thank Drs. Harry K. Phinney and C. David McIntire, of the Department of Botany, for their suggestions and criticisms and Dr. Donald R. Jensen, of the Department of Statistics, for his assistance in the statistical analysis of the data.

Funds for this research were provided by the U. S. Public Health Service (Grant No. WP-00423).

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METABOLISM OF PERIPHYTON COMMUNITIES IN TWO SMALL STREAMS

INTRODUCTION

In many small, rapidly-flowing streams oxygen metabolism of periphyton communities is masked by diffusion and consequently difficult to measure accurately with present field techniques. Compared with studies of phytoplankton in lakes, relatively few investigations of periphyton productivity, in situ, have been attempted in flowing waters. This can probably be attributed to the facts that current methods developed for field use cannot provide meaningful estimates of photosynthesis and respiration under turbulent conditions, and that the contribution to the energy structure of the ecosystem of aquatic primary producers, in such situations, is often not as great as it is in standing waters. The latter point has been demonstrated in several investigations. The primary consumers of a large turbulent stream in Georgia derived 66 percent of their energy from the surrounding watershed, primarily in the form of leaf material (Nelson and Scott, 1962). Stomach analyses of juvenile coho salmon (Oncorhynchus kisutch) in the present study streams indicated more than 50 percent of the food ingested by these fish was of terrestrial origin (Chapman and Demory, 1963).

This investigation was designed to:

- 1) develop a technique for measuring community metabolism in the field, based on the laboratory method of McIntire et al. (1964);
- 2) estimate the level of gross primary production and community respiration in two small streams;
- 3) evaluate and quantify the factors known to influence community metabolism; and
- 4) formulate a basis for predicting rates of gross production and respiration for each stream.

The study was part of a broader investigation to determine the effects of timber harvest on the biological characteristics of several coastal streams.

A comprehensive review of methods for study of community metabolism is provided by Wetzel (1964). A common method of estimating periphyton production uses a submerged uniform artificial substrate for colonization and subsequent measurement of biomass produced over a known time interval. Microscope slides generally provide a nonselective surface for algal attachment and make possible a quantitative expression of the biomass present (Patrick, Hohn, and Wallace, 1954). Extensive reviews of various other applications of this approach are presented by Cooke, (1956), Castenholz (1960), and Sládečková (1962). The most meaningful use of such standing crop estimates is in demonstrating qualitative and quantitative seasonal changes in community structure. However, the values obtained are more relative than absolute because

of errors resulting from grazing, sloughing, and variability in cell turnover rates.

A relationship has been shown between chlorophyll a concentration and rate of photosynthesis. The use of this index has been reviewed by Odum, McConnell, and Abbott (1958) and Strickland (1960), who have shown extreme variations in production for equivalent amounts of chlorophyll a resulting from differences in illumination, temperature, nutrition and species composition of the community under investigation. A linear correlation between chlorophyll a concentration and numbers of individuals has been demonstrated by Moul and Mason (1957) and Kobayasi (1961a) and between periphyton production and chlorophyll "phytopigment" units (Grzenda and Brehmer, 1960). The use of chlorophyll concentration in the estimation of the standing crop has been criticized by Strickland (1960) because of variability in pigment content of different species under changing conditions and the presence of detrital chlorophyll which may lead to erroneous results. Chlorophyll concentration has been used to estimate production in conjunction with a measurement of photosynthetic rate (McConnell and Sigler, 1959; and Kobayasi, 1961b).

There have been very few investigations of periphyton production in streams using the dissolved oxygen technique. Odum (1956) and Hoskin (1959) demonstrated a diurnal oxygen curve that depended

upon buildup and depletion of photosynthetic oxygen in relatively slow-moving streams, but their corrections for diffusion sometimes failed to account for changes in community respiration occurring during the period of the diffusion calculation (Copeland and Duffer, 1964).

McConnell and Sigler (1959) and Kobayasi (1961b) estimated gross photosynthesis in mountain streams by the light and dark bottle method. The numerous problems associated with this technique are reviewed by Strickland (1960). The most apparent limitations of the measurement involve a suppression of both photosynthesis and respiration that accompanies the absence of current and renewal of water. Whitford (1960) and Whitford and Schumacher (1961) reported significant increases in phosphate uptake and carbon dioxide evolution upon exposure of algal cultures to moderate currents.

The photosynthesis-respiration chamber, as utilized by McIntire et al. (1964) with laboratory communities, provided reasonably natural conditions under which estimates of community metabolism could be obtained. Diffusion errors are eliminated as the system is closed.

In this investigation a clear plexiglas cover was designed which could be clamped to a submerged porcelainized tray containing a portion of the community. The water was thus isolated from the atmosphere and circulated over the community for periods of

time sufficient to allow measurable changes in dissolved oxygen to occur.

Description of the Study Area.

The present investigation was pursued from July through December 1964 on Flynn Creek and Needle Branch, two small streams tributary to Drift Creek, which drains into Alsea Bay near Waldport, Oregon. The streams are approximately two miles apart in an area which receives about 100 inches of rainfall per year. The study areas are 2500 foot sections of the streams and have been described in detail by Chapman et al. (1961).

In general, most of the study area on each stream is well shaded by a dense understory of salmon berry (Rubus spectabilis), vine-maple (Acer circinatum), red elderberry (Sambucus callicarpa), skunk cabbage (Lysichitum americanum), and thimble berry (Rubus parviflorus), and an overstory primarily of red alder (Alnus rubra) and Douglas fir (Pseudotsuga menziesii). The Flynn Creek canopy contains a larger proportion of alder than that of Needle Branch, causing seasonal differences in available light between the two streams.

Generic composition of the algal community was determined by examination of glass slides which were placed in the trays and in other selected areas of the streams. The diatoms were by far

the most abundant group (70-80 percent by numbers) and during periods of high runoff were the only forms observed. Stigeoclonium was the only member of the Chlorophyta observed, appearing primarily in the more lighted sections of the streams. The blue-green algae, Chamaesiphon and Calothrix, appeared frequently but never in large numbers (Appendix III).

Aquatic animals were most abundant in the trays during the periods of stable stream flow, from July through October. Larger animals removed from the trays were the reticulate sculpin (Cottus perplexus) and the crayfish (Pacifastacus trowbridgii). The insect groups most frequently observed were mayflies (Ephemeroptera), stoneflies (Plecoptera), crane fly larvae and bloodworms (Diptera), and caddis flies (Trichoptera). The snail (Oxytrema silicula) was the most abundant animal in the trays.

The stream gravel was composed of marine sedimentary material consisting of micaceous sandstones, mudstones, and siltstones (Williams, 1964). The diameter of substrate sampled ranged from about 0.6 cm to 10 cm. Those sections composed of gravel smaller than 0.6 cm were not sampled, since immersion of such gravel in 90 percent acetone revealed no measurable amount of chlorophyll.

Monthly water quality reports were provided by the Pacific Northwest Water Laboratory of the U. S. Public Health Service (Table I). The water quality of the two streams was similar except for the nitrate level which was up to ten times greater in Flynn Creek than in Needle Branch during some months.

During the period of measurements the flow of Flynn Creek ranged from a low of approximately 0.25 cfs to a high of 23.2 cfs, while the corresponding flows in Needle Branch were 0.02 and 12.6 cfs, respectively. During some freshets gravel was scoured to a depth of as much as 15 cm , and erosion from increased suspended sediment was extensive. The increase in stream turbidity also reduced light penetration to the surviving communities.

TABLE I. WATER QUALITY DATA

Date		NH ₃ mg/l	NO ₂ mg/l	NO ₃ mg/l	Total PO ₄ mg/l	Soluble PO ₄ mg/l	K mg/l	Na mg/l	Water Discharge (cfs)	Stream Conductivity (μmho. cor- rected to 25 °C)
7-13-64	Flynn	0.05	0.004	0.75	0.04	0.04	0.8	5.4	0.55	54.0
	Needle	0.02	0.002	0.75	0.10	0.13	0.8	5.5	0.11	55.9
8-17-64	Flynn	0.05	0.001	0.90	0.05	0.05	0.6	5.8	0.36	52.8
	Needle	0.03	0.003	0.20	0.05	0.04	0.8	5.3	0.06	45.6
9-28-64	Flynn	0.03	0.001	0.55	0.17	0.11	0.8	6.0	0.25	66.5
	Needle	0.06	0.001	0.06	0.06	0.06	0.6	5.3	0.02	46.1
10-20-64	Flynn	0.15	0.001	0.68	0.06	0.04	0.8	5.4	0.30	54.3
	Needle	0.11	0.001	0.07	0.07	0.06	0.7	5.4	0.04	51.3
11-16-64	Flynn	0.10	0.001	1.43	0.04	0.02	0.9	5.3	2.10	56.3
	Needle	0.11	0.001	0.20	0.03	0.01	0.8	5.0	0.68	42.6
11-24-64*	Flynn	0.32	0.003	3.19	9.16	0.003	1.3	4.8	23.2	59.8
	Needle	0.25	0.004	0.41	0.23	0.007	1.1	4.5	12.6	49.6
12-7-64	Flynn	0.10	0.001	1.87	0.06	0.03	1.2	5.0	7.65	54.2
	Needle	0.10	0.001	0.11	0.05	0.01	0.9	4.6	2.37	41.2

* Freshet

METHODS

Description of the Chamber and Measurement Techniques

The porcelainized steel trays (Figure 1A) were placed in the stream bottoms to conform as closely as possible to the natural topography. Colonized gravel was arranged in the tray in a manner simulating the surrounding substrate (Figure 2). Tray locations were determined on the basis of gravel size, light availability, and current velocity to obtain representative estimates of primary production and community respiration. Equilibration periods were at least four weeks except during the winter months when they were shortened to avoid damage to the community from scouring and erosion caused by high runoff.

