9-1-1981

Application of a New Method for Quantitative Evaluation of Stream Benthic Algal Populations

Richard L. Meyer
University of Arkansas, Fayetteville

Neil Woomer
University of Arkansas, Fayetteville

APPLICATION OF A NEW METHOD FOR QUANTITATIVE EVALUATION OF STREAM BENTHIC ALGAL POPULATIONS

By
Richard L. Meyer
and
Neil Woomer

Arkansas Water Resources Research Center

Publication No. 80

ARKANSAS WATER RESOURCES RESEARCH CENTER
University of Arkansas
Fayetteville, AR 72701

1981

PROJECT COMPLETION REPORT

PROJECT NO. A-053-ARK AGREEMENT NO. 14-34-0001-0104

Starting Date: October 1, 1979 Ending Date: Sept. 30, 1981

APPLICATION OF A NEW METHOD FOR QUANTITATIVE EVALUATION OF STREAM BENTHIC ALGAL POPULATIONS

by

Richard L. Meyer

and

Neil Woomer

Arkansas Water Resources Research Center
University of Arkansas
Fayetteville, Arkansas 72701

Publication No. 80

September, 1981

This project was partially sponsored by the U. S. Department of the Interior in accordance with the Water Resources Research & Development Act of 1978. P.L. 95-467, Agreement No. 14-34-0001-0104.

The work upon which this publication is based is supported in part by funds provided by the Office of Water Research and Technology (Project No. A-053-ARK), U. S. Department of the Interior, Washington, D.C., as authorized by the Water Research & Development Act of 1978.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The work upon which this publication is based was supported with funds provided by the Office of Water Research and Technology, U. S. Department of Interior, through the Water Resources Research Center at the University of Arkansas under grant A-053-ARK as authorized under Water Resources Research and Development Act of 1978, P.L. 95-467.

The authors wish to express their sincere gratitude to Dr. David B. Czarnecki for his thoughtful and important contributions.

ABSTRACT

APPLICATION OF A NEW METHOD FOR QUANTITATIVE EVALUATION OF STREAM BENTHIC ALGAL POPULATIONS

The response of stream biota to changing water quality or other ecosystem perturbations is an important means of assessing water quality. The dynamic nature of streams induces significant sampling and measurement problems. In smaller streams a true algal plankton subcommunity is lacking and the major location for the production of algae is attachment onto stones and other stable surfaces at the substrate-water interface. Several artificial techniques have been developed to analyze the composition of a portion of the epiphytic periphyton (algae attached to stones) but not populations which are qualitatively and quantitatively similar to natural substrates. A newly developed substrate has been tested to determine residence time, qualitative similarity between natural and sampler populations, methodologies for determining primary production rates, seasonal succession, and colonization rates. The new method has been applied, for comparative purposes, to two streams. One stream is influenced by treated municipal sewage while the other is a non-impacted stream.

Meyer, Richard L. and Woomer, Neil

APPLICATION OF A NEW METHOD FOR QUANTITATIVE EVALUATION OF STREAM BENTHIC ALGAL POPULATIONS

Project Completion Report to Office of Water Resources Research, Department of the Interior, September 1981, Washington, D.C., p.

KEYWORDS - *Algae/ *Streams/ *Periphyton/ Sampling/ Primary Productivity

LIST OF FIGURES

LIST OF TABLES

APPLICATION OF A NEW METHOD FOR QUANTITATIVE EVALUATION OF STREAM BENTHIC ALGAL POPULATIONS

Introduction

The study of stream benthic algae (phycoperiphyton) has become increasingly important in recent years as a means of assessing the response of stream biota to changes in water quality or other ecosystem perturbations. The dynamic nature of flowing water systems poses significant methodological problems, many of which remain to be solved. This study is an attempt to fill some of the methodological gaps that exist in the study of stream phycoperiphyton.

Early studies of the benthic algal communities of flowing waters were primarily of a qualitative nature. Fritsch (1929) found blue-green algae to be the most important component in the encrusting communities of certain English streams, and diatom communities to be relatively unimportant. Butcher (1932) also studied the sessile algae of British streams. Quantitative methods for studying benthic algae have been slow in developing, primarily due to the inherently patchy distribution of this community, and to the problems encountered in determining the surface area of diverse and uneven substrata. Semi-quantitative descriptions of periphyton communities have been more commonly attempted. These rely on measures of relative abundance, percent dominance,or frequency estimates to compare samples collected at different times or from different locations (Weber, 1973; Weitzel, 1979). No attempt is made to relate these data to absolute number of organisms per unit area of bottom substrate. Blum (1957), in probably the most comprehensive investigation of the ecology and community structure of stream algae to date, studied the attached algae of the Saline River, Michigan. This study was based on semi-quantitative frequency estimates made using transect methods adapted from terrestrial plant ecology. Douglas (1958) studied the ecology of the attached algae (particularly diatoms of the genus *Achnanthes*) in a small British stream. Her study is particularly notable for its attempt to develop a method for removing the algae from a known area of stream bottom stones for quantitative purposes. Although frequently cited, this method has not been widely applied in subsequent studies, presumably due to its cumbersome and time-consuming nature.

