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THE UNIVERSITY OF ALBERTA

THE EFFECTS OF INCREASED TEMPERATURES ON PERIPHYTON COMMUNITIES OF ARTIFICIAL STREAM CHANNELS

by

BRADFORD B. OWEN, JR.

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

IN BIOLOGY

DEPARTMENT OF BOTANY

EDMONTON, ALBERTA

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled The Effects of Increased Temperatures on Periphyton Communities of Artificial Stream Channels submitted by Bradford B. Owen, Jr. in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Biology.

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To my Father, Dr. Bradford B. Owen, Sr.,
who first introduced me to the exciting
world to be discovered in a drop of water.

ABSTRACT

The effects of heat on periphyton communities was studied, using once-through flowing experimental streams with glass substrates. A control stream used Columbia River water, and the other four were maintained at 2.5°, 5.0°, 7.5°, and 10.0°C increments higher.

Standing crops of mature periphyton generally did not vary significantly among the different temperatures. The rate of standing crop accrual from cleaned surfaces increased with increasing temperatures. Net community production was measured from standing crop changes plus export. Heated streams out-produced the control in periods of high light and moderate temperatures. In periods of low light and high temperatures, net production of the heated streams was inhibited. Net annual production of the five streams were similar. Production was modelled as a function of temperatures and light.

Community structures differed considerably among the streams. *Melosira varians* dominated all fall and early winter communities. By mid-winter, the cooler streams were dominated by *Fragilaria* and *Nitzschia* species. *Rhopalodia gibba* dominated the +10°C communities in late spring, and by mid-summer also became important in the cooler streams. *Melosira* regained dominance by mid-summer in the control channel, and by late summer in the warmer streams.

A species succession was shown to exist in the spring when areas of bare substrate were allowed to colonize.

Shannon diversity indices were inversely correlated to net productivity and to water temperatures.

ACKNOWLEDGEMENTS

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I wish to thank the Battelle staff who aided and encouraged my research, and especially Dr. Charles C. Coutant. My thanks to Dr. George H. LaRoi for his suggestions and criticisms, and for helping me view aquatic ecology in refreshing ways. Thanks also to Dr. C. David McIntire for aiding in the identification of several diatoms.

Special thanks are due Marion, my wife, who has patiently typed and aided me in assembling this document.

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INTRODUCTION

The ever increasing needs of our industrialized, mechanized society have placed severe demands on the environment of this planet Earth. To nurture these demands, electrical energy is mainly supplied by inefficient systems of energy conversion, which necessitate the disposal of waste heat. This heat is frequently transferred to bodies of water, resulting in numerous ecological consequences. Although the effects of heat on fish, and to a lesser degree on invertebrates have been investigated, there have been to date few experimental attempts to analyze the effects of the organisms comprising periphyton communities. This thesis describes the results of research conducted to determine the reaction of one food chain base, the periphyton community, to constant thermal additions.

Periphyton may be defined as the community of attached plants, excluding rooted macrophytes, that develops on exposed underwater surfaces (Wetzel and Westlake 1969). It is virtually impossible to separate these largely microscopic plant forms from the protozoa, bacteria, fungi, and small invertebrates that are also an integral part of this attached community. Thus, the term "periphyton" will, in this study, be understood to include all the associated organisms that develop on underwater surfaces.

Periphyton is a source of primary production for virtually every body of water. It may be an unimportant producer in deep lakes, but in many shallow lakes and streams it may be the major source of production. Wetzel (1963) considered periphyton more important than phytoplankton in streams, rivers, and shallow lakes. In large rivers, such as the Columbia, the relative importances of periphyton and phytoplankton are difficult to assess, as many species are common to both communities. Many investigators (e.g. Butcher 1932, Chandler 1937, Lacky 1942, Whitford 1956, Lund and Talling 1957, Cushing 1964) have demonstrated that the components of river plankton (potamoplankton) are often partially, if not entirely, derived from periphyton. Similarly, species commonly considered to be potamoplankton may be present in periphyton, as will be shown in this study. Macrophytic plants also may be important primary producers in some bodies of water, but are virtually absent from the Columbia River. Thus, in large rivers such as the Columbia, the indirect subject of this study, periphyton may be regarded as a major source of primary production.

The ecology of periphyton communities has been studied extensively. Their importance was probably not recognized, however, until the 1930's when Butcher (1932) investigated the subject. Since then, numerous studies of periphyton from diverse habitats have been reported. No single best method for collection of periphyton organisms has been established or agreed upon. Removal from natural substrates is difficult, and may result in damage to the more vulnerable organisms (Douglas 1958). It is also difficult to quantify data from natural substrates, as the microhabitats available are extremely diverse, and the responses of the communities to these differences are difficult to assess. Consequently, much of the research on periphyton has centered around the use of various types of artificial substrates which provide the communities with uniform surfaces on which to colonize. Some of the artificial substrates used include wood, flat or uniform stones, paraffin, plexiglas, and glass. Much of the literature on the use of these has been reviewed by Cooke (1956), Lund and Talling (1957) and Sladeckova (1962). Glass has been the most widely used substrate. Many investigators (e.g. Patrick, Hohn and Wallace 1954, Lund and Talling 1957, Castenholz 1960, McIntire 1966) consider the plant communities that develop on glass surfaces to be representative of "natural" periphyton.

Although there is considerable literature characterizing the periphyton of many bodies of water, few investigators have attempted to demonstrate experimentally the correlation between specific environmental parameters and changes in various community characteristics. The effects of high temperatures on periphyton communities have been noted by many authors who have studied thermal springs

(Copeland 1936, Brock and Brock 1966, Brock 1967, Kulberg 1968, Stockner 1968, Winterbourn 1969). However, the periphyton of their studies was generally grown at temperatures well above the limits likely to be encountered in waters receiving thermal wastes. There have also been numerous studies of the responses of individual species of algae to temperature (e.g. Wallace 1955, Smayda 1969, Ignatiades and Smayda 1970, Peiterse and Botha 1971), but it is difficult to infer from the data of these reports the responses of communities composed of many species. Phytoplankton communities have been studied in relation to temperature (e.g. Steeman-Nielsen and Hansen 1959, Warinner and Brehmer 1966, Polteracka 1968, Morgan and Stross 1969, Hirayama and Hirano 1970), but while some of the species presented in these studies may occur in periphyton, it is doubtful that they would react similarly under benthic conditions.

Numerous reports are available concerning thermal effects on aquatic ecosystems; these are reviewed by Kennedy and Mihursky (1967), Patrick (1969), Coutant (1970), and Coutant and Goodyear (1972). Several reports concerned with the effects of thermal discharges include data on periphyton. Trembley (1960) states "...it is clear that with rising temperatures blue-green algae and one family of diatoms become relatively much more abundant, while other diatoms and green algae along with most other members of the periphyton community show a relative decline." This conclusion was based on studies of periphyton in, above, and below a thermal effluent of a steam electric power plant on the Delaware River. He also concluded that total yearly periphyton productivity in the heated zone was probably much greater.

Churchill and Wojtalik (1969) discuss data from several discharge areas. The authors state that below the discharge of the Colbert Steam Plant (Tennessee) the temperatures of Cane Creek increased from 67°F to 86°F in September 1967, while the periphyton changed from a diatom community to a blue-green algae dominated community. Periphyton production was observed to be slightly higher in the heated areas, for the same study period. The authors also discussed the results of research on the effects of thermal discharges of the Paradise Power Plant on the Green River, Kentucky. Periphyton growth rates were "substantially reduced" in the vicinity of the steam plant during summer months; in late fall and early winter, affected areas exhibited "moderately enhanced" growth rates. Buck (1970) compared the periphyton of the Connecticut River above and below the Yankee Atomic plant, Connecticut, during summer and early fall, 1968. He concluded that the thermal additions produced an obvious shift from a diatom dominated community to a blue-green algae dominated community.

Normandeau (1970) studied the periphyton from one collection period in July 1968, and found that in the Merrimack River, New Hampshire, all major groups of periphyton organisms were reduced or absent in a discharge canal where temperatures ranged from 88° to 100° F. These results are in conflict with others, leading one to suspect that additional factors, such as intake chlorination (Brook and Baker 1972) may have masked his results.

Recently, several researchers have attempted to reduce environmental variables by constructing artificial streams, and studying the periphyton grown under the controlled conditions of the streams. Kevern and Ball (1965) studied the periphyton of recirculating indoor laboratory streams, and found no significant differences in net productivity between two streams maintained at 20.0°C, and 25.6°C. The authors observed that a 10°C increase in mean temperature produced a significantly increased rate of gross oxygen production at light intensities over 11,100 lux. These observations were based on a periphyton community from water of 8.7°C to 12.2°C raised to 18.2° C to 21.1°C. They also concluded that in shallow lotic systems, a Q_{10} of approximately 2 might be applicable to the respiratory rates of communities exposed to temperatures not ranging too far from the acclimation temperature. Patrick, Crum and Coles (1969) studied the attached floras of experimental boxes using non-recirculated flowing water. They noted that a shift in average temperature from 34°C to 38°C resulted in a shift of dominance from diatoms to blue-green algae.

Patrick (1971) studied the effects of controlled light and temperature increases on the diatom component of artificial stream periphyton communities. The diatoms studied were grown during short and varying periods of colonization at four dates in a year. Based on community structure and diversity, Patrick states "one may conclude that optimum conditions of light and temperature formed a fairly narrow range within the range of tolerance, and that increases induced near the lower end of the range of tolerance improved the structure of the community significantly. Increases near the upper end of the range of tolerance produced severe degradation in community structure."

The present study attempts to further define the effects of temperature on periphyton communities. In order to simulate natural systems, a once-through artificial stream system was used. The total periphyton community was studied, as it was felt that although the diatom component was important, other groups might also display significant reactions to thermal additions. In order to examine the total spectrum of potential heat effects, a collection schedule was adopted, with the specific objective of defining the effects of heat on periphyton communities of varying maturity.

The general objective of the present investigation is to establish the major effects of sustained elevated temperatures (+2.5°, +5.0°, +7.5°, +10.0°C) above a seasonally varying ambient on undisturbed periphyton communities of outdoor artificial stream channels. An additional objective is to make the data from this research as applicable as possible to the Columbia River System. The search for these effects continued for one year, in order to encompass natural seasonal changes in environmental parameters that might interact with temperature. The specific objectives were to determine if the periphyton of the streams would develop significant differences in standing crop, productivity, and community structure.

METHODS AND MATERIALS

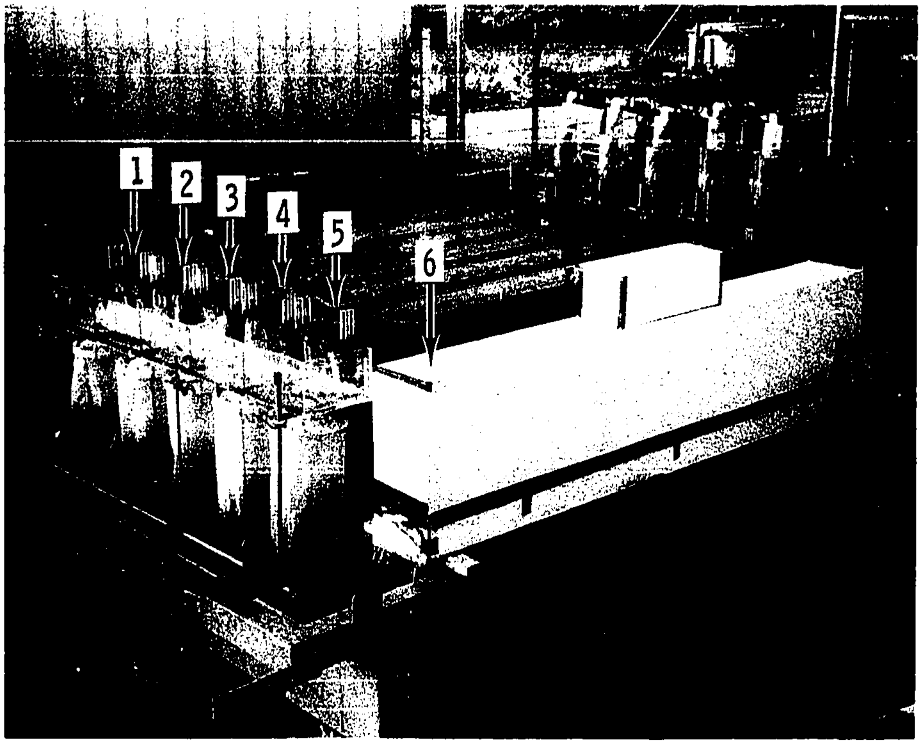
The Experimental Stream System

Six artificial streams, each consisting of a plexiglas channel 1.83 m long, 15.3 cm wide, and 7.6 cm deep (Figure 1) were constructed. At the head of each stream a deeper chamber was constructed (Figure 2) to provide a mixing area for the water that would be introduced at two temperatures. An additional cylinder of plexiglas was added to further mix the water, by forcing it through a series of holes, and then under a second larger cylinder. The latter additions also aided in allowing the heated water, which was air-supersaturated, to come to equilibrium before being introduced into the channel. Microscope slides were positioned in a double row flat against the bottom of the main channel of each stream, with the long axes perpendicular to the flow. A row of flat strips of plexiglas was run down the center of each channel between the rows of slides. Each plexiglas piece was screwed into the main channel with nylon hardware, and covered the ends of six slides, holding them firmly in place. Five channels were placed on a level steel bench in full sunlight exposure. They were oriented so that the flow was north to south. Each drained into a plexiglas receiver, to which a net was attached (Figures 1 and 3). The nets were nylon monofilament with a mesh opening of 210 microns (which was determined to be the most useful mesh size, as will be described later). A removable jar was attached to the bottom of each net, to facilitate the frequent collections of stream export. Exported particulate stream material passed into the nets, and remained trapped until it eventually sank into the collection jar. The exported matter was generally collected every second day.

The additional stream channel, to be referred to as "stream 6" of the "light control channel" was modified with a light sealed, hinged lid (Figure 4). Three Sylvania cool-white fluorescent 60 watt tubes supplied light for the stream 12 hours each day, as controlled by a timer. This photoperiod was constant for the whole year of study. Approximately 14.3 langleys (1 langley = 1 gram calorie/cm^2) of visible light energy were received at the water surface each twelve-hour photoperiod. This was determined using an "optical power meter" (Model 610 Optics Technology, Inc.). Stream 6 was similarly positioned with the other five in an outdoor location; however, for lack of space, an export net was not attached.