The upper portion of the chamber was constructed of plexiglas G which has many desirable physical characteristics. Transmission of visible light is uniform at all wavelengths, tapering off rapidly at the extreme ends of the visible spectrum. Total loss by reflection is approximately 8 percent at a 0° angle of incidence, increasing to approximately 10 percent at a 55° angle. In all thicknesses up to 2.5 cm, absorption of visible light is less than 0.5 percent (Rohm and Haas, 1964).

The plexiglas cover was fastened to a submerged tray with C-clamps positioned along the corresponding flanges (Figure 3).

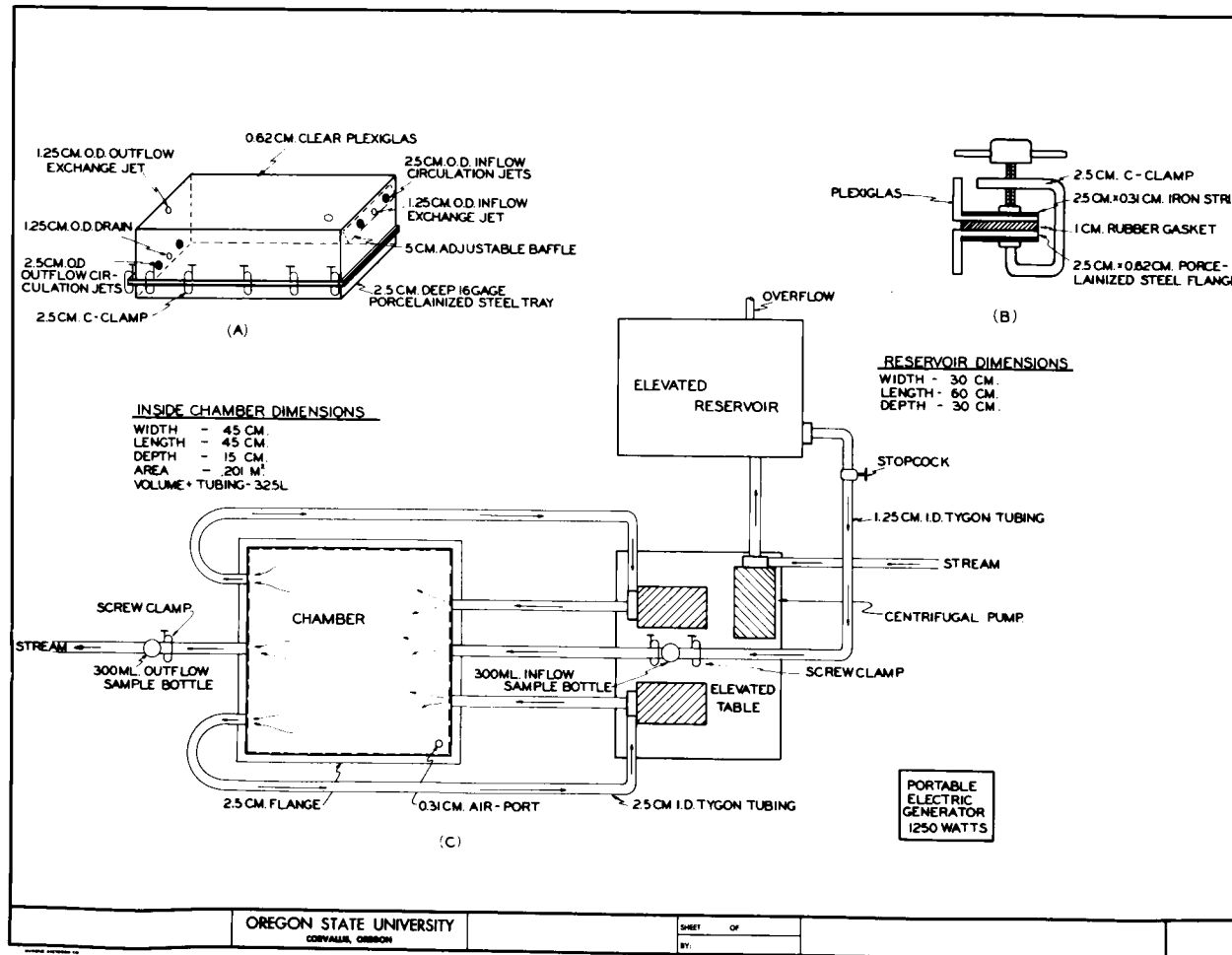


Figure 1. Diagram of photosynthesis-respiration chamber, showing the chamber with its circulation and exchange systems.



Figure 2. Tray during period of equilibration.

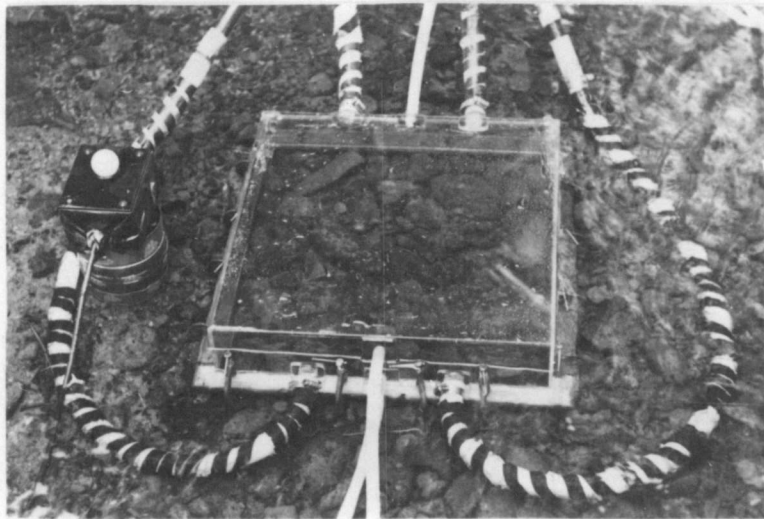


Figure 3. Photosynthesis-respiration chamber and sensing component of the illumination totalizer.

A rubber gasket glued to the plexiglas flange completed the seal. Iron strips equalized the pressure of the clamps (Figure 1A, B).

A system of plastic tubing (Figure 1C) provided for circulation and exchange of water through the chamber. Water from the reservoir flowed by gravity into the chamber. A small port released air as the chamber filled. A full-width, adjustable baffle prevented direct scouring of the community. Injection of dye into the system indicated that mixing was rapid and thorough.

The exchange rate of approximately 200 ml per minute was controlled by a stopcock near the reservoir. The rate could usually be controlled to plus or minus five ml per minute for an hourly period. At this rate, assuming complete mixing, the chamber had a 90 percent renewal cycle of approximately six hours.

Samples of the influent and effluent water were taken each hour (for 7-8 hours) and dissolved oxygen concentrations determined by the Winkler Titrimetric Method (American Public Health Association, 1955, p. 252-255). Subsamples of 100 ml were titrated using a burette calibrated to 0.02 ml. Differences between subsample pairs were generally less than one percent.

At the end of each series of measurements the chamber was drained and removed from the stream. All animals found in the community were removed and preserved in ten percent formalin. Wet weights of the fauna were used in all calculations.

Changes in dissolved oxygen concentration were calculated by determining mean flow rate, mean oxygen concentration for both influent and effluent water at the beginning and end of each time period, and the volume of water in the chamber according to the equation from McIntire et al. (1964):

$$\text{Net O}_2 \text{ change in mg.} = F \cdot t + (\bar{E} - \bar{I}) + V (E_1 - E_0) \text{ where:}$$

F = exchange rate in liters per hour

t = time in hours

\bar{E} = mean dissolved oxygen concentration (mg/l) of the effluent water for the time period

\bar{I} = mean dissolved oxygen concentration (mg/l) of the influent water for the time period

V = total volume of water in the system in liters

$E_1 - E_0$ = net gain or loss of dissolved oxygen concentration (mg/l) of the effluent water during the time period.

Because of the turbulent mixing and low exchange rate within the chamber, the dissolved oxygen concentrations of the chamber and effluent water were assumed equal.

Dissolved oxygen evolution and consumption were measured by the light and dark method. The chamber was covered with a black sheet of polyethylene for the measurements of community respiration. The dissolved oxygen changes during the initial hour of both the illuminated and dark periods were disregarded and these intervals considered as equilibration periods. No attempt was

made to separate animal and plant respiration, and the rate of respiration was assumed to be the same for both the light and dark measurements. The oxygen changes for both periods were summed to obtain an estimate of gross photosynthesis.