Studies conducted primarily by Patrick and her colleagues (Patrick, 1956, 1973; Hohn, 1961) at the Academy of Natural Sciences of Philadelphia have led to an emphasis on the diatom component of the periphyton as being a particularly sensitive monitor of water quality and stream conditions. In order to compensate for the patchy distribution of these organisms on natural substrates, and to obtain reproducible, quantitative data, artificial substrates have commonly been used. Patrick, et al (1954) devised the Catherwood Diatometer in which glass slides were attached to a float and exposed for variable periods of time for colonization by periphytic diatoms. This device and many modifcations of it have been used extensively in many subsequent ecological studies and water quality monitoring programs.

Other types of artificial substrates have also been used. Tuchman and Stevenson (1980) studied diatom communities developing on clay tiles and sterilized rock. Chessman and McCallum (1981) used strips of Mylar plastic as substrates. Neal, et al (1967) and Waite (1979) also utilized plastic substrates. Wooden blocks were used as substrates by John, et al (1980) in their studies of periphyton in the Volta Lake.

A number of difficulties exist which tend to reduce the usefulness of data obtained from periphyton sampling with artificial substrates. The composition, shape, surface texture and placement of the substrates are usually different from the natural substrates they are intended to emulate. As a result, the structural and functional characteristics of the colonizing periphyton populations do not accurately reflect those of the natural populations. In most lower order streams, the overwhelmingly preponderant natural surface available for colonization by periphyton is that of rocks. These rocks tend to be smooth to slightly granular in texture, usually relatively small, and rounded by the erosive forces of flowing water. The ideal artificial substrate for this type of habitat would also have these characteristics but would also have a constant, quantifiable surface area. Furthermore, it would be placed on or near the stream bottom among the natural rock substrates.

With these facts in mind, a new artificial substrate sampler for benthic algae was designed (see Figure 1). This sampler is hemispherical, approximating the shape of the natural rocks on the stream bottom, but still of constant and easily quantifiable surface area. The characteristics of water flow around the sampler are similar to those around the natural rocks. Numerous authors have noted the differential growth pattern of algae on stones in relation to the current (Fritsch, 1929; Blum, 1960; Hynes, 1972); algal populations growing on flat artificial substrates, such as, glass slides or Plexiglas plates, do not reflect the effects of these flow characteristics.

The hemispherical samplers are also designed to be placed on or near the stream bottom in the same environment with the natural rocks, in contrast to most other types of artificial substrates which are mounted on or suspended from surface floats where they are not subject to the same influences as the natural substrata.

The research plan called for placement of these hemispherical samplers in two or more streams that are subject to different environmental influences. The streams selected were Spring Creek, which receives the effluent from a municipal sewage treatment plant, and Illinois River, a relatively unaffected stream in the same watershed. The study was designed to compare these two streams in terms of community structure and seasonal succession of benthic algae and to determine, insofar as possible, the effects of light, current velocity, and water quality on the structural characteristics of the periphyton communities developing on the substrate samplers.

The hemispherical samplers are also adapted for use with methods developed to measure certain functional properties of the phycoperiphyton communities, in particular, primary production, using a light-dark bottle technique based upon the uptake of carbon-14 in chambers placed over the colonized samplers in which current-driven stirrers produce water movement to satisfy the "current demand" of the rheophilic algae growing on the samplers. Experiments were performed in both Spring Creek and Illinois River utilizing this technique. Preliminary results of these experiments will be included in this report, but detailed analysis is to be a portion of a Ph.D. dissertation based upon this study.

Materials and Methods

The hemispherical substrate samples are composed of portland cement, which is a combination of limestone (calcium carbonate) and clay (hydrated aluminum silicates). They are uniform in size and surface texture and have an exposed surface area of 38 cm^2. This size and shape is quite comparable to the size and shape of the "average" stone substrates that are overwhelmingly dominant in the two streams in which they were placed. Before the samplers were placed in the streams they were "seasoned" by soaking in water for several days to minimize any possible pH effects that might occur. Initial attempts were made to place the samplers in both pool and riffle habitats, but problems with siltation and sampler recovery in the pool habitats made it clear that the samplers could practically be used only in relatively shallow, fast-flowing habitats. (Figure 1)

Clusters of samplers were placed in Spring Creek near Cave Springs, Arkansas in November, 1979, and in Illinois River near Siloam Springs, Arkansas in January, 1980. Concrete bases were placed in the stream bottom and the samplers inserted into these bases. Preliminary work done in the summer of 1979 indicated that a minimum of six weeks' exposure was necessary before communities developing on the samplers were comparable to those on the natural rock substrata. After this incubation time an attempt was made to collect one or more of the samplers from each location every week. At times this was not possible because of high water, vanda-