A seventh stream channel, to be referred to as "stream 7" or the "Columbia River control" was constructed of plexiglas, with dimensions similar to the other channels. Styrofoam was attached to each side of the stream, and both ends were left open to allow the river to flow through in a manner similar to the other streams. It was

Figure 1. *Artificial stream system.*



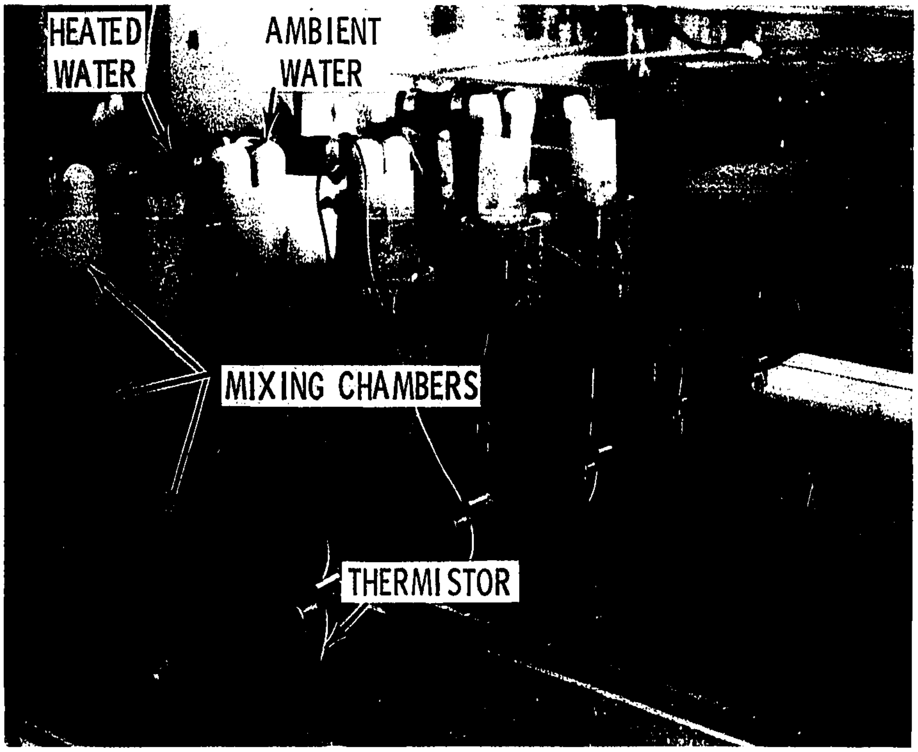
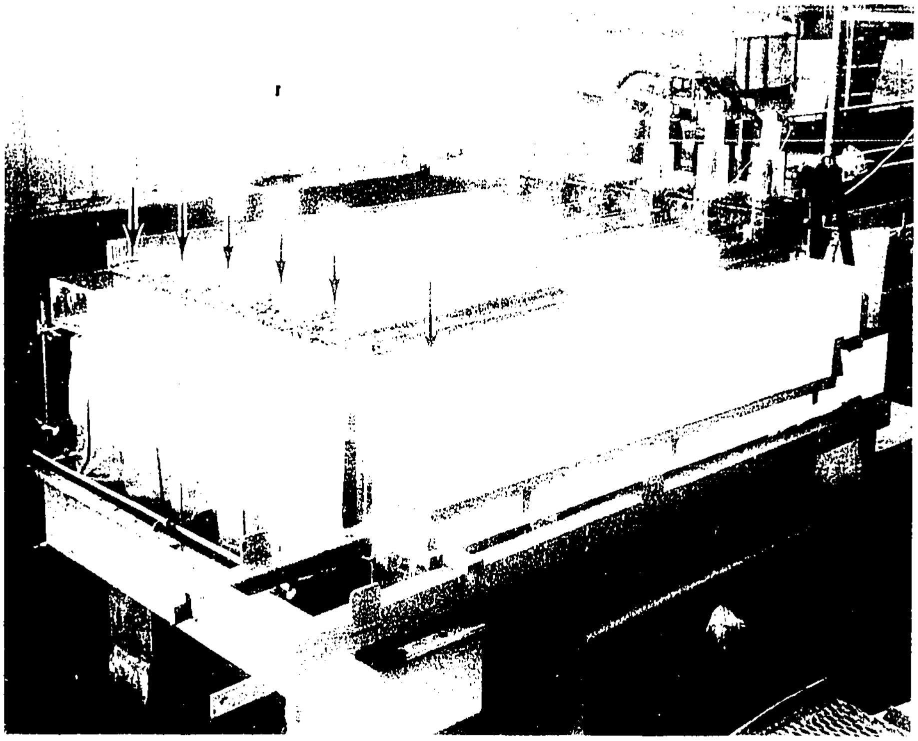


Figure 2. *Upstream ends of artificial streams, showing thermistors and mixing chambers.*

Figure 1. *Artificial stream system.*



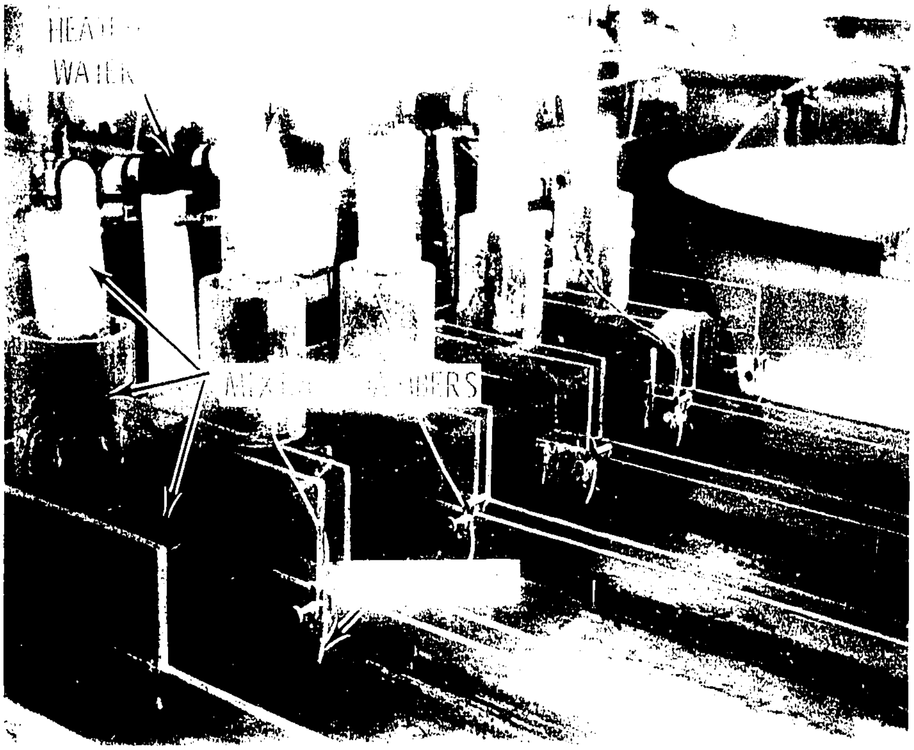


Figure 2. *Upstream ends of artificial streams, showing thermistors and mixing chambers.*

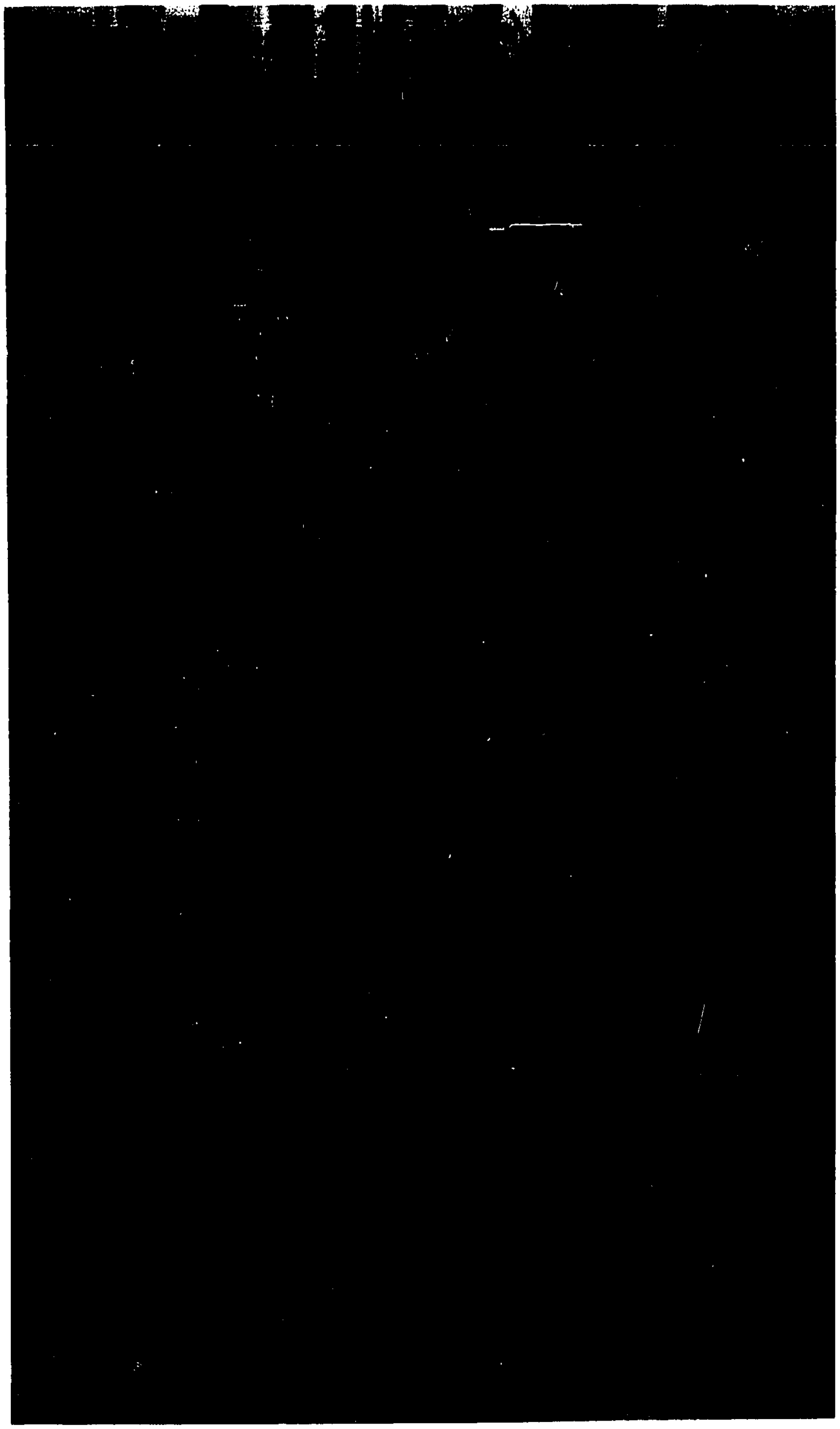


Figure 3. *Export net system of the artificial streams.*

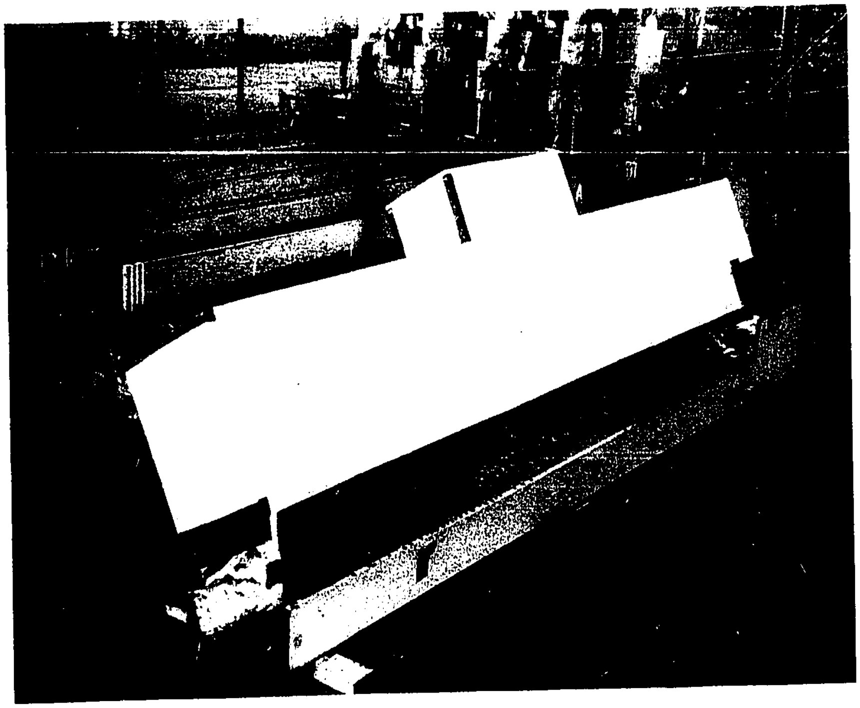
then attached to an anchored floating device in the Columbia River (Figure 5), in an area of flow velocity approximating that of the other experimental streams. This flow velocity, however, was not stable, as the Columbia River in this area is regulated by power dams upstream. The channel was lined with microscope slides attached as in the other streams. This stream was also positioned in full sunlight exposure. No net system could be attached to collect export.

Finally, it was deemed necessary to determine the quantity of imported organic matter that would be entering each stream system. To this end, an additional outlet from the river temperature water source was constructed, and a net identical to those described was attached. This net, referred to as the "control net" received water at the same rate as each of the other streams.

The experimental streams were installed at the Battelle Northwest aquatic laboratory facilities about 25 miles north of Richland, Washington, in the Hanford Atomic Reservation (Figure 6). They were situated outdoors, adjacent to the fish hatchery, approximately 150 feet from the Columbia River.