Solar Radiation

Solar radiation in gram-calories per cm^2 was measured with a portable illumination totalizer (Tukey et al., 1960). This recorder consists of two components; a diffusion chamber (Figure 3) housing an RCA No. 929 phototube (peak absorption 350-450 $\text{m}\mu$), and a recording unit consisting of a charge-discharge circuit that activates a numerical counter. One instrument was calibrated against an Epply pyrliometer. The linear regression of counts from the phototube and gram-calories per cm^2 from the pyrliometer had a correlation of 0.98 for an eight-hour period of variable sunny weather. This coefficient compared well with those computed by Tukey et al. (1960) of 0.94 and 0.96, respectively, for morning and afternoon observations, over a 30-day period. A correlation of 0.99 was computed for the simultaneous operation of the two totalizers used in the study. Each count was equivalent to 0.023 gram-calories per cm^2 .

During the measurements of production an illumination

totalizer was placed next to the chamber and counts per hour recorded. The instruments were also used to obtain estimates of light energy actually reaching each stream. Stations at which recordings were taken were selected by measuring random distances from surveyed markers that were positioned at each 100-foot interval within the 2500-foot study areas. The instruments were moved upstream in sequence after intervals of one to several days. Simultaneous measurements of light energy were obtained from a Belfort pyrliograph located in an exposed, elevated position within two miles of each stream. "Percentage light transmission" values were calculated from the ratio of total light energy in the open to light energy actually striking the streams. These values were multiplied by the total number of gram-calories per cm^2 recorded by the pyrliograph to obtain monthly values of energy reaching the streams. Total light energy for the area and mean length of photoperiod were also obtained from the pyrliograph charts.

Temperature

Stream flow recorders, maintained on each stream by the U. S. Geological Survey, provided a continuous record of stream flow and temperature. During the periods of measurement, water temperatures of the stream, reservoir, and outflow were read to

0.1° C. Stream and reservoir temperatures were generally identical, and temperatures within the chamber never deviated more than 3° C (average deviation = 1.5° C) from the temperature of the stream. The larger deviations occurred only when the stream level was too low to form an adequate water bath. Only on one occasion (involving high light intensity and low water level) was formation of oxygen bubbles because of supersaturation a problem.

Plant Biomass

Measurements of standing crop were made by manually scrubbing as much of the plant material as possible from the gravel and estimating the existing biomass on the basis of chlorophyll a concentration and percentage of organic matter. The total volume of the suspended material obtained from the gravel was mixed in a Waring blender and samples removed for analysis.

A 25-ml portion of this material was filtered through a type AA Millipore filter and the residue dissolved in 15 ml of 90 percent acetone. Chlorophyll a concentration was determined by the spectrophotometric method of Richards with Thompson (1952). The concentration per liter was converted to a unit area estimate by the following expression:

$$\text{chlorophyll } \underline{a} \text{ (mg/m}^2\text{)} = \left(\frac{V}{S}\right) (C) (T) (A)$$

where: V = volume analyzed in liters (0.015)

S = sample volume in liters (0.025)

C = chlorophyll a concentration in mg/liter

T = total volume of material from gravel in liters

A = factor converting tray area to m² (4.797)

A 500-ml sample of the material was oven-dried at 80° C and subsamples were later ashed at 500° C to obtain an estimate of the percentage of organic matter present. This value was converted to an estimate of organic matter per m² by the following expression:

$$\text{organic matter (g/m}^2\text{)} = \left(\frac{T}{S}\right) (R) (P) (A)$$

where: T = total volume of material from gravel in liters

S = sample volume in liters (0.500)

R = weight of oven-dried residue in grams

P = percentage of organic matter in subsample

A = factor converting tray area to m² (4.797)

A correction for chlorophyll a still remaining on the gravel after scrubbing was obtained by immersing one-quarter of the gravel in 90 percent acetone, determining the chlorophyll a concentration of the extract, and converting the result to a per m² basis. This value was then added to the original chlorophyll a estimate to give the total amount present.

An estimate of the organic matter remaining on the substrate after scrubbing was obtained by solving for X in the following expression:

$$\frac{\text{grams/m}^2 \text{ organic matter removed}}{X = \text{grams/m}^2 \text{ organic matter remaining}} = \frac{\text{g/m}^2 \text{ chlorophyll } \underline{a} \text{ removed}}{\text{g/m}^2 \text{ chlorophyll } \underline{a} \text{ remaining}}$$

The two organic matter estimates were then summed to give the total amount present.

Because of variability in the amount of organic matter within subsamples, the total estimate of organic matter was considered unreliable. Therefore chlorophyll a was used as the best estimate of the plant biomass despite errors resulting from presence of non-functional chlorophyll and non-chlorophyll bearing plant material. The variability in organic matter was attributed to non-uniform deposition of material during the drying process.

The scrubbed gravel was passed through a series of Tyler screens, and size composition was determined volumetrically. Total gravel volume was subtracted from total chamber volume for the dissolved oxygen calculations.

At the middle of each measurement-series an estimate of import and export was obtained by filtering several liters of influent and effluent water through Millipore AA filters and determining the chlorophyll a content of the residue. The influent sample also provided a seasonal index of tychoplankton (stream phytoplankton).

RESULTS

In general, the estimates of gross primary production were higher for Flynn Creek than for Needle Branch, and both streams showed an overall decline in photosynthetic rate during the six-month period (Figure 4A). Peak rates of photosynthesis (0.192 and 0.175 g O₂/m²/hr for Flynn Creek and Needle Branch, respectively) occurred during the periods of greatest light intensity (above 13.0 gram-calories/cm²/hr) and highest temperatures (14-17° C). The level of plant biomass, as estimated from chlorophyll a content, was higher in Flynn Creek than Needle Branch and in both streams exhibited a seasonal variation paralleling the estimates of gross production (Appendix I). Minimum rates accompanied the lower light levels, water temperatures and chlorophyll concentrations observed during the winter months.

There was a seasonal decline in community respiration (Figure 4B) in both streams that corresponded with declines in the abundance of animals in the trays, water temperature, and chlorophyll a content. In several instances, hourly rates varied as much as 50 percent in the same series although temperature increases were small (Appendix II). This variation was attributed primarily to differences in the activity of the animals during the periods of measurement.

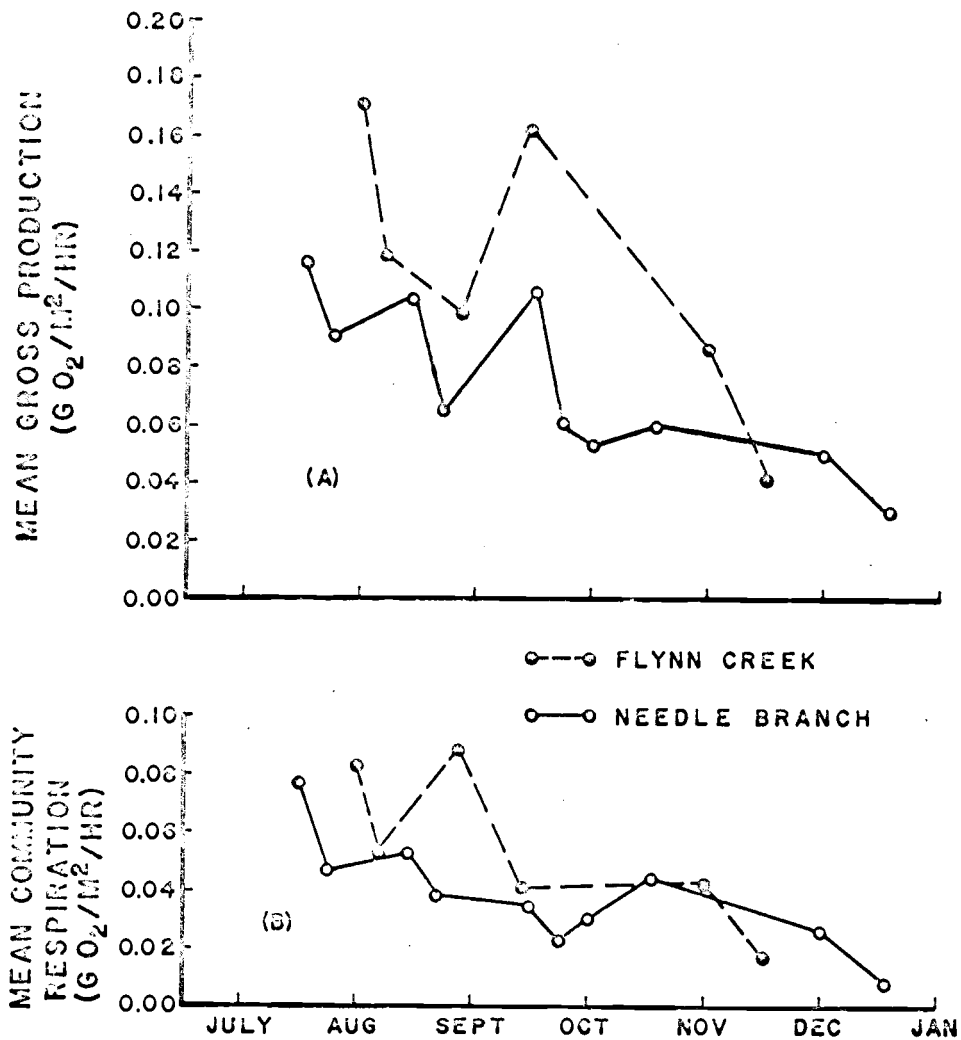


Figure 4. Mean hourly values of gross production and community respiration for each series of measurements.