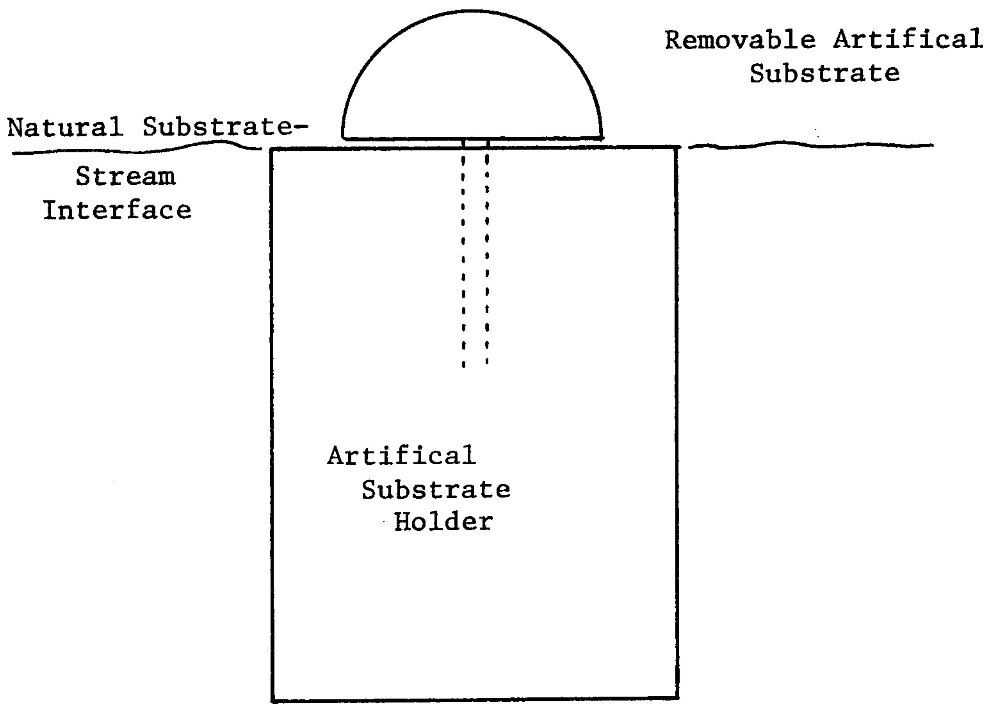

Figure 1. Configuration of the Meyer-Woomer sampler, complete with substrate and holder.

lism, or shifting gravel bottoms, which on occasion covered the samplers, requiring replacement and re-incubation of the samplers.

Each time a sampler was collected, a sample of the algae growing on adjacent natural rocks was also taken for qualitative examination and comparison with the artificial substrates. Routine sampling involved removing the algae from the substrates by brushing with a stiff-bristled toothbrush into a known volume of water. Microscopic examination of the brushed samplers showed that this method was effective in removing virtually all of the periphyton from the samplers. Physical disruption of the algal cells as a result of the brushing could not be detected in the samples. Aliquots from the resulting samples were then filtered for chlorophyll and biomass (ash-free weight) analysis. The remaining portion of the sample was then preserved with M-3 fixative (Meyer, 1971) for later microscopic analysis for species composition and enumeration.

Routine sampling also included field measurements of pH, temperature, specific conductance, current velocity and solar radiation. pH was measured using a Markson Model 88 portable pH meter; specific conductance and temperature were measured using a YSI Model 33 conductivity meter; current velocity was measured with a General Oceanics flow meter, and solar radiation and light penetration were measured with a Protomatic underwater photometer.

At intervals during the study water samples were taken from each stream for more thorough chemical and physical analyses. Alkalinity was determined electrometrically using a Markson Model 88 portable pH meter. Turbidity was measured with a Hach 2100A Nephelometer. Dissolved oxygen was measured by the modified Winkler method. Initially, both total phosphate and dissolved ortho-phosphate measurements were made but nearly 100% of the phosphate in both streams was in the form of ortho-phosphate, so total phosphate measurements were dropped. The stannous chloride method was used for ortho-phosphate. Nitrate-nitrogen was determined using the ultraviolet spectrophotometric method, and dissolved silica was measured using the heteropoly blue method. (All the test procedures in the above paragraph: APHA, 1976.) Ammonia determinations were made using the Chaney and Marboch method.

Simultaneous determinations of chlorophylls a, b, and c, and phaeophytin were made following the method of Jeffries (1977). Acetone extracts of the chlorophylls were analyzed using a Perkin-Elmer 202 spectrophotometer having a band width of 2 nm. Ash-free weight determinations were made by filtering a known volume of sample through a tared glass fiber filter, drying it to a constant weight, and then ashing the sample in a muffle furnace at 500° C. before the final weighing. Ash-free weight is the difference between the weights before and after ashing.

Populations of periphytic algae on the samplers were assessed by species identifications and enumeration. Diatom species identifications and proportional counts were made by treating a portion of the sample with potassium permanganate and hydrogen peroxide to remove all organic material, drying a few drops on a coverslip, and mounting in Hyrax on a microscope slide. Counts and identifications were then made at 1000X using an Olympus phase contrast microscope. The non-diatom species were identified and counted using a Zeiss Invertoscope and the inverted microscope method of Lund, et al (1958). At the same time the non-diatom species were being counted, total diatoms were also counted and an estimate of absolute numbers of each diatom species in each sample was obtained by reference to the species proportional counts made on the cleaned and mounted diatom slides. In this way a measure of the population of both diatom and non-diatom species per unit area on each sampler was obtained. Primary productivity measurements were made using a new technique that combines the hemispherical substrate sampler with a device that isolates a volume of water in a transparent polycarbonate container affixed over the sampler. A simulated current is maintained within the container by means of a dual paddlewheel, with the external stream current driving the outside paddlewheel, which in turn spins the paddle inside the container. Thus, an internal current is produced that is proportional to the stream current at the point of incubation. Primary productivity is then determined by adaptation of the carbon-14 uptake method of Steeman-Nielson (1957). A known volume of ^{14}C-labelled sodium carbonate is injected into the container, and the sample is incubated for 2-3 hours. The sampler is then removed and the periphyton is scraped from the sampler into the water that was in the dome. This is all filtered through membrane filters which are then exposed to an acid mist to remove any precipitated carbonates. The filters are placed in scintillation vials, a Nen Aquasol II scintillation cocktail added and the amount of ^{14}C incorporated into the algal cells is measured by standard liquid scintillation techniques.