Excepting the Columbia River Control channel, water was supplied to the experimental streams from a large head tank located in the hatchery facilities. The head tank received water pumped about 0.4 km from the Columbia

Figure 4. *The artificially illuminated stream (channel 6).*



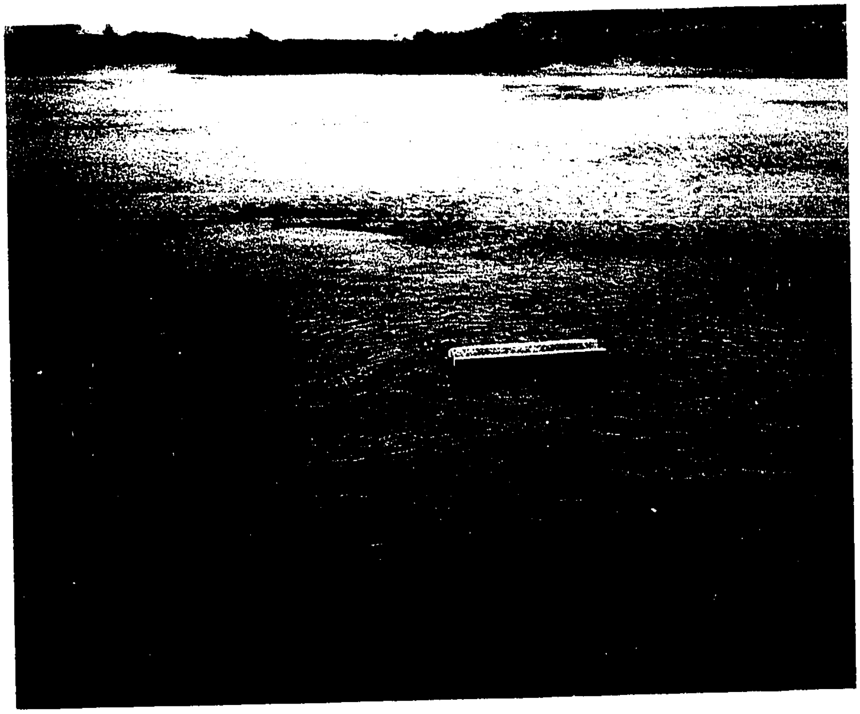
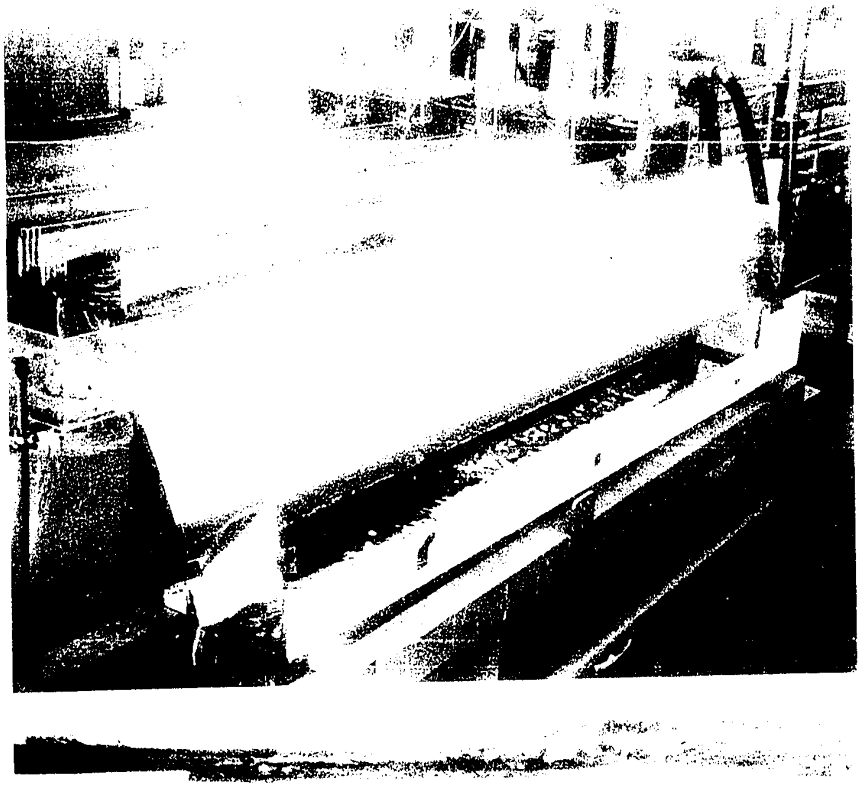


Figure 5. *Columbia River control channel (channel 7).*

Figure 4. *The artificially illuminated stream (channel 6).*



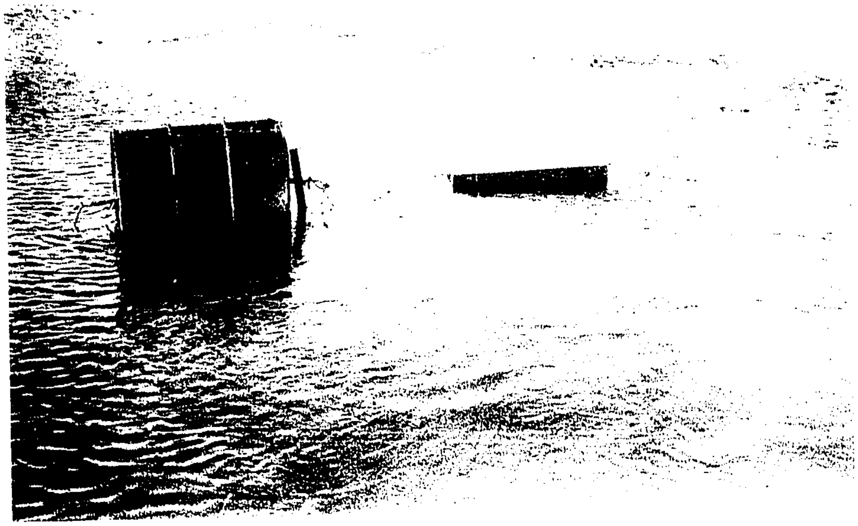


Figure 5. *Columbia River control channel (channel 7).*

Figure 6. *Columbia River drainage and the study site.*

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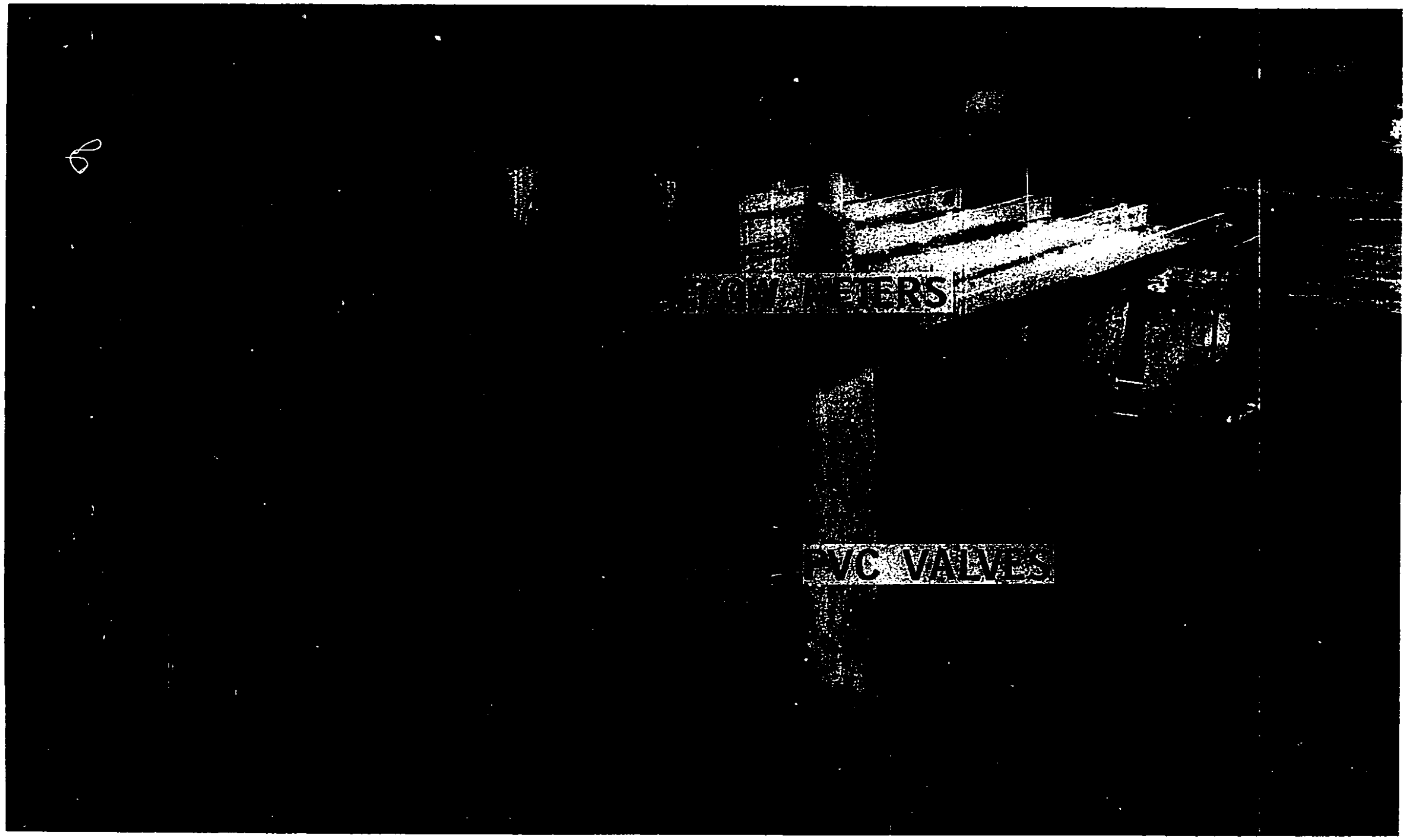
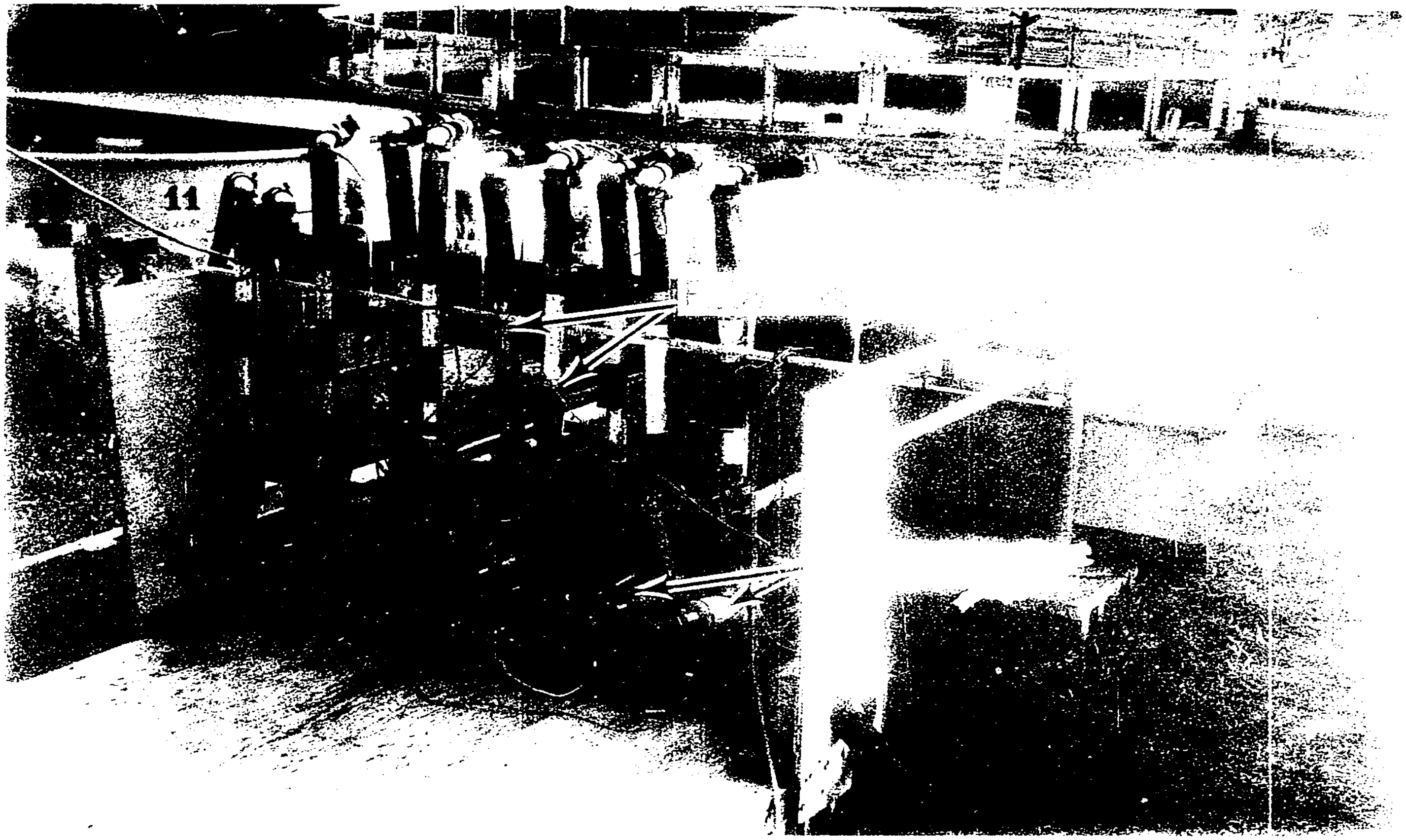


Figure 7. *Outdoor plumbing of the artificial stream system.*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River. Water from the head tank was supplied at constant pressure to the streams, through one heated and one unheated system. A steam heat exchanger was automatically controlled to supply water 10°C above river temperatures for the heated system. The river temperatures varied from approximately 5° to 21°C during the year studied. These two water supplies were piped to two manifolds at the head of the streams. Here, the water was supplied to each stream through calibrated flow meters (Figure 7) at the constant rate of 13 liters per minute. This rate of flow gave a surface speed averaging 0.15 m per second. To maintain the desired temperatures of +10.0°, +7.5°, +5.0°, +2.5°C and river temperatures for streams one through five, respectively, the exact proportions of +10.0°C water and river temperature water necessary for each stream were determined. These proportions were marked on the flow meters, and maintained with polyvinyl chloride valves. The settings were checked twice daily. Stream 6, the light control channel, also received river temperature water at 13 liters per minute. All water was wasted after passing through the net system. This was necessary in order to simulate a segment of natural river periphyton habitat, in which the same water passes over the community only once. Recirculating systems may effect changes in species structure (Patrick, Crum and Coles 1969) not correlated with changes in comparable natural systems.

Tests of the Experimental Stream System

The experimental stream system was designed to simulate natural periphyton habitats, but with uniform substrate and controlled flow. The heated channels simulated conditions directly below outfalls of heated water. For conclusions on the effects of elevated temperatures on the periphyton communities to be valid, four tests were deemed necessary to establish how well the experimental streams and the sampling procedures were functioning.