Relationships of Variables

Interpretation of the raw data is difficult because of the simultaneous variation of several of the environmental parameters that occur during the dissolved oxygen measurements. Under these circumstances, a multiple regression analysis seemed most appropriate. A stepwise regression of the form $Y = a + b_1 X_1 + b_2 X_2 \dots$ was determined on an IBM 1410 computer. This equation provided a means of predicting rates of gross production and respiration based on measurements of the several environmental parameters, and to some degree provided a measure of the quantitative relationship of each variable to these rates.

The b values (partial regression coefficients) represent the change to be expected in the dependent variable due to a change in one independent variable with the other independent variables held constant.

In practice there were limitations in the interpretation of the equations. Ideally, each independent variable should be completely unrelated to the other independent variables used in the equation (Snedecor, 1956). The environmental variables used in this study are not strictly independent because a change in one variable may cause or be accompanied by changes in another variable even though all the variables exist independently of one another. An increase in light intensity can cause a rise in water temperature.

and also stimulate the growth of plants. Because of this relationship among the environmental variables it was sometimes necessary to go beyond the arithmetic scope of the multiple regression technique to adequately correlate the statistical results with the mechanics of the process being described and to depend to some degree upon known biological relationships.

The use of the multiple regression and correlation method of evaluating and quantifying the relationships and interrelationships of a biological process (dependent variable) and its environmental parameters (independent variables) is justified only if based upon known biological relationships. A known cause and effect relationship exists between the rates of photosynthesis and community respiration and the environmental variables used in this study (Rabinowitch, 1951; Steward, 1960). The goodness of fit of the regression (that fraction of the total sums of squares of Y accounted for by the equation) is expressed by R^2 , which shows whether or not the results are consistent with the hypothesis and whether unexplained variation may exist resulting from unmeasured variables (Riley, 1939).

The following regression equations statistically describe the biological relationship of light intensity, water temperature, and chlorophyll a content to the rate of gross production in the two study streams.

$$Y_{FC} = -0.0352 + 0.0061 X_1 - 0.00001 X_2 + 0.0082 X_3 + 0.1568 X_4$$

$$Y_{NB} = -0.0055 + 0.01721 X_1 - 0.0005 X_2 + 0.0016 X_3 + 0.4619 X_4$$

where: Y = rate of gross photosynthesis in g O₂/m²/hr

X₁ = light intensity in gram-calories/cm²/hr.

X₂ = X₁² (accounts for observed curvilinearity of the light relationship)

X₃ = water temperature in °C

X₄ = chlorophyll a concentration in g/m²

The R² values were 0.971 and 0.800, respectively. This disparity between streams (significant at five percent) indicates that unmeasured variables may influence the process of gross production differently on each stream either directly or indirectly by altering the effect of another parameter. Nitrate level and the current velocity at which the communities have developed are possible sources for this variation and should be included in further studies.

The relationship of the environmental variables to the rate of gross production is indicated, to some extent, by the simple correlation coefficients shown in Table 2. However, these values do not account for existing interrelationships among the independent variables and, as demonstrated by Riley (1939), can be misleading. Examination of the partial regression coefficients can provide better insight into the relationships, however, this type of analysis is also subject to misinterpretation because of the significant

Table 2. Simple correlations between multiple regression variables.

<u>Flynn Creek</u>				
	Gross Production	Light	Light ²	Temperature
Light	0.65			
Light ²	0.46	0.95		
Temperature	0.95	0.32	0.25	
Chlorophyll <u>a</u>	0.73	0.32	0.37	0.81

<u>Needle Branch</u>				
	Gross Production	Light	Light ²	Temperature
Light	0.78			
Light ²	0.63	0.93		
Temperature	0.71	0.47	0.24	
Chlorophyll <u>a</u>	0.54	0.23	0.13	0.72

<u>Both Streams</u>				
	Community Respiration	Animal Weight	Temperature	
Animal Weight	0.77			
Temperature	0.82	0.56		
Chlorophyll <u>a</u>	0.66	0.75		0.54

relationships that occurred between the independent variables in this study.

The primary production regimes of the two streams appear to differ with respect to the relative importance of environmental parameters. Statistical analysis of the absolute values of equivalent partial regression coefficients, with a one-tailed Student's "t" test for normal populations having different variances and unequal sample sizes (Li, 1964), indicated a significant difference, at the five percent level, between the coefficients for temperature and light intensity only. Flynn Creek ($b_T = 0.0082$ and $b_L = 0.0061$) exhibited a more pronounced temperature effect than Needle Branch ($b_T = 0.0016$ and $b_L = 0.0172$), while the reverse was indicated for light intensity. These conclusions are physiologically tenable when the amount of available light for each stream is considered (Figure 5B). Laboratory experiments in which the rate of photosynthesis is measured at various temperatures under increasing light intensity show that temperature fluctuations exert only a small influence on the rate at light intensities below the level of light saturation, but that above the saturation point temperature becomes a limiting factor (Rabinowitch, 1956). Light energy on Flynn Creek apparently reached the saturation level for long enough periods that the influence of temperature was greater there than on Needle Branch, which was exposed to lower light levels.

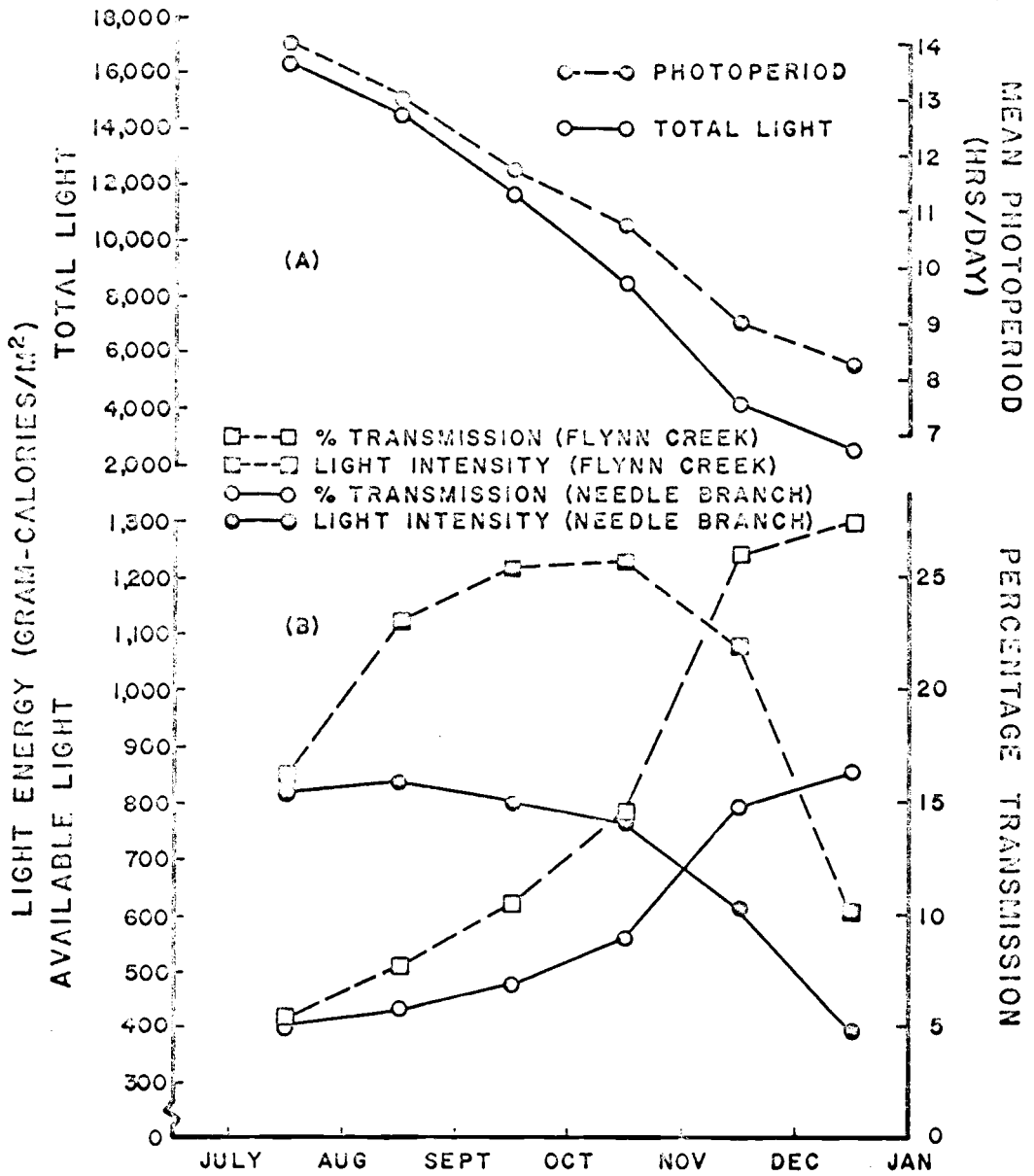


Figure 5. (A) Total unobstructed light energy and length of photoperiod, (B) percentage light transmission and amount of available light for each stream (July-Dec. 1964).