RESULTS: PHYSICAL - CHEMICAL PARAMETERS

SPRING CREEK

A summary of the chemical and physical results for Spring Creek is presented in Table 1. Spring Creek is a circumneutral to slightly alkaline stream, ranging in pH from 6.27 in late August to 8.56 in early April, with an annual arithmetic mean of 7.46. Seasonally, pH was highest in the spring, lowest in the autumn, and intermediate in winter and summer. The stream is moderately well buffered, having an average total alkalinity of 98 mg/l. There is little seasonal variation in this parameter but, in general, alkalinity is highest in late winter and early spring, and lowest in mid-summer.

A normal seasonal temperature curve occurs in Spring Creek, with a low of 5.5^{o}C occurring in early January, and a high of 30.2^{o}C occurring in late June. Specific conductance tracks the seasonal temperature curve quite well, averaging 247 µmhos/cm in winter and 414 µmhos/cm in summer. The water clarity is quite good in all seasons except during periods of high runoff. Turbidity ranged from 1.9 NTU to 9.1 NTU, with an annual average of 5.2 NTU.

Detailed measurements of oxygen dynamics were not made but indications are that the oxygen levels in Spring Creek were slightly depressed most of the time, however, they were never near dangerously low levels during the day. The average dissolved oxygen concentration was 8.4 mg/l, and the average oxygen saturation was 86 percent.

Nutrient levels are very high in Spring Creek. The mean dissolved ortho-phosphate level was 6.95 mg/l. Daily values ranged from a high of 19.10 mg/l in late February to a low of 2.38 mg/l in mid-April. Seasonal trends in phosphorous levels were generally indiscernible, except that concentrations tended to be more variable in the late-winter/early spring period. Total phosphorous measurements were also made several times but in no case were total phosphorous levels more than 10 percent higher than dissolved ortho-phosphate levels.

TABLE 1

Summary of Physical - Chemical Data

Spring Creek - 1980

	No. Observations	Mean	Range
Temperature (^{o}C)	33	17.5^{o}	5.5 - 30.2
Conductivity (μmhos/cm	31	317	130 - 440
pH	33	7.46	6.27 - 8.56
Total Alkalinity (mg/l)	14	97.9	62 - 128
Dissolved Oxygen (mg/l)	8	8.4	5.6 - 12.0
Dissolved Oxygen (% Saturation)	8	86	65 - 136
Turbidity (NTU)	14	5.2	1.9 - 9.1
O - phosphate (mg/l)	12	6.95	2.38 - 19.10
Nitrate - Nitrogen (mg/l)	12	7.58	4.47 - 11.01
Ammonia (mg/l)	12	1.54	0.10 - 3.64
Silica (mg/l)	12	2.45	0.90 - 5.55
Current velocity (cm/sec)	32	59	19 - 142
Light Intensity at Sampler Depth (klux)	35	215	0.75 - 53.8

Concentrations of nitrate-nitrogen were also very high, ranging from 11.01 mg/l in early January to 4.47 mg/l in late June. The mean annual concentration was 7.58 mg/l. Again, consistent seasonal trends were not observed although nitrate-nitrogen levels were not as variable as those of ortho-phosphate.

Ammonia was also very high for a stream of this type. A high of 3.64 mg/l was recorded for mid-February and a low of less than 0.10 mg/l was observed in early August. The mean annual ammonium concentration in Spring Creek was 1.54 mg/l. There appeared to be a marked seasonal variation in ammonia levels, being highest in winter and lowest in summer, with intermediate values in spring. An insufficient number of observations were made during autumn, but indications are that ammonia increased during that period.

Dissolved silica concentrations ranged from a high of 5.55 mg/l in late February to a low of 0.10 mg/l in early January. Concentrations were generally higher in the late-winter/early-spring period and lowest during the summer. Again, an insufficient number of samples were taken in the fall, but indications are that silica levels increased during that period.

Current velocity at the sampler sites averaged 59 cm/s over the course of the year, ranging from 19 cm/s in early May (at a sampler located in an eddy behind a washed-in rock) to 142 cm/s immediately after a hard rain in early September. There were no obvious seasonal trends in this parameter but, in general, flows were faster in fall and slower in summer.

Light measurements, of course, are greatly dependent on cloud conditions, shade conditions, and time of sampling, all of which varied greatly from time to time. Depth of sampler is also an important variable. Sampler depth ranged from 9 to 22.5 cm. Light intensity at the depth of the sampler ranged from 5000 foot/candles (52.8 klux) on a clear, sunny April afternoon to 70 foot/candles (0.75 klux) on an overcast February date late in the afternoon. The mean light intensity at the sampler depth was 2000 foot/candles (21.5 klux), which was 42 Percent of the surface intensity.

Illinois River

A variety of problems with the samplers placed in the Illinois River resulted in an incomplete data set being obtained for analysis over the annual cycle. After mid-August only one sampling trip was made to this site because colonized samplers could not be obtained. Table 2 summarizes the chemical-physical data that were obtained at the Illinois River site. Twenty sampling trips were made prior to July 31; only two thereafter.

Illinois River tends to be an alkaline stream, with an average pH during the period of record of 7.86. The pH range was from 8.80 in early March to 7.11 in mid-February. Seasonal variations were slight. Illinois River is moderately to well buffered, having a mean total alkalinity of 109 mg/l. Again, seasonal variations were slight and inconsistent.