1) It was important to determine if variations in the quantity and quality of planktonic input occurred among the streams, in order that conclusions on their periphyton species composition, standing crop, and export could be adjusted accordingly, to be comparable. To establish if there were any visible adverse effects to the planktonic organisms exposed to the +10°C heated water, 5 liter samples of the heated and unheated water sources from the points of entry into the streams were millipore filtered. Samples were examined microscopically, and every fourth field from the edge of the filter toward its center was counted. The condition of each encountered cell was evaluated (it was considered dead if the protoplast was missing, or obviously abnormal) and the counts were divided into numbers of live and dead individuals. These data were statistically treated with the student

t-test for each species, to determine if there were significant differences in the numbers of live individuals between the two sources of water for the stream. Two sets of samples were collected on different dates, and analyzed as described. There were no significant differences for counts of any species. Although these data were not conclusive, they did indicate that the short exposure in the heat exchanger (approximately 30 seconds) did not visibly affect planktonic organisms of the Columbia River. Cairns and Lanza (1972) indicated similar results for similar temperatures tested.

2) A second test was conducted to determine 1) if there were any planktonic species that were significantly precipitating or being trapped by the established periphyton communities, and 2) if the export material from the periphyton was composed of large enough chunks to pass into the collection jar without being lost through the relatively coarse netting. Millipore samples were collected at the input of one stream, and again after the water had flowed over the periphyton of the same stream, and through the export net. The samples were treated as described above. *T*-tests indicated no significant differences in the numbers of individuals of any species from the two collections (Appendix 1). Thus, it would seem that the bulk of the potamoplankton input from the Columbia River passes over the periphyton of the artificial

streams, and does not become trapped in the export nets. Further evidence of this was provided by the control export net data (see "Periphyton Community Export"). These data also support the visual observation that periphyton is exported from the streams in large masses, and is captured in the nets, and that there probably is no significant export of cells or groups of cells small enough to be lost through the nets. On the basis of these data, it was decided that the net mesh size of 210 microns was adequate to sample export from the artificial stream communities.

3) As there were temperature differences among the streams, it followed that there could be temperature related differences in either growth or decomposition of the net-collected export that settled into the jars. This could have resulted in misleading differences in biomass after a certain number of days of exposure before the jars were collected. The following experiment was conducted to evaluate this possibility. A large amount of periphyton was collected from the control stream, and mixed thoroughly in a large container until there was a uniform suspension. Eight net sample jars were filled with equal volumes of the periphyton suspension. Three jars of the samples were oven dried at 60°C, and the other five were covered with the 210 micron netting, and replaced on the net systems of each stream. The streams were first totally cleaned of periphyton, and the temper-

atures were adjusted to give the maximum possible spread, with temperatures of 30°, 25.8°, 21.5°, 17.3°, and 14°C, for streams one through five, respectively. Flows were maintained at the normal rate of 13 liters per minute. After three days of exposure, the jars were removed, and samples oven dried at 60°C. The eight dried samples were weighed, ashed, and reweighed. Comparisons to the three control samples indicated no significant effects of the three-day exposures. It was therefore decided that a maximum of a three day interval between net collections would be acceptable.

4) Preliminary experiments indicated that there were significantly different rates of periphyton colonization and growth at different temperatures. It was conceivable that the horizontal slides were only collecting the results of different rates of phytoplankton precipitation, and not reflecting periphyton growth rates. Physiological changes in the planktonic organisms exposed to heat could have accelerated their precipitation; or, temperature related changes of the water, such as viscosity decreases, could have produced similar results. To test that the observed differential rates of periphyton growth were not artifacts related to the horizontal position of the slides, a series of slideholders were constructed to position twelve microscope slides vertically in the upper pool section of each stream. The slides were collected

after eight days of exposure. Samples from two sets of six slides from each stream were ashed. None of the ranges of the biomass collected from these vertical surfaces in different streams overlapped. These data were evidence that the horizontally-positioned slides were not producing spurious results.

Non-biological Sampling Procedures

Major chemical and physical parameters of the Columbia River water were monitored twice monthly by the Douglas United Nuclear Company analytical laboratory, located on the Hanford Atomic Reservation. The samples for these analyses were collected near the water intake of the hatchery facilities used in this research, and were thus expected to have equal validity for the experimental stream system. Samples were collected simultaneously from the standard location, and from the experimental stream input at two times during the study, to determine if there were any major alterations in water quality resulting from water passage through the 0.4 km of piping. Daily rates of solar radiation were monitored by the Battelle Northwest Meteorology Station, located approximately 19 km from the experimental streams. This distance was considered to be insignificant, as the weather patterns over the Hanford Project are generally uniform.

Temperatures of the experimental streams were continuously monitored from thermistors (Figure 2). The thermistors were connected to a modified Yellow Springs Instrument Company scanning tele-thermometer (model YSI-47). The instrument was modified by R. P. Gribble and N. S. Porter, so that in connection with a strip-chart recorder, it would give temperature recordings approximately 36 times a day for each stream. The recordings were not accurate to more than ± 2°C, and consequently were only of use as a continuous check against major fluctuations. The temperatures of the heated water source were also continually recorded, and changes of 0.2°C could be observed. The latter were of considerable use, as problems in maintaining stable temperatures originated at the heat exchanger. In addition, an alarm system was set to instantly sound if the temperature of the water from the heat exchanger exceeded a preset level, usually about 4°C above the regulated temperature. The most accurate data of the actual temperatures of the streams were obtained twice daily with a hand-held standard mercury thermometer.

Biological Sampling Procedures

As described earlier, the bottom of each stream was lined with two rows of microscope slides. For sampling purposes, each stream was considered to consist of three sections longitudinally, A, B, and C, each containing 36 slides. Section A, the furthest upstream, was always maintained as an undisturbed mature community except for sampling, while sections B and C were seasonally cleaned bare for the studies of growth and development of immature periphyton communities. No area of growing immature communities was sampled more than once in each seasonal study. For the mature communities, sampling procedures were established so that no area could be sampled more frequently than once every three months. The majority of investigators using glass substrates have considered a period of less than two months sufficient to develop a mature growth of periphyton. However, preliminary work on the experimental streams suggested that there was generally a complete turnover of periphytic material in less than one month, making the above inter-sampling period ample.

Duplicate or triplicate samples of periphyton were collected each month to evaluate quantitatively and qualitatively the standing crops of the mature periphyton communities of each stream. Each sample consisted of from two to four slides. Once during each season, the lower 2/3 of every stream was cleaned bare, and allowed to become recolonized. When possible, standing crop samples were collected from the resulting immature communities at four intervals during the growth phase. The growth phase was defined as the period of net biomass increase prior to the establishment of a more or less stable standing crop. Export net samples were collected every two or three days throughout the study period. Both mature and immature periphyton communities were treated in three basic ways. One set of replicate samples was used to determine the weight of the periphyton present, a second set of replicate samples was used for the extraction of pigments, and a third set was processed for microscopic studies of actual organisms present.

The 36 slides in each stream segment were numbered consecutively, and the choice of slides for any sample was based upon random numbers tables. The first encountered number in the range of 1 to 36 was used as the number of the first slide to be collected. The adjacent downstream slide was also collected, as the periphyton growth was usually so thick that inaccuracies would result from breaking up smaller segments of the community. Thus, every sample consisted of at least two adjacent slides. Collections of mature periphyton consisted of three adjacent slides for each replicate, while only two slides were collected from the immature communities. A second area to be sampled was always chosen directly opposite from the first (these two samples were analyzed for different parameters , thus the replicates to be analyzed for the same parameters were from different positions along the length of the stream, but opposite sides). There were two reasons for collecting samples from opposite sides of the stream. 1) Although the streams were transparent, and oriented north-south, there could possibly have been an effect of differences in quality of light of east versus west exposure. 2) Despite the fact that each sample of slides and periphyton collected was replaced with fresh slides, there was enough change in the bottom configuration to considerably alter the stream flow, i.e., from both sides of the stream. The replicate samples for each analysis were chosen from different areas of the stream, using new random numbers. In the studies of the immature communities, the replicate samples were taken from different sections (B and C). Replicate mature community samples were removed from different areas along the length of section A.

Samples collected in the export nets when the lower sections of each stream were cleaned every season also were analyzed for standing crop, as were collections resulting from a misguided lawn sprinkler that removed all the growth on one date. Other non-scheduled sampling included various collections of the invertebrates that colonized the artificial streams several times. Droppers full of periphyton were also frequently sampled for microscopic examination.

Analyses of Samples

One of the three groups of samples removed from each stream was oven dried at 60°C overnight, then desiccated to a constant weight over $CaCl_2$. After weighing, these samples were ashed at 550°C as suggested by Wetzel and Westlake (1969), and reweighed. The ashed periphyton was cleaned from the slides, and the slides were dried and weighed. Standing crops in terms of dry weight, ash-free dry weight, and percent loss on ignition were recorded. The material from the export net samples was treated similarly.

The second set of samples from each stream was partially dried in a dark container into which a fan constantly conducted room temperature air. They were then desiccated in another dark container to a constant weight, and weighed. The periphyton material was scraped from the microscope slides, and the slides re-weighed. The dry weights of the periphyton samples were recorded. The removed material was ground with refined sand to break up any cells that might otherwise not be extractable. Pigments were extracted in 90% aqueous acetone, into which a small amount of $MgCO_3$ was added. The extracting samples were refrigerated in the dark for 24 hours. After centrifuging, the optical densities were read on a Beckman DU-2 Spectrophotometer at 7500, 6650, 6300, 5100, 4800, and 4300 Å. Phytopigment concentrations were computed according to the formulae of Parsons and Strickland (Strickland and Parsons 1970). Additional spectrophotometric readings were obtained from one set of collections that were acidified after an initial reading. These data were used to compute the amount of phaeo-pigments present according to the methods of Lorenzen (1967). The 4300 Å readings were used to compute the pigment diversity ratio

D4300/D6650 of Margalef (1965). Another ratio, D4800/D6650 was also computed.

The third set of samples were processed for microscopic examination. Except during the earliest stages of growth, the periphyton communities were too thick (1cm or more) to be studied intact. Thus, the material was removed from the slides, and processed to make thin microscopic mounts. As it is the firm belief of this author that it is important to study as many components of the periphyton community as possible, the widely accepted acid cleaning methods (described in Patrick and Reimer, 1966) were not used. Acid cleaning the periphyton removes everything except diatom frustules. Many authors consider this cleaning process necessary to facilitate diatom identification. However, since periphyton communities invariably include dead individuals of almost every diatom species, the identifications may be made from these individuals. Comparisons of dead, empty diatoms and acid cleaned ones revealed no differences in the ease of identification. Benefits in not cleaning the periphyton were 1) being able to distinguish the live from the dead diatoms, and 2) having all of the other taxonomic groups of the communities available for identification and counting.

With the above in mind, the following technique was found to be satisfactory. The collected samples were fixed overnight in a solution of chromic acid, acetic acid, and alcohol (Baker 1960), then washed several times. The periphyton was then scraped from the substrate, put in a Waring blender with a known dilution of water, and blended at low speed. Immediately, as the blender was stopping, a 4 ml sample was withdrawn and placed in a small screw-capped vial, which was centrifuged, decanted, and filled with stain. This stain was a mixture of methylene blue, acid fuchsin, and a small amount of acetic acid. After staining to the desired intensity, a series of dehydrating alcohol solutions were used to prepare the periphyton material for xylene, the final storage solvent. The dehydration was achieved through a lengthy series of centrifugations and decantations which were determined not to damage the organisms to the point where identifications were impossible.

The final permanent mount slide was made with Hyrax mounting medium (Custom Research and Development, Inc., Richmond, California). Several drops of Hyrax and a known number of drops of room temperature xylene-periphyton suspension were placed on a microscope slide, spread evenly, and mixed until the xylene evaporated. Then the slide was heated on a hot plate and covered with a 20 x 60 mm coverglass. The amounts of periphyton and medium were critical in determining the thinness of the mount, as excess material could not be squeezed out, without destroying the basis for computing the actual proportion of the original sample present.

The final microscopic preparations were an even dispersion of all periphytic organisms and detritus that had been present in the periphyton. The staining procedure allowed the microscopist to distinguish between live and dead organisms by staining the fixed protoplasts pink. Most organic debris and cellulose walls stained blue, while diatom frustules remained clear. Blue-green and green algae as well as protozoa and bacteria were also stained, and could be at least partially identified. However, live mounts of samples of forms other than diatoms were helpful in identification.

Classification of diatoms generally followed Patrick and Reimer (1966) for the *Fragilariales, Achnanthales,* and *Naviculales,* and Cleve-Euler (1951) for all other diatom orders. Other sources used to aid in diatom classification were Hustedt (1930) and Van Heurck (1896). Green algae were classified according to Prescott (1962) and blue-greens according to Drouet (1968). Attempts to classify and count the protozoa of the periphyton were in vain, as they were unevenly dispersed. It was decided that all microscopic efforts would be devoted to the primary producers.

The prepared slide material was identified and counted with a Leitz microscope, with 16X Periplan oculars, and 3.5X, 10X, 40X, and 100X achromatic objectives, the latter with a 1.30 numerical aperture. A series of 25 numbered coordinates were taken from random numbers tables, and used to select the fields to be counted, by matching them with the microscope stage coordinate numbers. For each slide, 25 fields were counted at 640 X, and questionable identifications in any field were checked under oil immersion. The larger species of algae that could be identified with lower power were counted under 160X using the same 25 fields. Filamentous green algae and blue-green algae were counted as the lengths of all the filaments in a field, estimated in tenths of the field width. Diatoms were counted as either live or dead individuals. If the frustule had any visible protoplast, it was considered alive. All species that were represented only by dead individuals were eliminated from the final counts, as they did not contribute to the biomass of the community.

The resultant counts at three magnifications were summed and converted to numbers per species per square millimeter of the original sample. The conversion factor used depended on the size of the sample, the amount of water used in the blender, the amount withdrawn for staining, the amount of xylene in the final storage, the number of drops of xylene suspension used on the slide, and the actual area counted. To test the reliability of the methods, and to check on community variability within each stream, slides of the duplicate samples from every stream were counted once every season.

The mean dimensions of an individual of each major species was computed once every season, by averaging measurements of at least ten individuals. The mean volume of an individual of a species was computed from formulae idealizing the shapes to cylinders, cones, spheres, and cubes. The contribution of each species to the biovolume of the community was then computed as the mean volume times the count.

Interpretation of Data

The diversity of a community is one simple expression of its structure, although no precise ecological significance should be attached to such numerical simplifications. The index of diversity used in this study was:

$$H' = - \sum_{i=1}^{s} \frac{n_i}{N} \log_2 \frac{n_i}{N}$$

where "s" is the number of species in the community, "n_i" is the number of individuals in the "i"th species, and "N" is the total number of individuals of all species in the community. This formula, now widely used in ecological studies, was derived by Shannon and Weaver (1948) in a study of information theory. This index is dependent on evenness of the species abundances (Lloyd and Ghelardi 1964). The maximum diversity theoretically possible for a community with "s" number of species was computed using

$H'_{max} = \log_2 s$, in which each species would have a theoretically equal abundance. To measure the relative abundance component, the index $J' = H'/H'_{max}$ was used (Tramer 1969).