The process of community respiration is statistically described by the following equation:

$$Y = - 0.369 + .0030 X_1 + 0.0058 X_2 + .0150 X_3$$

where: Y = rate of community respiration in g O₂/m²/hr.

X₁ = wet weight of animals in g/m².

X₂ = water temperature in °C.

X₃ = chlorophyll a concentration in g/m².

An "F" test of the R² values for the individual streams showed no significant difference at the five percent level, and the relationships for both communities were assumed to be equivalent. The R² value for both streams was 0.820. Part of the existing error was probably due to differences in the behavior of larger animals during measurements. Observed variations in chlorophyll a content produced insignificant variations in the predicted rate of respiration, suggesting that the plant biomass contributes little to total community respiration.

Available Light

Total light energy and length of photoperiod in the open field near the streams both show maxima in July followed by a parallel decline until January (Figure 5A). The amount of light energy reaching the streams is a function of shading by the canopy and surrounding topography, as well as the total radiant energy and

photoperiod. On both streams the percentage of light transmission increased steadily, with a sharp rise during October and November which corresponded with the periods of greatest leaf fall. Flynn Creek exhibited a continuous increase in available light through October, paralleling the rise in transmission, even though the total amount of energy and the hours of effective light decreased. Finally, the increase in transmission no longer countered the decline in total sunlight and photoperiod, and there was a major decline in available light energy (Figure 5B).

The more modest increase in light transmission on Needle Branch was not sufficient to counter-balance seasonal losses of total energy and hence there was a steady decline in light striking the stream. Minimum light penetration during the summer was about five percent on both streams and increased to a maximum of approximately 27 percent on Flynn Creek and ten percent on Needle Branch. This disparity resulted from the presence of more deciduous trees on the former stream and a high ridge which shaded the latter during the morning hours.

A comparison of the relationship of illumination intensity to the rate of gross production between a laboratory community (McIntire et al., 1964) and the present field data is shown in Figure 6. The intensities for the field curve were calculated by converting gram-calories per cm^2 to lux (Rabinowitch, 1951). Both curves have

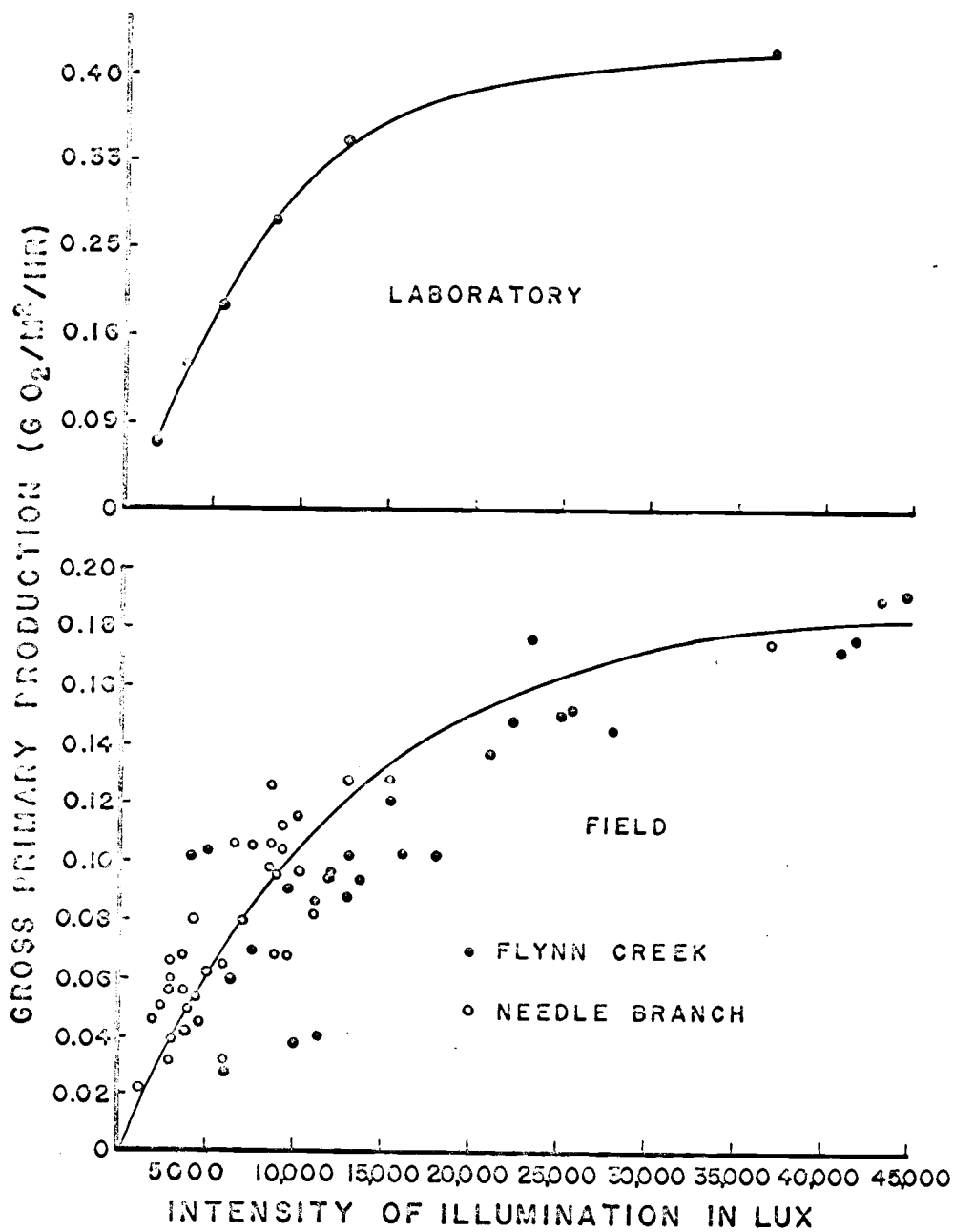


Figure 6. The relationship between illumination intensity and gross primary production in laboratory and field situations. Laboratory data from McIntire et al. (1964).

an asymptotic shape, suggesting that the kinetics of photosynthesis in the respective communities are similar. The exact shape and position of the saturation level of the curves is not directly comparable here because of the different scales used in plotting the data. The curvilinear shape of the field curve was confirmed by the significant improvement of the regression equation due to inclusion of the light-squared variable. Kobayasi (1961b) found an asymptotic relationship in his study of a mountain stream in Japan using the oxygen evolution method. Light intensities in his study were generally higher than either of the investigations discussed above.

Water Temperature

Maximum temperatures occurred during the summer, after which there was a gradual decline to a minimum in November. There was a warming of the streams during December possibly resulting from winter runoff (Figure 7B).

The role of water temperature in regulating rates of gross production and community respiration under varying seasonal light intensities was demonstrated by Kobayasi (1961b). The rates of both processes at equivalent light intensities were suppressed during a seasonal decline in temperature from 26° C to 12° C, although the shapes of the resulting curves remained the same. The influence of chlorophyll a content was held constant by expressing gross