Normal seasonal temperature variations were observed, averaging 8.2°C in winter, 16.1°C in spring, and 29.80°C in summer. Conductivity varied directly with temperature, averaging 161 μmhos/cm in winter, 177 μmhos/cm in spring, and 318 μmhos/cm in summer. The river tends to be clear to slightly turbid, with nephelometric readings ranging from 1.4 NTU in early November to 11.0 NTU in late June. The effects of runoff tended to be greater and to persist longer in this stream than was the case in Spring Creek. The mean turbidity in the Illinois River was 6.5 NTU.

Dissolved oxygen levels were consistently at or above saturation values in the Illinois River. The mean dissolved oxygen concentration was 9.9 mg/l, which represents a mean saturation of 107 percent.

Concentrations of algal nutrients were high in the Illinois River in absolute terms, but much lower than those found in Spring Creek. The mean dissolved ortho-phosphate concentration was 1.77 mg/l, with a range of 0.73 to 3.22 mg/l. The highest values were recorded in late winter. Nitrate-nitrogen levels averaged 2.39 mg/l, tending to be higher in the winter and spring and lower in the summer. Concen-

TABLE 2

Summary of Physical - Chemical Data

Illinois River - 1980

	No. Observations	Mean	Range
Temperature (°C)	17	16.40	2.5 - 30.5
Conductivity (µmhos/cm)	15	222	135 - 400
pH	14	7.86	7.11 - 8.80
Total Alkalinity (mg/l)	10	109.4	76 - 156
Dissolved Oxygen (mg/l)	10	9.9	7.2 - 14.1
Dissolved Oxygen (% Saturation)	10	107	84 - 125
Turbidity (NTU)	11	6.5	1.4 - 11.0
O - phosphate (mg/l)	9	1.77	0.73 - 3.22
Nitrate - Nitrogen (mg/l)	9	2.39	1.30 - 3.18
Ammonia (mg/l)	9	0.01	$<$0.01 - 0.06
Silica (mg/l)	9	2.72	1.29 - 5.20
Current Velocity (cm/sec)	24	46.0	$<$10 - 93
Light Intensity (klux)	27	31.2	4.3 - 53.8

trations ranged from 1.30 mg/l in early November to 3.18 mg/l in late February. There was essentially no free ammonia detected in Illinois River samples.

Dissolved silica levels differed little from those found in Spring Creek. The mean concentration over the period of record was 2.72 mg/l. A high of 5.55 mg/l occurred in late February and a low of 1.29 mg/l occurred in late January. The seasonal pattern of silica concentrations corresponded with that found in Spring Creek almost exactly.

Current velocity was measured at each of four separate sampler clusters placed in pool and riffle areas at the Illinois River location. An initial attempt was made to place samplers in a slow-moving pool environment. Current velocity at that location was below that measurable with the method used (less than 10 cm/s). Difficulties with siltation and recovery of those samplers resulted in the pool station being abandoned after several attempts. Three clusters of samplers were placed in a riffle environment, one in the head of the riffle, one in mid-riffle, and one in the lower portion of the riffle. In general, current velocity was lowest at the head of the riffle, highest at the mid-riffle location, and moderate to high at the lower cluster, depending on the general water level. Mean current velocity was less than 10 cm/s at the pool location, 55 cm/s at the head of the riffle, 75 cm/s at the mid-riffle station, and 57 cm/s at the lower riffle station. In general, within the riffle, sampler depth was lowest at the head of the riffle, highest at the lower end of the riffle, and between these extremes at mid-riffle. There was a deviation from this pattern at the maximum and minimum water levels however. Sampler depths in the riffle stations ranged from 5 cm during very low water in August to 32 cm on several occasions during moderately high water periods. The overall average sampler depth in the riffle was 21 cm. The mean depth at the pool station was 51 cm. Measurements were not taken during high water periods when the samplers could not be located for retrieval.

Light penetration to the sampler depth averaged 49 percent of the surface value. The mean light intensity at the sampler depth was 2900 foot/candles or 31 klux. This, of course, was influenced by weather conditions, water clarity, and time of measurement. Nearly all of the Illinois River measurements were made within $\pm$ two hours of mid-day.

RESULTS: BIOLOGICAL

Spring Creek

Expressed in terms of biomass, the predominant alga in Spring Creek during most of the year was Cladophora glomerata. It began growing profusely on both the artificial and natural substrates in mid-October with the onset of cool weather, and continued through May, and had disappeared by early-June. During that time periods of growth alternated with periods of sloughing and scour. Sloughing was observed to be associated with the mass of the Cladophora plume and water velocity. Scour occurred following storm events and instability of the substrate. The biomass expressed as Ash-Free Weight (AFW) attained a peak growth in late February to early March when AFW values as great as 48.6 g/m^2 were recorded. From early January through early March AFW values averaged 29.4 g/m^2. High water caused the heavy Cladophora growths to be scoured from the substrates, and partial recovery occurred before rising water temperatures caused Cladophora to disappear by early June. During that time the mean AFW was reduced to 15.6 g/m^2.

Following the disappearance of Cladophora, encrusting green and blue-green algae dominated the periphyton community in Spring Creek. Gongrosira debaryana and several species of Oscillatoria predominated. Ash-Free Weight (AFW) values during the period between mid-June and mid-October, when Cladophora again appeared in quantity, averaged 9.6 g/m^2. From that time until the last sample was taken in early December, AFW averaged 15.0 g/m^2. The overall annual mean AFW in Spring Creek was 16.9 g/m^2.