Net community production (Odum 1971) of the periphyton was calculated from export and standing crop data. Changes in the standing crop from one collection to the next were added to the amount of material exported during that period to give the total net community production for that time interval. Attempts were made to measure production *in situ* from upstream-downstream changes in pH and oxygen content. However, even under temporarily reduced flows, these methods proved much too insensitive to provide accurate measures of production.

Finally, a simple prediction model for net community production was developed with the aid of R. J. Buschbaum (Battelle-Northwest, Reactor Physics). The model is based on light and water temperature, which emerged as the environmental variables of major significance in this study. (Several other variables were tried in the model, but were discarded). The least squares method of curve fitting was applied to data on mean light, temperature, and production rate of mature and immature communities, for twelve periods of approximately one month each.

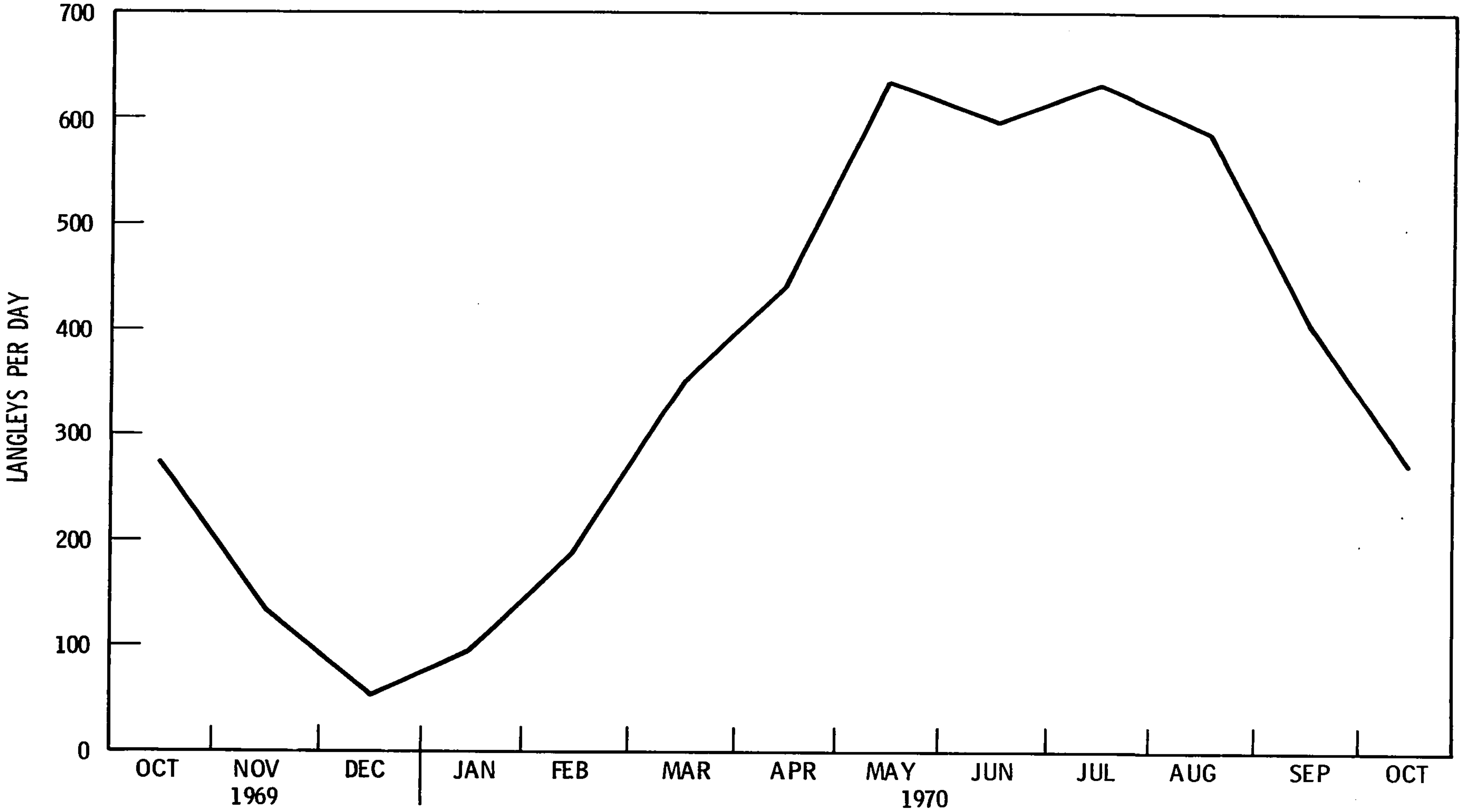
RESULTS AND DISCUSSION

The site of this investigation was the Hanford Atomic Project in Southeastern Washington (Figure 6). The Columbia River is free-flowing in this area, although the majority of the upstream and downstream sections are now a series of man-made lakes. This section, which is likely to remain free-flowing, is being considered as an important future site for extensive nuclear power generation. This is one of many reports that have attempted to quantify the potential ecological effects of any thermal additions to the river that might result from such development.

Climate

The climate of the Hanford Atomic Project is characterized by long, cloudless summers, and mild cloudy winters. Semi-arid, it has a mean annual precipitation of 16 cm. The light climate has sharply contrasting seasonal means, and daily totals of solar radiation varied during the study period from 14 langleys to 773 langleys (Figure 8). The climate from October 1969 to November 1970 was fairly normal, except for December, which had record low light. These data represent the total direct and scattered solar radiation from 0.3 to 3.6 microns wavelength, received on a horizontal plate. The great seasonal changes in incoming solar radiant energy are accompanied by changes in the energy-wavelength distribution, which may be

Figure 8. *Mean daily insolation (Langleys) at the Hanford Atomic Reservation, 1969-1970.*


LANGLEYS PER DAY
700
600
500
400
300
200
100
0
OCT
NOV
1969
DEC
JAN
FEB
MAR
APR
MAY
1970
JUN
JUL
AUG
SEP
OCT

affected by changes in solar angle and cloud cover (Vollenweider 1969). Daytime cloud cover varied sharply from the dense, almost total sky cover in midwinter, to the brilliant cloudless days of summer (Figure 9).

Approximately 45% of the radiation measured may have been in the visible range, and of this, 38-53% has been reported as photosynthetically available (op. cit.). Thus, the amount of usable solar energy that reached the periphyton in the experimental streams (assuming no significant loss through the shallow water) may have been from 17-24% of the values in Figure 8.

Water Chemistry

Chemical and physical data for the Columbia River near the hatchery water intake are presented in Table 1. A comparison of samples taken simultaneously from both the intake and the experimental streams with these river samples indicates that the water quality at the experimental streams is apparently not altered from that of the river (Appendix 2). The possible exception is the suspended solids which may have been significantly reduced by sedimentation in the head tank before reaching the experimental streams. Thus, the data of Table 1 are considered fairly representative of the experimental stream water.

The Columbia is relatively stable in terms of chemical composition. Seasonal patterns are not very evident from the data presented here, although Cushing (1964b) did

Figure 9. *Mean monthly cloud cover at the Hanford Atomic reservation, 1969-1970.*

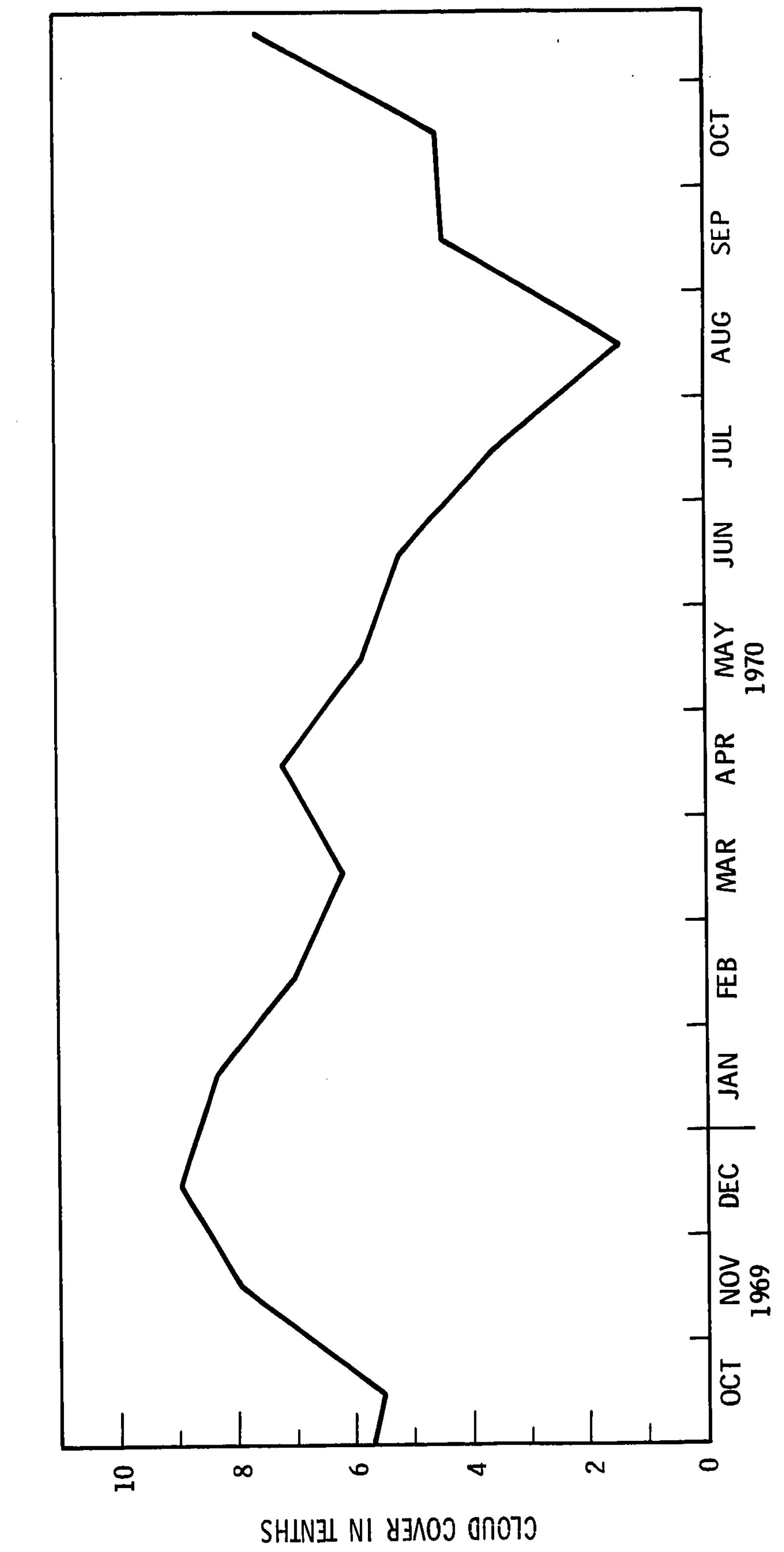

CLOUD COVER IN TENTHS
10
8
6
4
2
0
OCT
NOV
1969
DEC
JAN
FEB
MAR
APR
MAY
1970
JUN
JUL
AUG
SEP
OCT

Table 1. *Chemical and physical properties of Columbia River water near the hatchery intake of the Hanford Atomic Reservation.*

	parts per million														
SAMPLING DATE	SO_4	Mg	Fe	PO_4	Cl	Cu	O_2	Phth.Alk.	M.O. Alk	Hardness	Ca	Solids	NO_3	pH (monthly means)	Turbidity J.T.U. (monthly means)
10/20/69	14	2.0	.03	.02	.17	.000	9.66	0	60	68	24	70	.004	7.7	1.8
11/04/69	12	5.0	.04	.02	.33	.010	7.36	5	76	79	24	78	.23	8.0	1.8
11/18/69	15	5.0	.04	.02	.28	.002	10.53	2	79	74	21	79	.09		
12/02/69	15	6.0	.02	.06	.36	.000	10.56	3	70	74	21	84	.23	7.8	1.6
12/16/69	14	6.0	.04	.10	.66	.004	10.40	2	70	71	18	101	.20		
01/06/70	15	6.0	.03	.00	.33	.002	--	2	68	74	20	93	.19	--	--
01/20/70	15	4.0	.01	.05	.36	.004	7.80	2	71	73	22	84	.31		
02/03/70	13	4.5	.01	.06	.33	.002	12.20	2	69	72	21	100	.20	7.8	1.0
02/17/70	19	4.9	.01	.01	.33	.004	11.20	2	68	75	22	105	.00		
03/03/70	17	6.2	.03	.02	.50	.004	13.40	1	65	73	19	81	.16	7.8	1.5
03/31/70	17	6.2	.07	.02	.39	.005	12.20	2	69	76	20	81	.31		
04/14/70	20	4.4	.22	.05	.60	.002	11.80	1	66	77	24	100	.62	8.1	3.4
04/28/70	24	6.3	.12	.02	.56	.005	12.30	1	70	82	22	115	.13		
05/12/70	23	5.5	.02	.01	.40	.017	11.80	2	72	85	25	104	.16	8.5	2.8
06/16/70	13	4.6	.00	.04	.29	.011	10.70	2	56	68	22	74	.13	8.2	3.1
08/04/70	17	3.9	.02	.02	.46	.007	9.60	1	70	78	25	86	.29		

Table 1.-- Continued.

SAMPLING DATE	*parts per million*														pH (monthly means)	Turbidity J.T.U. (monthly means)
	SO_4	Mg	Fe	PO_4	Cl	Cu	O_2	Phth.Alk.	M.O. Alk	Hardness	Ca	Solids	NO_3			
08/18/70	13	4.0	.03	.02	.26	.004	8.9	1	70	77	24	106	.16		8.4	1.3
09/08/70	15	4.8	.03	.08	.43	.005	9.0	3	70	77	23	73	.14		8.2	1.1
09/22/70	13	5.3	.02	.03	.26	.002	9.4	2	63	65	17	87	.18			
10/06/70	20	4.0	.03	.02	.66	.003	8.2	2	66	70	21	99	.51		8.2	.83
10/20/70	12	5.4	.02	.01	.32	.006	10.6	0	92	66	16	80	.23			
11/03/70	18	5.3	.01	.11	.49	.001	20.0	2	70	68	19	80	.16		8.1	1.4

* Data for July missing, except pH-8.3 and Turbidity-1.7.

note a seasonal pattern of variation in NO_3 and PO_4 in samples from the same area of the river in 1962. (Additional upstream impoundment has occurred since 1962). Cushing also measured silica, and found that it increased during the period that diatom populations were increasing. He concluded that neither silica nor any other nutrients commonly considered limiting to phytoplankton growth were likely to be strongly limiting in the Columbia River, and that the probable causal factors for population changes were changes in light and water temperatures. These conclusions seem equally justified for the periphyton studied in this research, as will be discussed in a later section.