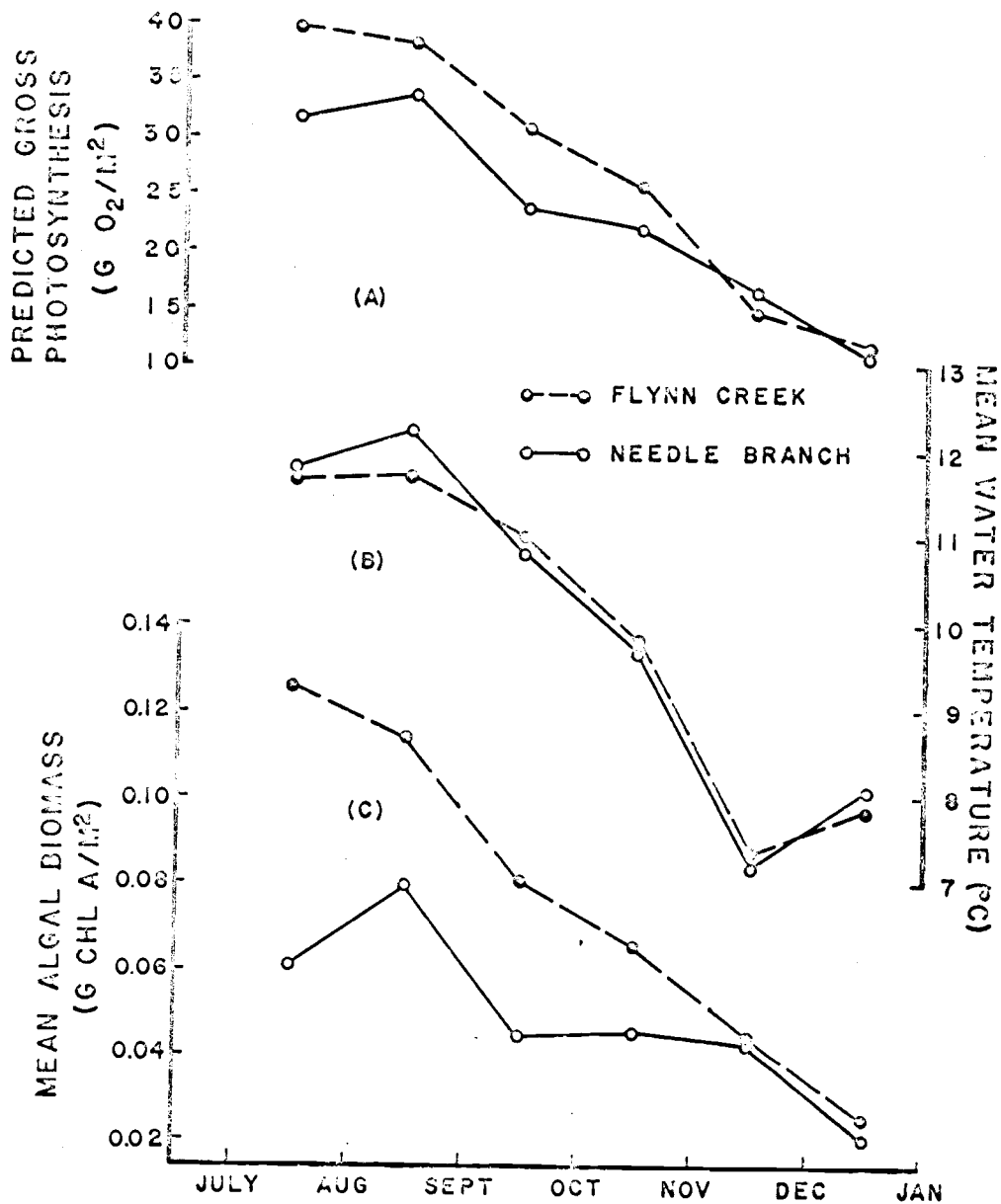


Figure 7. (A) Monthly totals of gross photosynthesis predicted from the multiple regression equations, (B) mean water temperatures from thermograph records, and (C) mean algal biomass expressed as chlorophyll *a*.

production in terms of oxygen evolved per milligram of chlorophyll. Light levels were controlled with filters.

The apparent relationship of temperature to hourly gross production and community respiration was plotted. Both patterns suggested curvilinearity similar to that found by Riley (1939), indicating that the change in community metabolism due to a given temperature change was greater at higher temperatures than at lower ones. However, an analysis of the residuals from the multiple regression plotted against temperature failed to reveal a distinct curvilinear pattern for either process, and the effects of temperature were treated as linear. This apparent curvilinearity was attributed to simultaneous variations in other environmental variables and to increased animal activity at higher temperatures.

Chlorophyll a Content

Plant biomass, as indicated by chlorophyll a content, showed a seasonal decline on both streams. The significance of chlorophyll a as an independent variable in the two processes of community metabolism differs. Variation in concentration of pigment produced significantly greater changes in oxygen evolution than in oxygen consumption, indicating the limited contribution of the plants to total community respiration.

The amount of chlorophyll extracted from the gravel after

scrubbing had been completed constituted between 50 and 60 percent of the total. Crumbling of the gravel made any increase in efficiency impossible.

Animal-Plant Interaction

Snails constituted 60 to 90 percent of the wet weight of the animals collected in the trays. The weight of the shell was considered to be 50 percent of the total weight (Earnest, 1965). Aquatic insect larvae, sculpins, and crayfish constituted the remaining 10 to 40 percent of the animals observed. A simple correlation of 0.75 between chlorophyll a content and weight of animals indicated a reasonably strong association between the two components of the community, probably involving utilization of the algae as an energy source. Direct observation showed the snails to be the primary grazers.

Gravel Size

In this study, possibly because of the narrow range of mean gravel size and small number of samples, gravel size, per se, appeared to be of little importance in determining the distribution and abundance of plants and animals. Analysis of the residuals of the regression equations for gross production and community respiration revealed no discernible relationship between

variations in gravel size and rate of community metabolism. The simple correlations between gravel size and the estimates of animal and plant biomass were low (0.21 and 0.36, respectively). Perhaps the most important characteristic of the gravel that influences community metabolism is its stability during periods of high current velocity.

Stream Flow

Beginning in November there was a steady increase in discharge in both streams (Table 1). Freshets with peak flows of about 23 and 13 cfs, on Flynn Creek and Needle Branch, respectively occurred during the study. These flows, combined with an increase in turbidity, caused shifting and grinding of the substrate which eroded away the attached algae and dislodged clinging animals. Studies by Ellis (1936) and Sprules (1947) show a significant reduction in the productivity of periphyton communities resulting from turbidity, erosion, and siltation.

Predicted Gross Production

An ultimate objective of the study was to determine the feasibility of the prediction of annual production based on relatively few measurements with the respirometer and more extensive sampling of light, temperature, and chlorophyll. The primary value of

the measurements was in quantifying the relationships of the environmental parameters with the rate of gross production and in formulating a basis for prediction. Selection of representative sampling sites impaired the statistical justification of the measurements, but also insured that all types of productive stream substrate were sampled under prevailing conditions. The reliability of the predictions depends upon the biological validity of the statistical computations, therefore it must be assumed that the relationships determined from the actual measurements existed throughout the duration of the study. Estimated averages were computed for light intensity (gram-calories/cm²/hr), water temperature (daily mean) and plant biomass (g chlorophyll a/m²). The small number of samples and the method of selection of the latter variable constituted a source of unknown error in the predictions.

The trend of gross production is similar for both streams with the highest rates (39.7 g O₂/m²/mo on F. Cr. and 33.8 g O₂/m²/mo on N. Br.) occurring during the summer (Figure 7A). Although higher light availability persisted until November on Flynn Creek (Figure 5B), the reduction in water temperature and plant biomass (Figure 7B, C) caused a steady decline in production over the fall and winter months. After November, light availability sharply declined and thus contributed to the reduction of gross production. The situation on Needle Branch differed in that there

was a seasonal decline in gross production, light availability, temperature, and chlorophyll content, indicating that all three independent variables contributed to the continuous decline in production. The lowest periods of production (11.7 g O₂/m² on F. Cr. and 10.6 g O₂/m² on N. Br.) were during December. A small rise in stream temperature produced no apparent increase in the production rates.

Predicted Community Respiration

Estimates of the mean monthly rates of respiration were calculated using average values for animal weight, water temperature, and plant biomass. The rates declined, over the six-month period, in a pattern reflecting the changes occurring in the factors controlling the process (Figures 7C and 8A, C). The significant role of the animal population in controlling community respiration is apparent when the slopes of the respective curves are compared for the period from September through November. Both streams show a 75 percent reduction in the weight of animals which is accompanied by an 83 percent drop in the rate of respiration for Flynn Creek and a 77 percent drop in Needle Branch. A mean decrease of 3.6° C in each stream for this period also reduced respiration. Respiration levelled off when the animal portion of the community reached a nearly constant minimum.

An undetermined amount of the dissolved oxygen consumed during respiration was the result of bacterial decomposition.