From early March through early December, chlorophyll analyses were also performed on samples taken from the artificial substrates. Generally, similar patterns to those described above for AFW were noted. Autotrophic Index (AI), the ratio of AFW to chlorophyll-a, provides a good indication of the degree of organic pollution in a body of water (Weber, 1977). Autotrophic Index values in excess of 100 indicates a high probability of organic pollution. Autotrophic Indices in Spring

Creek ranged from 85.5 to 329.5 with a mean AI of 157.2.

The Phaeophytin Index (PI)is frequently used as a measure of the general physiological condition of the periphytic algal community. It can be calculated using data obtained from artificial substrate samples. Phaeophytin, a product of the degradation of chlorophyll, absorbs light in the same spectral region as chlorophyll-a. The PI is the ratio of the optical density of a sample of 663 nm before and after acidification. A ratio of 1.7 indicates a pure solution of chlorophyll, therefore, a vigorous, healthy algal population. A ratio of 1.0 indicates a pure solution of Phaeophytin, therefore, a dead and decaying algal population. Solutions with PI values between 1.0 and 1.7 contain a mixture of the two pigments and provide a clue to the physiological status of the standing crop. Phaeophytin Index was calculated on nine samples, taken from early April to mid-August, and ranged from 1.37 to 1.73. The mean Phaeophytin Index was 1.55, indicating healthy, rapidly growing algal populations on the samplers.

The diatom community in Spring Creek, in numerical terms, was dominated throughout the year by small species of the genus *Navicula*, collectively known in the literature as the *Navicula minima* group. In this case, *N. seminulum*, *N seminulum* var. *intermedia*, and *N. luzonensis* were the species present in the greatest numbers. The populations of the larger forms were also surprisingly constant throughout the year but with some seasonal variation. Several species of *Nitzschia* were uniformly abundant, including *N. intermedia*, *N. paleacea*, and *N. amphibia*. Other common forms encountered throughout the year were *Cocconeis placentula*, *C. placentula* var. *euglypta*, *Gomphonema parvulum*, and *Navicula cryptocephala* - including the nominate and the variety *veneta*.

Among those species exhibiting seasonal abundance patterns was *Synedra ulna*, which appeared in large numbers in early January and then disappeared almost completely by the middle of the month. *Diatoma vulgare* is a cold water species that appeared during the winter and early spring, but never achieved large numbers. *Navicula mutica* appeared in large quantities in November but was present in very few of the samples during the remainder of the year.

The diatom populations developing on the artificial substrates compared very well with those found on the adjacent natural substrates. This was especially true of the dominant forms which, in almost every case, were the same on both substrate types. In general, a larger number of rare species were found on the natural substrates and in some cases, a greater total number of diatoms per unit area occurred on the natural substrates. Complete species lists, along with a statistical analysis of the diatom populations of the artificial versus the natural substrates, will be presented in a doctoral dissertation now in preparation (NW).

Illinois River

Samplers were initially placed in the Illinois River in January, 1980. They were collected at weekly intervals until mid-March to determine the rate of colonization. Heavy rains during that period caused the gravel substrate to shift, covering the samplers and obliterating the attached periphyton. New sites were chosen for the sampler array and new samplers were implated. These events delayed the availability of "mature" samplers being collected until early July. After that time samplers were collected until mid-August when similar difficulties resulted in sampling being discontinued for the remainder of the year, with the exception of a final collection in mid-November.

Growth on the samplers, as indicated by the AFW determinations, was generally increased each week after three weeks' exposure, until eight weeks' exposure. After one week's exposure in January, the mean AFW was 0.86 g/m^2. After three weeks, it was only 0.80 g/m^2. Growth then increased steadily to a mean AFW of 15.8 g/m^2 in mid-March after eight weeks' exposure. Mean chlorophyll-a concentrations in the completely colonized winter samples was 141.7 mg/m^2. The mean AFW for that period was 9.3 g/m^2 while the mean PI was 1.54 and the mean AI was 90.1.

The samples taken in July and August had more growth than the summer samples. Mean AFW was 19.4 g/m^2 and mean chlorophyll-a was 210.3 mg/m^2. The overall AI in summer samples was 104 and the PI was 1.80. The high PI value is difficult to explain since it represents an average of six samples, ranging in PI from 1.72 to 1.80. It is possible, however, that other chlorophyll species may have influenced the results.

The overall mean AFW for all Illinois River samples was 5.2 g/m^2. Mean chlorophyll-a concentration overall was 170.7 mg/m^2. Autotrophic Index (AI) and PI averaged 95.3 and 1.65 respectively, for the fully colonized samplers for which these indices were computed.

The non-diatom flora of the Illinois River exhibited a pattern similar to that described for Spring Creek. Cladophora glomerata dominated from late fall through late spring, and the encrusting greens and blue-greens dominated during the warmer months of late spring, summer and early fall. Due to the relatively sporadic periods of sampling, detailed seasonal patterns were not discernible for either the non-diatom or the diatom portion of the flora. However, during periods when samplers were fully colonized, collections were much more intensive. During the period between January 15 and March 14, twenty-two samplers were collected from the Illinois River, along with an identical number of samples of the natural epilithic flora. The results of the analysis of diatom populations from these collections illustrates the usefulness of the hemispherical samplers in detailed studies of diatom colonization and short-term succession.