Flow

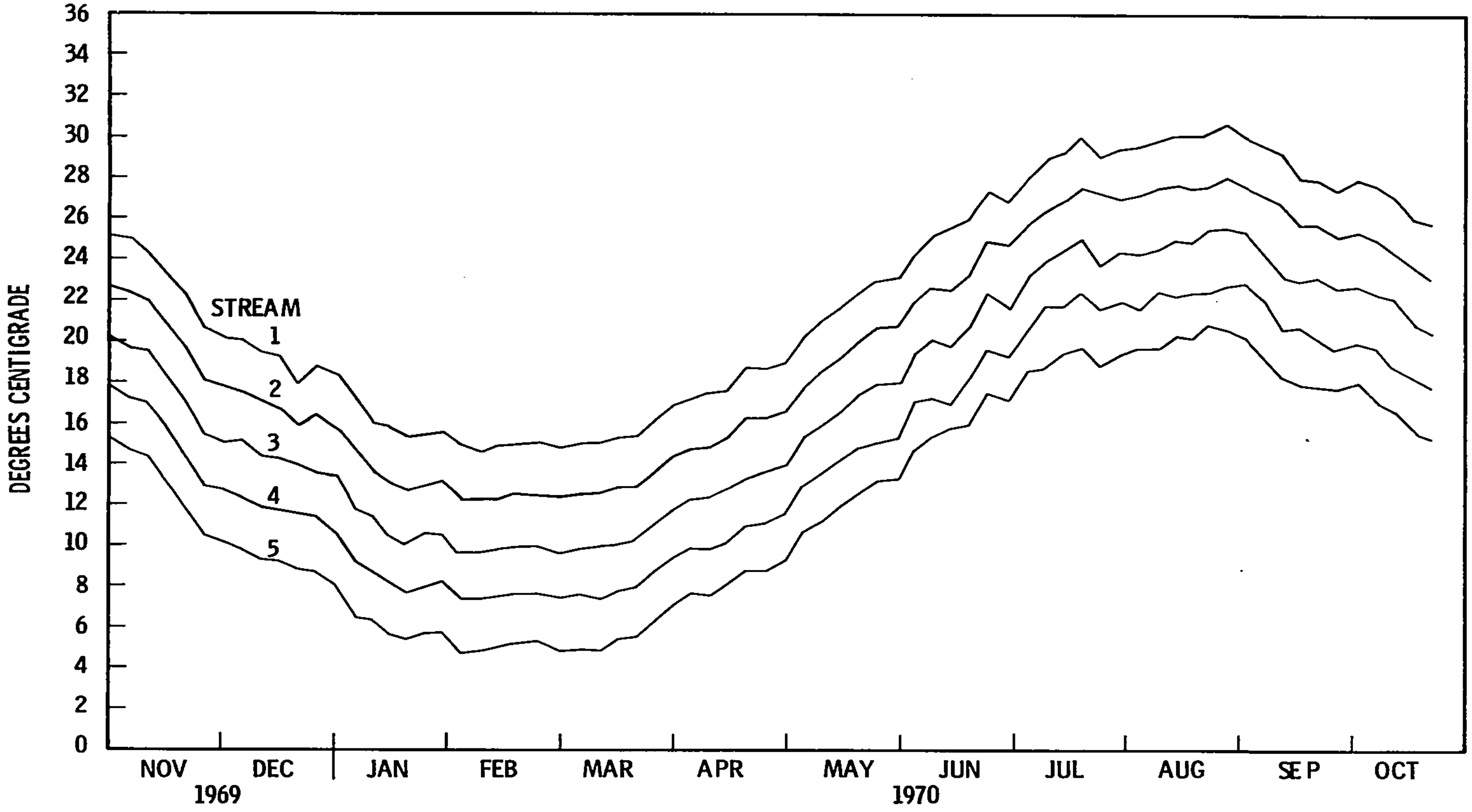
The flow rate of a river is one physical factor which profoundly affects the natural plankton and periphyton communities (Hynes 1970). Spring snow-melts in the mountains create a yearly peak of flow of nearly threefold the mean rate (Appendix 3). The artificial stream system could not reflect this factor, as the flows were continuously maintained at one level. However, the increase in river flow is coincident with a great increase in the visible silt load (the "solids" data in Table 1 do not reflect this accurately). This increased silt load combined with the increased flows undoubtedly seriously scoured the periphyton communities in the river. Nelson et al (1964) observed that large amounts of sediments were scoured from the Columbia River bottom during the spring freshet. In the artificial streams, the only visible effect was a tendency for the rate of silt collection to almost exceed the rate of periphyton growth in some streams during a short period in late spring.

Temperature

Temperature data for the artificial streams are plotted in Figure 10. The graph is based on the hand-held thermometer readings for streams 1 through 5. Stream 6 was always the same temperature as the control channel (5) and the river channel (7) generally had water temperatures of 0.5°C lower. This discrepancy was due to the long distance the river water was piped to the hatchery, and to a lesser degree, its retention in the head tank (approximately 1 minute) which consistently raised the temperature of the water above the ambient river temperatures. Thus, the experimental stream system used water already slightly warmed, although this was preferable to using a chilling system of unknown reliability.

River temperatures make a relatively smooth transition from the February-March minimum to maximum temperatures in late August. The annual maxima and minima lag considerably behind the air temperature maxima and minima. This is partially caused by the numerous dams upstream of the area under discussion. The dams have increased the retention time of the water, thus delaying the seasonal

Figure 10. *Temperatures of the five experimental streams, 1969-1970; five-day means of measurements taken twice daily with a hand-held thermometer.*


DEGREES CENTIGRADE
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
STREAM
1
2
3
4
5
NOV
DEC
1969
JAN
FEB
MAR
APR
MAY
JUN
1970
JUL
AUG
SEP
OCT

temperature trends (Jaske and Goebel 1967). The maxima and minima now occur almost coincident with the solar equinoxes, which has considerable ecological significance to the primary producers, as will be discussed later.

Small variations in temperature are not shown in figure 10. Daily variations in river temperature seldom exceeded 1.0°C, and generally amounted to only 0.2°C in the winter, and around 0.5°C in the summer.

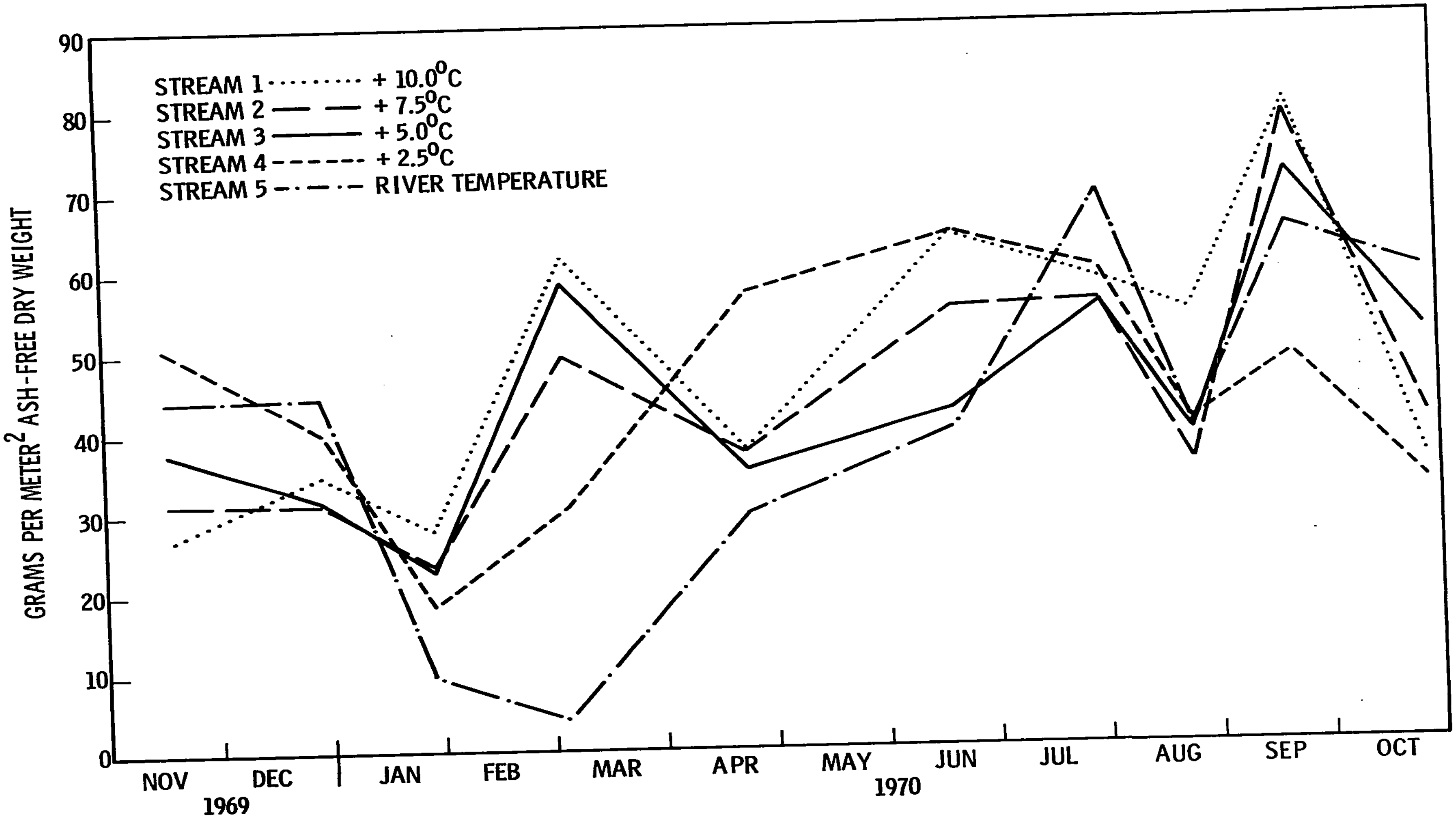
Mature Periphyton Community Standing Crops

Ash-free dry weight was used as an estimate of the organic matter present in mature periphyton communities (Figure 11). These data show the standing crops of periphyton communities that are not subject to intensive grazing, with the exceptions of data from streams 4 and 5 in January and March, and stream 4 in September, as will be discussed later. There was little pattern to the annual cycle of standing crops of the undisturbed communities, although there was an evident peak in September and a low point in January. Excluding the noted exceptions, each stream maintained a standing crop generally in excess of 30 g/m^2 and up to 80 g/m^2 of ash-free dry weight.

Variations among collection periods were considerable, however, two collections -- July and September -- stand out as significantly different from most other dates (Appendix 4). The non-significant variability may largely be considered a product of the natural trend of these un-

7

Figure 11. *Standing crops of mature periphyton communities of the experimental streams.*


STREAM 1 .... + 10.0°C
STREAM 2 — — + 7.5°C
STREAM 3 ——— + 5.0°C
STREAM 4 - - - - + 2.5°C
STREAM 5 -·—·- RIVER TEMPERATURE
GRAMS PER METER² ASH-FREE DRY WEIGHT
90
80
70
60
50
40
30
20
10
0
NOV
DEC
1969
JAN
FEB
MAR
APR
MAY
1970
JUN
JUL
AUG
SEP
OCT

disturbed communities to become structurally heterogeneous. Growth occurs until a standing crop which cannot be physically maintained attached to the substrate is reached. Both the force of the current and the lifting action of oxygen bubbles during bright days (Drum 1963) caused localized masses of periphyton to break loose and float downstream. Frequently, the loss of one area of periphyton precipitated a chain reaction that resulted in a major reduction of the standing crop of a whole stream. Cycles of growth and export were at times particularly evident, e.g. the +10°C stream in late summer, when blue-green filamentous algae contributed to the structural instability of the community.

Another source of variability of the standing crop was the limited area that could be sampled each date. Means and standard deviations show that standing crops of stream 6 exhibited the greatest variability of any stream (Appendix 5). The peak standing crop in January, when the other five streams were at a low point, may have been due to a unique (unusually productive) species composition (see Table 11). Channel 7 maintained a fairly stable standing crop, although these data may not be compared with the data of the other six streams, due to the flow fluctuation in the river.

Temperature increments did not effect major differences in standing crops, although annual means of standing crops are larger for each 2.5°C increment added (Appendix 5). These means, however, failed to test significantly different, using the paired *t*-test.

Ash-free weights may give a good estimation of the amount of organic matter present, but no distinctions may be made among the forms of organic material. In Table 2 standing crop data computed from ash-free weights are compared to standing crop data computed from organism counts The data calculated from counts represent a total of the counts of individuals of all algal species times their computed cell volumes. This estimate of the cumulative volume of living algal matter was then converted to grams per square meter, following the assumption that the specific gravity of most algal species approximates 1.0. (Specific gravities may vary above and below 1.0 according to Hutchinson, 1967). Thus, these values represent living, wet weights, and should be considerably larger than the ash-free dry weights. This was usually not the case, indicating that the data from ashing are probably measurements of more than just algal organic matter.