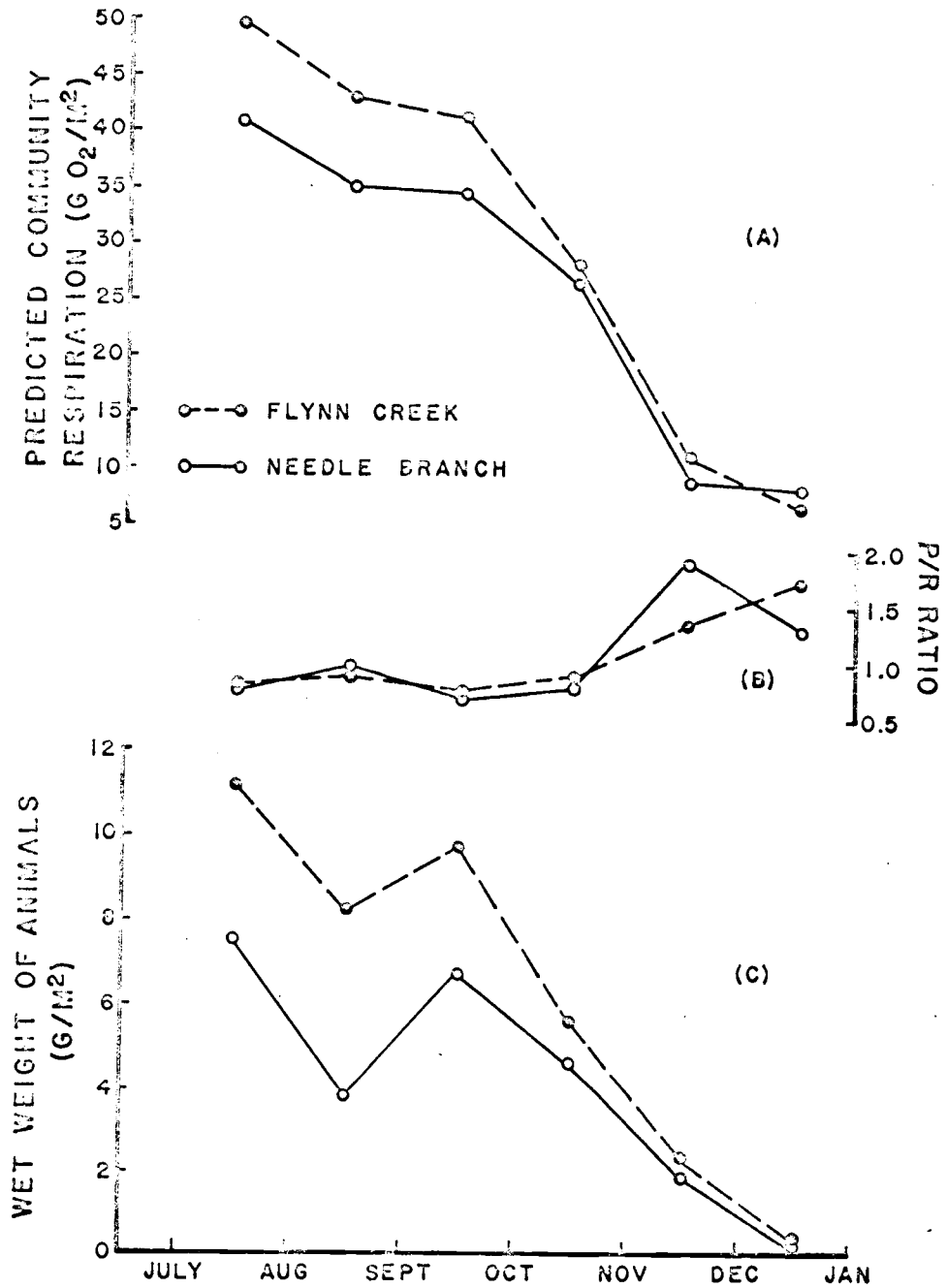


Figure 8. (A) Monthly totals of community respiration predicted from the multiple regression equation, (B) seasonal estimates of photosynthesis-respiration ratios, and (C) mean animal biomass expressed as wet weight.

Although the biomass of the bacteria is small they are characterized by a high rate of metabolism and a rapid turnover of protoplasm (Odum, 1959). Since there was relatively little accumulation of detritus in the chamber during measurements, the amount of decomposition may not have been extensive, but there is presently no reliable method for effectively separating the bacterial portion of community respiration.

Chlorophyll a estimates exhibited a pattern similar to that of animal weight on Flynn Creek for the September through November period but remained nearly constant on Needle Branch. This disparity indicates diversity in the interactions of the controlling parameters. A reduction of approximately 50 percent in the amount of chlorophyll a during December was accompanied by a reduction in community respiration of only 21 percent on Flynn Creek and 35 percent on Needle Branch. At this point, most of the respiration measured was apparently due to the algae and bacteria.

Photosynthesis-Respiration Ratios

Both communities were heterotrophic ($P/R < 1$) until November (Figure 8B) and received some organic material from the surrounding watershed. After November, following removal of most of the animals from the trays, the systems became autotrophic ($P/R > 1$). Odum (1956) and Hoskins (1959)

reported a variety of streams both clean and polluted that exhibit a pattern similar to these streams.

Tychoplankton

Mean estimates of the seasonal levels of tycho plankton (Table 3) were constant through the summer and early fall on both streams but increased approximately 65 percent during the periods of high runoff. Much of this material was non-functional detritus suspended in the water, but an undetermined portion was material eroded from the gravel.

Table 3. Mean levels of tycho plankton in mg chlorophyll a per liter.

	July	Aug.	Sept.	Oct.	Nov.	Dec.
Flynn Creek	0.068	0.061	0.074	0.050	0.201	*
Needle Branch	0.079	0.068	0.076	0.072	0.184	0.186

* no measurement

DISCUSSION

A comparison of rates of community metabolism, based on oxygen evolution and consumption, obtained with the present technique and data from other in situ investigations is shown in Table 4. McIntire et al. (1964) obtained estimates of gross production and community respiration, in six laboratory streams, several times greater than any determined for either Flynn Creek or Needle Branch. A reason for these higher rates was the greater algal density of the laboratory communities (monthly estimates of chlorophyll a generally greater than 1.0 g/m^2). The laboratory streams were continually autotrophic while the natural streams were so only during the winter months.

Hoskin's (1959) diurnal oxygen measurements from the Neuse River system in North Carolina indicated relatively high rates of community metabolism, with riffle sections exhibiting greater productivity than pools. P/R ratios were constantly less than one; however, seasonal abundance of fauna was not reported. In general these streams were much richer and less turbulent than either of the streams in the present investigation. When the diurnal curve method was applied to a mountain stream, community metabolism was completely masked by diffusion (Hoskin, 1959).

Both McConnell and Sigler (1959) and Kobayasi (1961b)

Table 4. Examples of community metabolism in flowing waters.

Gross Production	Community Respiration	Remarks	Reference
2.4-4.7 g O ₂ /m ² /day	1.6-4.2 g O ₂ /m ² /day	Laboratory Streams 6000 lux illumination	McIntire <u>et al.</u> , 1964
0.3-9.8 g O ₂ /m ² /day	0.7-21.5 g O ₂ /m ² /day	North Carolina streams Diurnal Curve Method	Hoskin, 1959
0.5-0.7 g O ₂ /mg Chl <u>a</u> /hr	not given	Logan River Light and Dark Bottles	McConnell and Sigler, 1959
2.1-4.9 g O ₂ /mg Chl <u>a</u> /hr	not given	Mountain Streams Japan Light and Dark Bottles	Kobayasi, 1961b
0.34-1.09 g O ₂ /m ² /day	0.26-1.32 g O ₂ /m ² /day	Needle Branch	
0.38-1.28 g O ₂ /m ² /day	0.22-1.60 g O ₂ /m ² /day	Flynn Creek	
0.11-0.21 mg O ₂ /mg Chl <u>a</u> /hr	-----	Needle Branch	
0.07-0.18 mg O ₂ /mg Chl <u>a</u> /hr	-----	Flynn Creek	

presented gross production values related to the concentration of chlorophyll using the light and dark bottle method. Equivalent values derived from the present data suggest rates considerably lower than for either of the mountain streams mentioned above, even though the consensus is that the photosynthetic rate is suppressed in confined algal communities. A comparison of the light conditions under which each series of measurements were made would probably explain the disparities in the observed rates. Kobayasi (1961b) has recorded summer light values that greatly exceed the peak intensities recorded for Flynn Creek and reported that open sky constituted 35 to 70 percent of the celestial hemisphere above his study stream. McConnell and Sigler's (1959) description of the Logan River suggests a similar situation with most shading resulting from mountains and trees rather than a dense understory.

Evaluation of the Method

The most conspicuous artificial element of the technique is the non-uniform circulation of water within the chamber. In communities such as those of Flynn Creek and Needle Branch, that are composed primarily of diatoms, the multidirectional force of the currents generated within the chamber may not be too significant in eroding the gravel because of the strong attachment of these forms. However, the samples of filtered effluent water, taken for each

measurement series, showed a 10 to 75 percent increase in chlorophyll a over the corresponding estimates of influent water. The maximum increase in chlorophyll obtained for an eight-hour period was 0.001 grams, which was seven percent of the total amount of chlorophyll from that experimental community. An unknown, but considerable, portion of this chlorophyll came from detritus which had settled in the trays during the periods of equilibration.

The fall freshets caused accumulation of silt and detritus in the trays, some scouring of the gravel from the trays, and hindered installation of the apparatus. The increase in temperatures within the chamber, above stream temperatures, resulting from absorption of heat from the pumps and the solar radiation probably caused some increase in the rate of community metabolism. Although these temperature deviations were relatively small (mean 1.5°C for an eight-hour period) the increased rates could be sufficient to seriously bias the estimates of both gross production and community respiration.

In addition to the errors caused by abnormal currents and temperature within the chamber, loss of light energy because of reflection from the plexiglas causes overestimation of the energy actually reaching the community. However, if the loss of energy by reflection from the water (Ruttner, 1953) is considered, the

situation in the chamber more nearly approximates that of the natural community. Use of an underwater sensing device placed in the chamber could rectify this. A more serious error in the measurement of available light energy may stem from the type of sensor used in the study. The RCA No. 929 phototube has peak sensitivity in 350 to 450 m μ range of the visible spectrum and exhibits a sharp decline in efficiency for longer wavelengths (RCA 1963). Because of canopy and cloud cover, light of short wavelengths tends to be absorbed, reflected, and fluoresced to longer wavelengths, resulting in underestimates of light energy.

Suggested Improvements

The reliability of the present technique could be improved in the following ways:

1. A dome-shaped cover for the P-R chamber which would decrease the amount of energy lost through reflection,
2. Installation of screens in the chamber to produce a unidirectional flow over the substrate,
3. Relocation of the outflow circulation jets to help reduce the amount of erosion,
4. Additional ports for the removal of air bubbles,
5. A sprinkler system to help insulate the chamber during periods of low stream flow,

6. An auxilliary system of tubing to allow for regulation of the rate of circulation and provide for removal of air from the inflow sample bottle, and
7. A flowmeter for the inflow line to give more precision and accuracy in measurements of flow rate.