Initially, Nitzschia dissipata was overwhelmingly dominant on both natural and artificial substrates, except in the riffle samples, when Diatoma vulgare was sub-dominant. In subsequent samples, N. dissipata continues to be dominant on natural substrates but Gomphonema olivaceum, a common cold water form, began to appear in large numbers on the artificial substrates. Cocconeis pediculus, an epiphytic form, appeared in abundance on the natural substrates but was uncommon on the artificial substrates. Toward the end of this period of intensive sampling small forms of *Navicula*, especially *N. luzonensis* and *N. caduca*, began to dominate, first on the artificial and then on the natural substrates. *Cymbella affinis*, another cold water species, also appeared as a sub-dominant on some artificial substrates.

In general, those species making up the top 90 percent of the total diatom populations were the same on both the natural and artificial substrates but the proportions varied considerably and there was often a lag of some duration between the appearance of new dominants or sub-dominants and their appearance in large numbers on the natural substrate.

Complete species lists and statistical analyses of these results will appear in a forthcoming doctoral dissertation.

RESULTS: PRIMARY PRODUCTION

The hemispherical samplers used in this study are adaptable for making *in situ* measurements of primary productivity, using the dome apparatus described previously and illustrated in Figure 1. **A number of** such experiments were performed using samplers incubated in Illinois River, Spring Creek and White River. The latter site was located near Crosses, Arkansas and was included in order to compare results from an unenriched stream having a protected forested watershed, with results obtained from the highly enriched Spring Creek site and the moderately enriched Illinois River site. The results of these experiments are summarized in Table 3.

Two relatively large scale experiments were carried out at the Illinois River site in July. In the first experiment, productivity determinations were made on nine different samplers in which a current was induced. The mean production rate in these samplers was 18.42 mg $C/M^2/hr$ and the range was from 1.40 to 47.81 mg $C/m^2/hr$. The sampler having the extremely low rate of production had been partially covered by gravel and was incompletely colonized. Productivity measurements were made on three samplers using the dome but with the induced water movement inside. The productivity measured in these cases ranged from 3.61 to 6.27 mg $C/m^2/hr$, with a mean productivity of 4.88 mg $C/m^2/hr$.

The second July experiment gave quite comparable results, with an overall average productivity of 21.02 mg $C/m^2/hr$. The range in this case was 13.62 to 34.41 mg $C/m^2/hr$. A final experiment was carried out in the Illinois River in early November. Productivity rates at this time were slightly less than in July, averaging 14.41 mg $C/m^2/hr$, with a range of 7.11 to 24.46 mg $C/m^2/hr$.

The results of experiments carried out in Spring Creek and White River were consistent with those for the Illinois River. Smaller scale experiments in the White River in early April and early July resulted in mean productivity estimates of 9.50 and 6.31 mg $C/m^2/hr$. Experiments in Spring Creek in August were designed to track increases in production rate during colonization of the samplers. The productivity estimate after one week's exposure was 28.90 mg $C/m^2/hr$ and this increased

TABLE 3

Summary of Carbon-14 Primary
Production Experiments

Location	Date	Production Estimate (mg $C/m^2/hr$)	
		Mean	Range
Illinois River	7-10-80	18.42	1.40 - 47.81
	7-31-80	21.02	13.62 - 34.41
	11-07-80	14.41	7.11 - 24.46
Spring Creek	8-05-80	28.90	-
	8-12-80	37.69	-
	8-19-80	57.74	-
	11-04-80	65.42	-
White River	4-05-80	9.50	-
	7-02-80	6.31	-

to 37.69 mg C/m^2/hr after two weeks' exposure and to 57.74 mg C/m^2/hr after three weeks' exposure. An early November estimate for "mature" samplers was 65.42 mg C/m^2/hr.

Complete details of these experiments, along with a complete data set and implications, will be presented later in a doctoral dissertation.

DISCUSSION:

A primary disadvantage to the use of many artificial substrates in periphyton studies has been that the communities developing on them are not the same as those on the natural substrates they are designed to emulate. This study has shown that the concrete hemispherical samplers of our design are colonized by the same algae and, in general, in the same proportions as those found in adjacent natural rock substrates. The variability that exists appears to be well within the range of natural biological variability. Perfect comparability, in terms of species composition and proportion, would not be expected even among natural substrates of the same type. As Round (1964) has pointed out, "even though certain groups of species tend to occur together their ratios differ greatly from place to place even in one stream; because of the instability of the habitat the arrangement is probably largely due to chance".

Another common complaint concerning studies of periphyton growing on artificial substrates is that they usually are suspended in the water column and are, thus, inadequate for predicting dynamics of periphyton communities on the stream bottom. The hemispherical samplers tested in this study are comparable in terms of size, texture, shape, placement, and position with respect to the current to the natural rock substrate in the streams studies. Even though a number of difficulties were encountered in this study, none proved insurmountable and the results showed that successful measurements of the structural and functional characteristics of the stream benthic algal populations can be made with relative ease using these samplers.