Assuming that the ashing did not remove inorganic substances such as carbonates (Vollenweider 1969), the excess organic weight must have been due to non-algal components. Microscopic examinations seldom revealed bacterial, fungal, or protozoan populations of any significance. Recognizable organic detritus such as fibers were occa-

Table 2. *A comparison of two measurements of standing crops of mature periphyton communities of experimental streams.*

	COLLECTION DATE									
STREAM	11-17-69	12-29-69	1-29-70	3-4-70	4-7-70	6-1-70	7-30-70	8-24-70	9-21-70	10-26-70
1 A	22.59	25.71	28.12	41.66	17.78	30.38	15.44	48.68	68.61	18.81
B	26.69	34.74	35.41	61.02	60.34	80.44	58.03	53.75	79.55	39.39
C	84.64%	74.01%	79.41%	68.27%	29.47%	37.77%	26.61%	90.57%	86.25%	47.76%
3 A	43.91	26.44	18.17	41.03	11.66	12.33	31.55	20.04	34.91	39.42
B	37.63	31.38	29.14	58.06	--	52.29	54.80	39.00	70.99	59.41
C	117.69%	84.26%	62.35%	70.67%	--	23.58%	57.57%	51.38%	49.18%	66.35%
5 A	44.95	32.28	9.03	6.07	13.72	16.06	29.81	47.25	59.27	29.91
B	44.12	44.44	17.54	4.14	--	46.83	69.06	39.79	64.31	57.71
C	101.88%	72.64%	51.48%	146.62%	--	34.29%	43.17%	118.75%	92.16%	51.83%
6 A	--	--	85.37	--	64.41	--	22.48	--	--	15.64
B	67.48	46.66	128.17	42.39	--	51.74	47.43	39.84	85.63	44.49
C	--	--	66.61	--	--	--	47.40	--	--	35.15
7 A	--	--	--	--	--	--	9.08	--	--	--
B	12.82	12.13	25.85	15.60	--	--	28.37	29.85	33.22	82.49
C	--	--	--	--	--	--	32.01	--	--	--

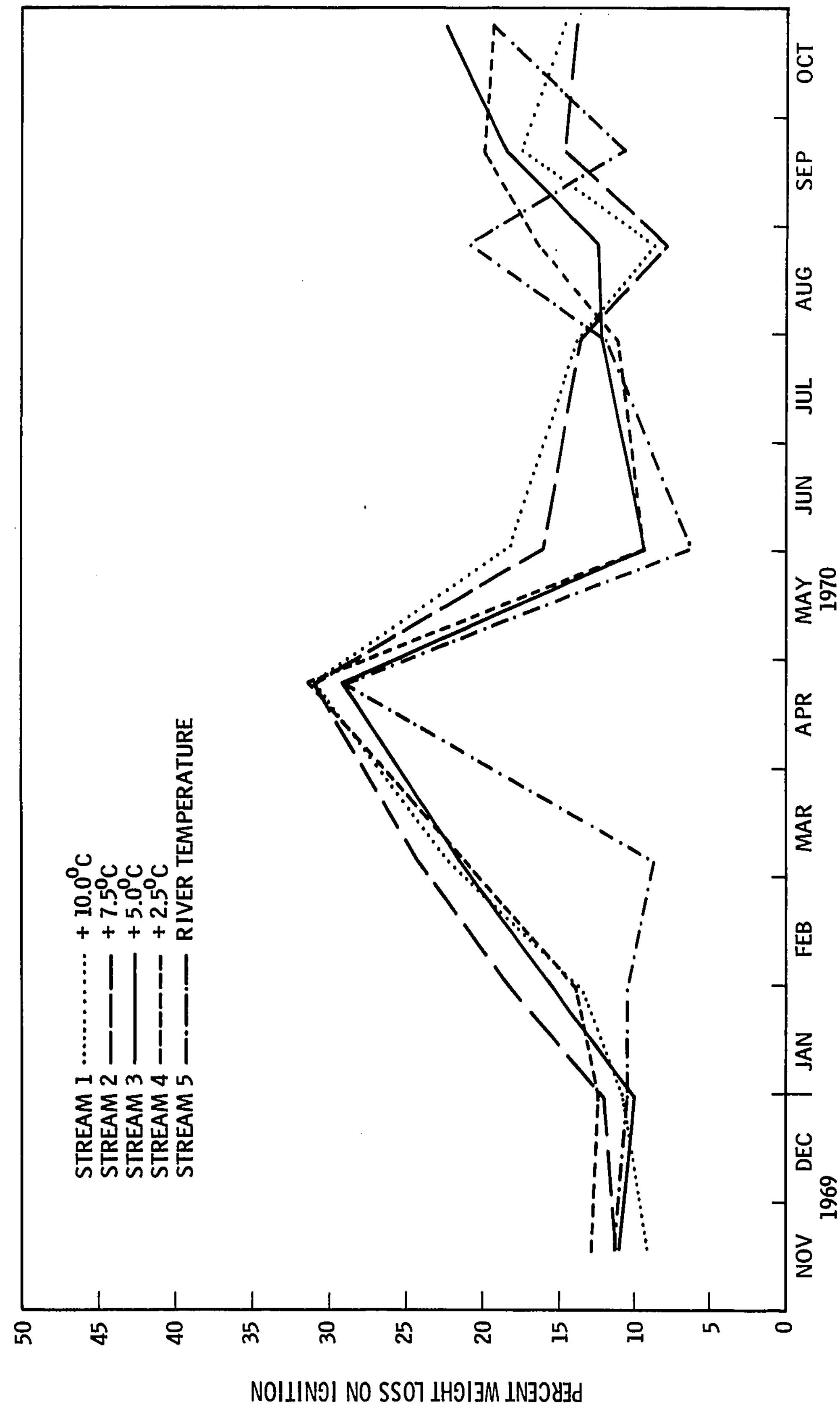
(A) Mean live biomass in grams per square meter, as calculated from counts and dimensions of organisms -- one sample for each date, except two samples for 1-29-70, 4-7-70, 7-30-70, and 9-21-70.
(B) Mean biomass in grams per square meter as calculated from 2 to 4 samples ash-free dry weight.
(C) A/B x 100.

sionally encountered, but the bulk of the "missing" organic weight determined by the ashing techniques may have been the mucilage, stalks, and other extracellular products that are present in periphyton communities (Round 1965).

Inorganic components, including both diatom frustules and silt particles, are very abundant in periphyton communities. Figure 12 shows the percent weight loss on ignition of samples of mature periphyton. The remaining fraction of dry weight was assumed to be inorganic matter. The inorganic fraction averaged considerably higher than values reported in the literature. For example, McIntire (1968) found from 32% to 56% of the periphyton dry weight in his recirculating artificial streams was organic material. There appear to be no significant differences among the five test channels over the whole year, the mean organic content being: 16.7%, 16.3%, 16.2%, 16.3%, and 13.9% for streams 1-5 respectively. Additional data are supplied in Appendix 6. The low figure for channel 5 is chiefly due to the low March datum resulting from the intensive chironomid grazing.

Although it may not be statistically sound to select one month to examine for differences, the data do suggest that during June there was a direct relationship between temperature and percent organic content of the periphyton communities. Direct observations of the streams indicated

Figure 12. *Percent weight loss on ignition of mature periphyton communities of the experimental streams.*


STREAM 1 + 10.0°C
STREAM 2 + 7.5°C
STREAM 3 + 5.0°C
STREAM 4 + 2.5°C
STREAM 5 RIVER TEMPERATURE
PERCENT WEIGHT LOSS ON IGNITION
0
5
10
15
20
25
30
35
40
45
50
NOV
DEC
1969
JAN
FEB
MAR
APR
MAY
1970
JUN
JUL
AUG
SEP
OCT

that in June the colder streams were unable to maintain periphyton growth as fast as they were being buried by silt.

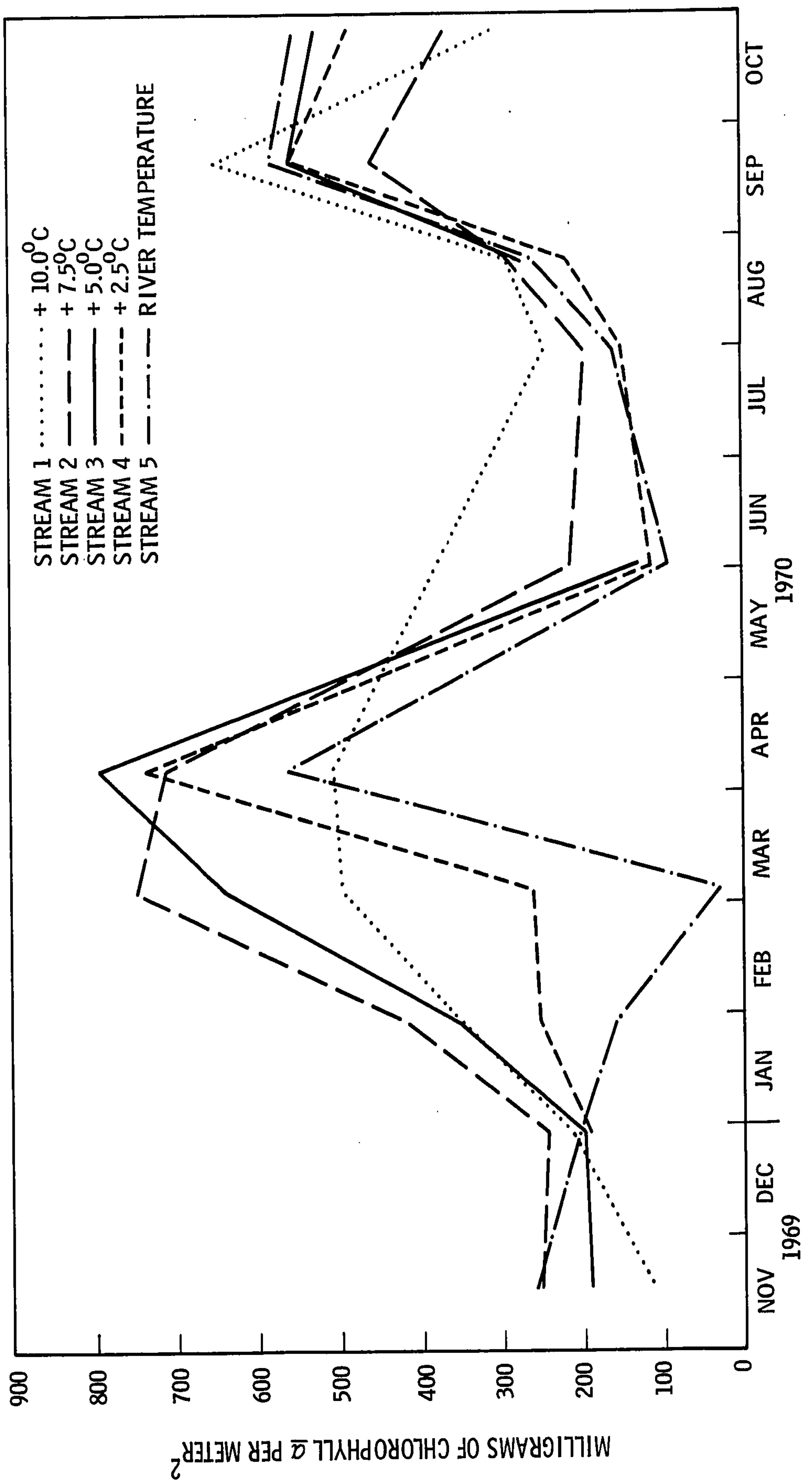
The bimodal pattern of percent organic content in Figure 12 is similar to the specific pigment content shown in Figure 14, and inversely related to the percentage of intact diatoms that were empty (Figure 31). The periphyton communities of all the test streams followed a pattern of relatively high percentage of living, photosynthetic matter in spring, and to a lesser degree in early fall, while the amount of inorganic detritus in the communities peaked in mid-summer and mid-winter.

It is impossible to accurately quantify the sources of inorganic components. However, empty diatom frustules were relatively more important in the summer than winter, and contributed considerably to the inorganic content (Figure 31). This could be attributed to several causes: 1) planktonic diatoms of the river may have precipitated as the bloom subsided in early summer with high river flows; 2) diatoms in the winter communities probably reproduced more slowly than their summer counterparts, thus inorganic silts collected at a relatively slow rate; 3) the summer communities were so thick that the shaded diatoms may not have received sufficient light to allow enough carbon to be fixed to compensate for the high respiration losses caused by the high temperatures, and 4) empty diatoms may have been resuspended, along with the river sediments that Nelson et al (1964) observed during high river flows. Heavy silica walls of freshwater diatoms may form 50% or more of their weights, according to Soeder and Talling (1969). The data represented here indicate that empty diatoms may have comprised a major portion of the inorganic matter present in periphyton communities. Direct microscopic observations confirmed this.

Chlorophyll *a* is frequently used as an indicator of primary production. Seasonal variations of standing crops of chlorophyll *a* in the mature periphyton communities are shown in Figure 13. Carotenoid standing crops are supplied in Appendix 8. With the exceptions noted for the gravimetric data, these data represent the pigment standing crops of undisturbed communities. The annual means of pigment (Appendices 7, 8) may indicate that a 5°C increase in temperatures over Columbia River ambient produces a maximum pigment standing crop, averaged over a year.

The two peaks of chlorophyll *a* standing crops (Figure 13) are apparently not the result of higher standing crops of organic matter (as measured by loss on ignition) at those times (Figure 11). However, biomass estimates based on cell counts (Table 2) also have a weakly bimodal pattern, with the highest peak in September. The

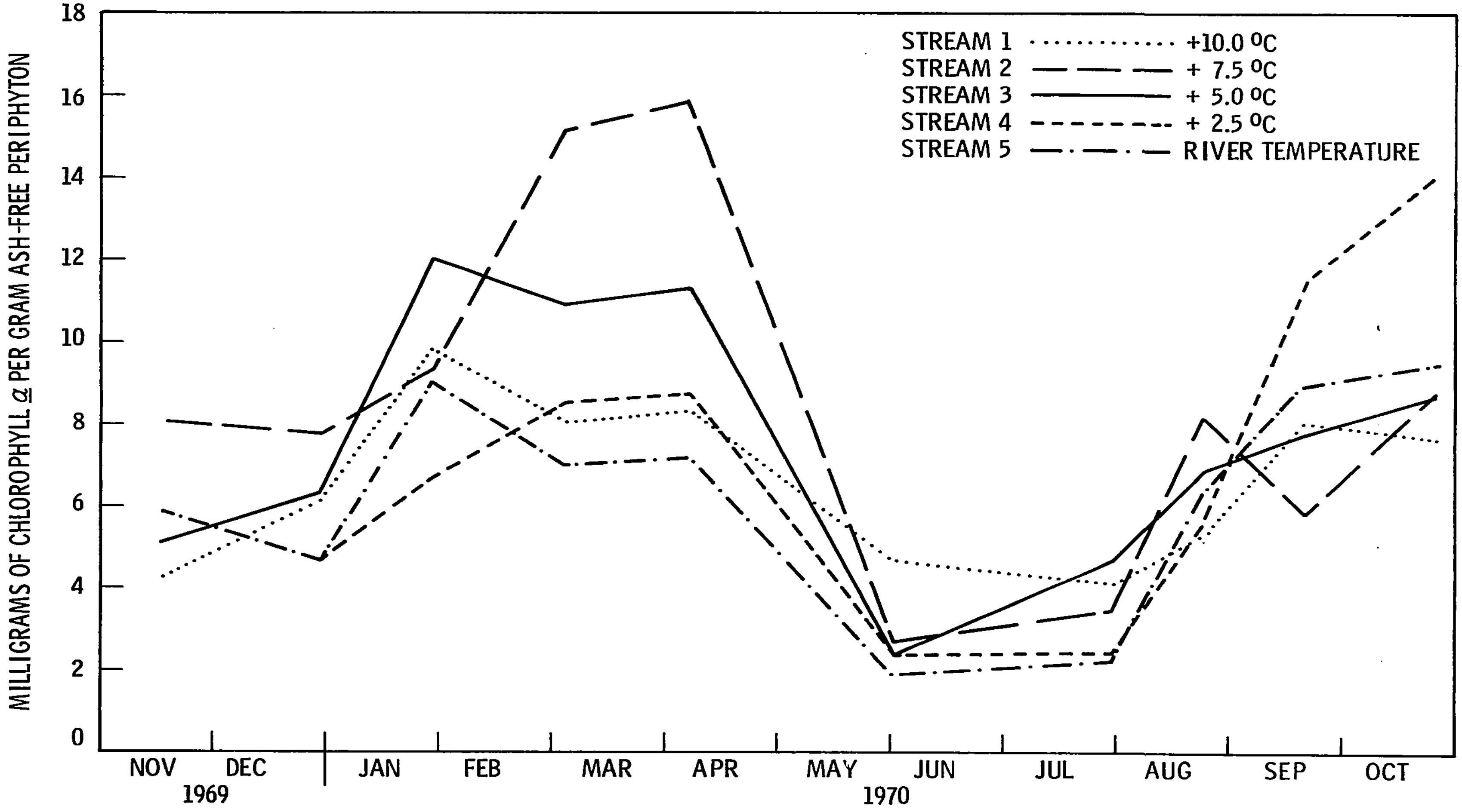
Figure 13. *Standing crops of chlorophyll a in mature periphyton communities of the experimental streams.*