Other Areas of Application

The apparatus described here has facilitated the estimation of production and respiration rates of portions of stream periphyton communities, in situ, through determination of net oxygen changes, but its utility could readily be extended to include a variety of other investigations. The technique could be expanded to make simultaneous measurements in different sections of the stream for complete 24-hour periods and could be modified to incorporate the use of carbon-14 in estimating net primary production as well as to include many phases of pollution study, qualitative and quantitative aspects of nutrient utilization, and experimentation with animal respiration. The experimental results already obtained have indicated considerable potential value for this approach to investigation of periphyton communities.

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APPENDICES

Appendix I. Gross production measurements. Needle Branch.

		Gross Production g O ₂ /m ² /hr	Light Energy g-cal/cm ²	Temperature °C
7-15-64				
Station ^a	695	0.082	2.67	14.1
Time ^b	1300	0.126	4.07	14.6
O. M. ^c	48.5	0.128	4.53	14.8
C ^d	0.060	0.128	5.52	14.8
7-22-64				
Station	1390	0.031	2.44	12.7
Time	1100	0.068	3.17	13.1
O. M.	37.4	0.175	13.25	13.8
C	0.061	0.095	4.37	14.4
		0.079	2.51	14.5
8-12-64				
Station	1850	0.098	2.55	14.1
Time	1200	0.106	2.53	14.3
O. M.	35.8	0.107	2.75	14.5
C	0.080	0.108	2.42	14.6
8-19-64				
Station	380	0.058	1.27	13.4
Time	1200	0.060	1.20	13.6
O. M.	42.0	0.069	1.27	14.0
C	0.078	0.067	1.15	14.3
9-16-64				
Station	0800	0.097	3.63	12.9
Time	1200	0.105	3.36	13.4
O. M.	14.1	0.112	3.38	13.6
C	0.058	0.108	3.20	13.9

^a Distance upstream from weir in feet

^b Beginning of hourly periods

^c Organic matter in g/m²

^d Chlorophyll a in g/m²

Appendix I. (continued)

		Gross Production g O ₂ /m ² /hr	Light Energy g-cal/cm ²	Temperature °C
9-22-64				
Station	990	0.042	1.61	11.8
Time	1200	0.063	1.86	12.3
O. M.	15.4	0.068	3.45	13.0
C	0.028	0.065	2.32	13.6
10-3-64				
Station	527	0.045	1.68	10.6
Time	1200	0.055	1.54	10.9
O. M.	14.7	0.057	1.47	11.2
C	0.043	0.056	1.38	11.5
10-17-64				
Station	1850	0.047	0.78	8.3
Time	1400	0.052	0.85	8.9
O. M.	22.3	0.082	1.43	10.8
C	0.048			
11-27-64				
Station	380	0.044	0.69	8.4
Time	0800	0.048	1.36	8.5
O. M.	23.5	0.054	1.44	8.9
C	0.043	0.053	1.52	9.3
		0.051	1.36	9.4
12-18-64				
Station	616	0.040	1.24	6.3
Time	1400	0.31	1.04	6.2
O. M.	15.4	0.023	0.48	6.1
C	0.020			

Appendix I. (continued) Flynn Creek

		Gross Production g O ₂ /m ² /hr	Light Energy g-cal/cm ²	Temperature °C
7-29-64				
Station	-75	0.145	10.23	13.2
Time	1100	0.147	7.94	14.5
O. M.	41.4	0.177	8.44	15.9
C	0.127	0.192	15.87	16.5
		0.192	44.85	17.0
8-5-64				
Station	6.95	0.137	7.47	12.6
Time	1100	0.121	5.45	13.6
O. M.	44.3	0.118	3.57	13.8
C	0.138	0.114	1.73	13.9
		0.103	1.31	13.9
8-25-64				
Station	825	0.152	9.13	14.8
Time	1200	0.173	15.23	14.9
O. M.	31.6	0.150	8.97	15.1
C	0.089	0.172	14.77	15.2
9-11-64				
Station	890	0.091	6.37	12.0
Time	1200	0.097	4.30	12.2
O. M.	31.6	0.101	4.95	12.2
C	0.080	0.102	5.98	12.3
10-31-64				
Station	750	0.070	2.76	9.7
Time	0700	0.087	4.65	10.0
O. M.	25.0	0.086	4.19	10.2
C	0.067	0.091	4.50	10.3
		0.093	4.95	10.7
11-14-64				
Station	342	0.028	2.30	5.8
Time	0800	0.039	4.55	6.1
O. M.	34.5	0.039	3.68	6.2
C	0.044	0.040	2.85	6.3
		0.061	2.35	6.5

Appendix II. Measurements of community respiration.

Needle Branch			Flynn Creek		
	Respiration g O ₂ /m ² /hr	Temperature °C		Respiration g O ₂ /m ² /hr	Temperature °C
7-15-64			7-29-64		
Sta. ^a 695	0.072	13.4	Sta. -75	0.085	12.4
Time 0800	0.077	13.6	Time 700	0.081	12.6
W ^b 8.69	0.078	13.6	W 11.29	0.080	12.8
7-22-64			8-5-64		
Sta. 1390	0.045	11.7	Sta. 695	0.056	10.8
Time 0700	0.048	11.9	Time 700	0.050	11.1
W 6.53	0.047	12.2	W 8.62	0.051	11.4
8-12-64			8-25-64		
Sta. 1850	0.041	13.0	Sta. 825	0.080	13.8
Time 0800	0.053	13.3	Time 800	0.088	14.4
W 6.08	0.066	13.5	W 7.90	0.092	14.6
8-19-64			9-11-64		
Sta. 380	0.023	11.9	Sta. 890	0.027	9.6
Time 0700	0.033	12.0	Time 800	0.041	9.7
W 1.61	0.045	12.4	W 9.75	0.047	10.3
	0.052	12.9			

^a Same as Appendix I

^b wet weight of animals in g/m²

Appendix II. (continued)

Needle Branch			Flynn Creek		
	Respiration g O ₂ /m ² /hr	Temperature °C		Respiration g O ₂ /m ² /hr	Temperature °C
9-16-64			10-31-64		
Sta. 380	0.023	11.9	Sta. 750	0.036	11.2
Time 0700	0.033	12.0	Time 1200	0.038	11.2
W 1.61	0.045	12.4	W 5.52	0.046	11.0
	0.052	12.9			
9-16-64			11-14-64		
Sta. 800	0.028	11.4	Sta. 342	0.018	6.6
Time 0800	0.038	11.8	Time 1300	0.017	6.9
W 4.98	0.039	12.2	W 2.46	0.015	6.9
9-22-64					
Sta. 990	0.020	10.2			
Time 0800	0.019	10.5			
W 1.26	0.027	11.0			
10-3-64					
Sta. 527	0.026	9.8			
Time 0800	0.035	10.0			
W 4.77	0.046	10.2			

Appendix II. (continued)

Needle Branch		
	Respiration	Temperature
	g O ₂ /m ² /hr	°C
10-17-64		
Sta. 1850	0.049	10.7
Time 0800	0.048	10.7
W 3.74	0.038	10.3
11-27-64		
Sta. 380	0.025	9.4
Time 1300	0.026	9.3
W 1.90	0.028	9.2
12-18-64		
Sta. 616	0.009	6.3
Time 1000	0.010	6.2
W 0.10	0.010	6.2

APPENDIX III. Genera of algae observed attached to glass slides in percentages by numbers.

Flynn Creek								
Classification	8/5	8/10	8/25	9/11	10/16	10/31	11/14	11/21
Chlorophyta								
<u>Stigeoclonium</u>	--	10	12	6	6	5	5	5
Cyanophyta								
<u>Chamaesiphon</u>	8	10	--	--	5	15	2	10
<u>Calothrix</u>	15	16	5	5	4	--	--	5
Chrysophyta								
<u>Gonphonema</u>	--	1	--	--	--	--	--	--
<u>Navicula</u>	35	25	35	80	70	20	18	20
<u>Tabellaria</u>	40	35	48	9	15	60	75	60
<u>Cocconeis</u>	2	3	--	--	--	--	--	--

APPENDIX III. (continued)

Classification	Needle Branch												
	7/15	7/22	8/12	8/19	9/13	9/16	9/22	10/3	10/17	10/18	11/14	11/27	12/18
Chlorophyta													
<u>Stigeoclonium</u>	17	--	5	2	10	5	4	13	10	5	45	6	15
Cyanophyta													
<u>Chamaesiphon</u>	6	15	5	2	--	--	--	3	--	3	10	6	10
<u>Calothrix</u>	13	17	--	4	3	5	3	4	11	3	5	--	--
Chrysophyta													
<u>Gonphonema</u>	4	--	2	--	--	--	--	1	--	--	--	--	--
<u>Navicula</u>	27	28	20	22	20	5	8	10	8	4	12	8	25
<u>Tabellaria</u>	31	40	65	70	65	85	85	67	71	84	28	80	50
<u>Amphora</u>	2	--	1	--	--	--	--	--	--	--	--	--	--
<u>Cocconeis</u>	--	--	2	--	2	--	--	2	--	1	--	--	--