The hemispherical samplers are particularly well suited for detailed colonization and short-term and seasonal succession studies, and their uniformity makes them applicable for inter-stream comparisons using many parameters, including enumeration and identification of species, standing crop estimates from biomass and chlorophyll measurements, and productivity estimates using both the carbon-14 and light-dark oxygen bottle techniques. They provide numerous possibilities for use in water quality and pollution related investigations in relatively shallow, fast-flowing streams, such as were investigated in this study. Collins and Weber (1978) have emphasized the importance of the benthic algal communities in relation to water quality and pollution studies. They also noted that existing methodologies for many of the meausrements required are extremely crude, particularly those for productivity measurements. In that regard, Hynes (1972) has noted that, "only direct measurement of undisturbed periphyton in chambers in which the water is kept moving offer any real hope of determining the primary production by periphyton .....". The methods tested in this study have given consistent results generally comparable with published estimates using much more complicated techniques that are not as applicable for extensive field measurements.

Weitzel, et al (1979) notes that the role of periphyton as a primary producer in streams or lakes is very important and has often been overlooked primarily because of methodological deficiencies. He states, "the apparent absence of practical, accurate methods, or the failure to publicize methods as they develop, may be in part responsible for the fact that periphyton is not too often measured as an index of primary production".

Literature Cited

American Public Health Association, 1975

Standard Methods for the Examination of Water and Wastewater. 14th Edition, APHA, Washington, D.C.

Blum, J. L., 1957

An Ecological Study of the Saline River, Michigan Hydrobiologia 9:361-408

Blum, J. L., 1960

Algal Populations in Flowing Waters. In the Ecology of Algae. C. A. Tryon, Jr., and R. T. Hartman, editors. The Pymatuning Symposia in Ecology. Spec. Publ. No. 2. Pymatuning Laboratory of Field Biology. Edwards Bros. Inc., Ann Arbor, MI.

Butcher, R. W., 1932

Studies of the Ecology of Rivers. II. The Microflora of Rivers with Special References to the Algae on the River Bed. Annals of Botany 46:813-861.

Chessman, B. C. and S. D. McCallum, 1981

A Simple and Inexpensive Artificial-substrate Unit for Obtaining Periphyton Collections from Streams. Water Research 15:351-352.

Collins, G. B. and C. I. Weber, 1978

Phycoperiphyton (algae) as Indicators of Water Quality. Trans. American Micros. Soc. 97(1):36-43.

Douglas, B., 1958

The Ecology of the Attached Diatoms and Other Algae in a Small Stony Stream. J. Ecology 46:295-322.

Fritch, F. E., 1929

The Encrusting Algal Communities of Certain Fast-flowing Streams. New Phytologist 218:165-196.

Hohn, M. H., 1961

Determining the Pattern of the Diatom Flora. J. Water Pollution Control Federation 33(17):48-53.

Hynes, H. B. N., 1972

The Ecology of Running Waters. University of Toronto Press.

Jeffery, W. W. and G. Humphrey, 1975

New Spectrophotometric Equations for Determining Chlorophylls a, b, c_1 and c_2 in Higher Plants, Algae and Natural Phytoplankton. Biochem. Physiol. Fflanzen 167:191-194.

John, D. M., Ek. Obeng-Asamoa and H. N. Appler, 1980

Periphyton in the Volta Lake. II. Seasonal Changes on Wooden Blocks with Depth.
Hydrobiologia 76:207-215.

Lune, J. W. G., C. Kipling and E. D. LeCren, 1958

The Inverted Microscope Method of Estimating Algal Numbers and the Statistical Basis of Estimations by Counting.
Hydrobiologia 11:144-170.

Meyer, R. L., 1971

A Study of Phytoplankton Dynamics in Lake Fayetteville as a Means of Assessing Water Quality.
Arkansas Water Resources Research Center, Publ. No. 10.
University of Arkansas, Fayetteville. 59 p.

Neal, E. C., B. C. Patten and C. E. DePoe, 1967

Periphyton Growth on Artificial Substrates in a Radioactively Contaminated Lake.
Ecology 48:918-924.

Patrick, R., 1973

Use of Algae, Especially Diatoms, in the Assessment of Water Quality In Biological Monitoring of Water and Effluent Quality.
ASTM STP 528, J. Cairns, Jr., K. L. Dickson and G. F. Westlake, editors. American Soc. for Testing & Materials, Philadelphia, PA.

Patrick, R., M. H. Hohn and J. H. Wallace, 1954

A New Method for Determining the Pattern of the Diatom Flora.
Not. Nat. Academy of Natural Sciences, Philadelphia 259:1-12.

Patrick, R. and M. H. Hohn, 1956

The Diatometer - a Method for Indicating the Conditions of Aquatic Life. Proc. American Petroleum Inst., Sec. 3, Refining, Addresses and Reports, 36(3):332-339.

Round, F. E. 1964

The Ecology of Benthic Algae. In Algae and Man.
D. F. Jackson, Ed., Plenum Press, New York.

Steeman-Neilson, E. 1951

Measurement of the Production of Organic Matter in the Sea by Means of Carbon-14.
Nature 167:684-685.

Tuchman, M. C. and R. J. Stevenson, 1980

Comparison of Clay Tile, Sterilized Rock and Natural Substrate Diatom Communities in a Small Stream in southeastern Michigan,USA.
Hydrobiologia 75:73-79.

Waite, D. T., 1979

A Periphyton Growth Substrate Useful for Nutrient Impact Studies in Large Rivers.
Water Research 13:1947-1349.

Weber, C. I., 1973

Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents.
U. S. Environmental Protection Agency, EPA-6401/4-73-001.

Weitzel, R. L., 1979

Periphyton Measurements and Applications. In Methods and Measurements of Periphyton Communities. A review. ASTM STP 690. R. L. Weitzel, editor. American Society for Testing and Measurements, Philadelphia, PA.