MILLIGRAMS OF CHLOROPHYLL a PER METER^2
0
100
200
300
400
500
600
700
800
900
NOV 1969
DEC
JAN
FEB
MAR
APR
MAY 1970
JUN
JUL
AUG
SEP
OCT
STREAM 1 .... + 10.0°C
STREAM 2 — — + 7.5°C
STREAM 3 —— + 5.0°C
STREAM 4 - - - - + 2.5°C
STREAM 5 —·— RIVER TEMPERATURE

same bimodal pattern exists in the specific pigment content (Figure 14). These peaks are coincidal with solar equinoxes, indicating a possible relationship to a certain light intensity. However, stream 6 also developed high pigment standing crops at the same time (Appendices 7, 8) in spite of its constant light regime. If pigment content is assumed to be closely correlated with productivity, then peak production occurred in April, with a minor peak in September.

The value of pigment data in estimating production of standing crops of primary producers is debatable. The pigment content of algae is frequently determined by factors unrelated to standing crop or productive capacity (Wetzel and Westlake 1969). Animal pigments and phytopigment degradation products may interfere with measurements, although in this study, one complete set of samples were analyzed for phaeo-pigments, which were found totally lacking. The pigment standing crops presented here seem unrelated to either net production measurements (Figure 27) or standing crops of organic matter as measured by loss on ignition. Although pigment content may be a useful measurement to aid in understanding the physiology of primary production, this study indicates it may have limited use in the analysis of either standing crop or net productivity of mature periphyton communities.

Figure 14. *Specific pigment content of mature periphyton communities of the experimental streams.*


MILLIGRAMS OF CHLOROPHYLL $\underline{a}$ PER GRAM ASH-FREE PERIPHYTON
18
16
14
12
10
8
6
4
2
0
NOV
DEC
1969
JAN
FEB
MAR
APR
MAY
JUN
1970
JUL
AUG
SEP
OCT
STREAM 1 +10.0 °C
STREAM 2 + 7.5 °C
STREAM 3 + 5.0 °C
STREAM 4 + 2.5 °C
STREAM 5 RIVER TEMPERATURE

This study was unable to find any major differences in standing crops of mature periphyton maintained at several increments above Columbia River temperatures. There was little agreement among the three methods of estimating standing crop, either seasonally or annually. It should be stressed that the standing crop measurements discussed were of communities that were not subject to grazing pressures or other disruptive influences that normally occur in natural streams. It is doubtful that "mature" communities ever constitute a major proportion of the total periphyton component of natural streams.

Periphyton Colonization and Growth

In natural river ecosystems, there are numerous variable forces such as silt load, flow velocity, and grazing pressure which may prevent periphyton communities from ever reaching a mature condition, as described in the last section. Large areas of substrate may be completely denuded at times. To simulate the latter, lower sections of each experimental stream were allowed to develop periphyton on a bare surface, as described in the Methods section. The accrual of periphyton organic matter on a bare glass surface during each seasonal period of growth is plotted in Figures 15-18. The data used in these plots are based on standing crops measured by loss on ignition (Appendix 9).

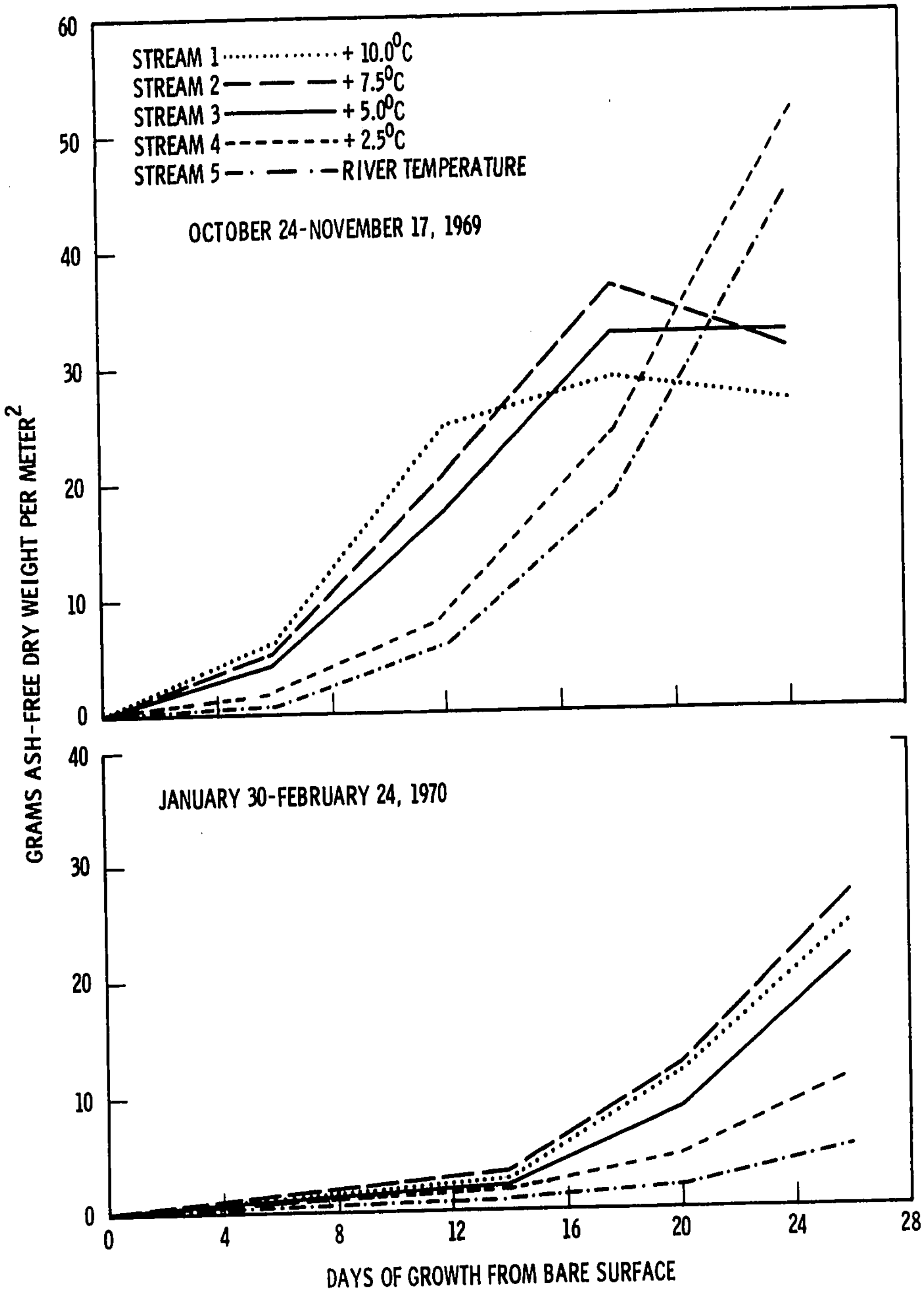
The fall series of collections indicated that when the standing crops exceeded approximately 25 g/m^2, the warmer streams did not gain biomass as fast as the streams nearer control condition (Figure 15). This may have been caused by differing species compositions. A more likely explanation is that as the biomass developed, the lower layers became light restricted and could not photosynthesize fast enough to keep up with the high respiration rates at the warmer temperatures. Nevertheless, for the first two weeks, each temperature increase accelerated the rate of growth.

The winter series (Figure 16) was not completed, as there was considerable grazing in the cooler channels in the later phases of growth. However, the warmest channel (15°C) did not grow periphyton as fast as the 12.5°C one, although the other streams followed the pattern of higher standing crop development for higher temperatures. This would suggest that temperatures in excess of 12.5°C may allow respiration to increase to levels that are less efficient in the restrictive winter light climate.

The spring series (Figure 17) indicate a direct, positive relationship between temperatures and standing crop development through the period. The high light intensity apparently allows for efficient growth at the

Figure 15. *Periphyton standing crop accrual on bare substrates, October 24-November 17, 1969.*

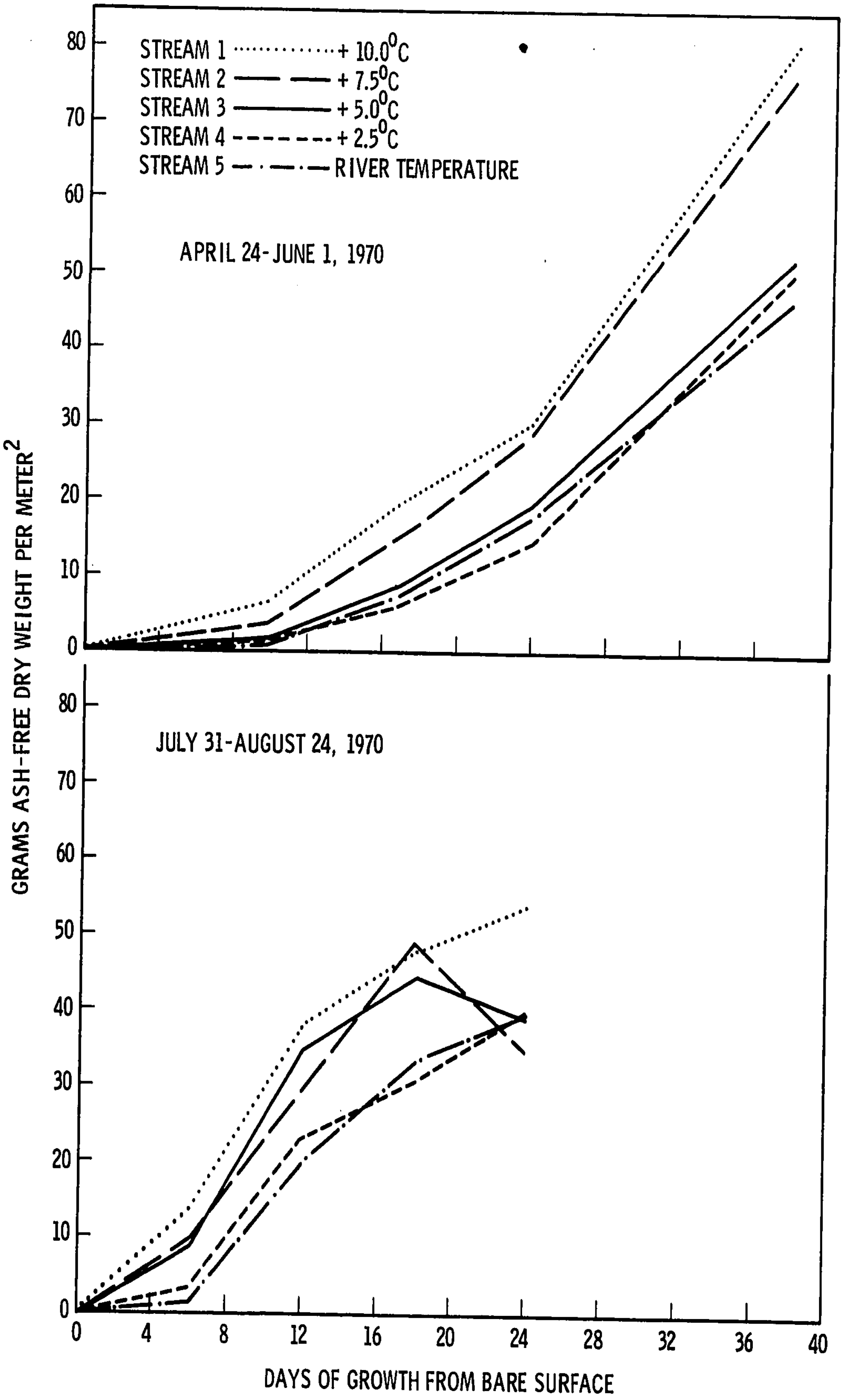
Figure 16. *Periphyton standing crop accrual on bare substrates, January 30-February 24, 1970.*


STREAM 1 ············ + 10.0°C
STREAM 2 — — — + 7.5°C
STREAM 3 ——— + 5.0°C
STREAM 4 - - - - - - + 2.5°C
STREAM 5 —· —·— RIVER TEMPERATURE
OCTOBER 24-NOVEMBER 17, 1969
JANUARY 30-FEBRUARY 24, 1970
GRAMS ASH-FREE DRY WEIGHT PER METER²
DAYS OF GROWTH FROM BARE SURFACE
0
10
20
30
40
50
60
0
10
20
30
40
0
4
8
12
16
20
24
28

7

Figure 17. *Periphyton standing crop accrual on bare substrates, April 24-June 1, 1970.*

Figure 18. *Periphyton standing crop accrual on bare substrates, July 31-August 24, 1970.*


STREAM 1 ·············· + 10.0°C
STREAM 2 — — — + 7.5°C
STREAM 3 ———— + 5.0°C
STREAM 4 - - - - - - + 2.5°C
STREAM 5 —·—·— RIVER TEMPERATURE
APRIL 24-JUNE 1, 1970
JULY 31-AUGUST 24, 1970
GRAMS ASH-FREE DRY WEIGHT PER METER²
0
10
20
30
40
50
60
70
80
0
4
8
12
16
20
24
28
32
36
40
DAYS OF GROWTH FROM BARE SURFACE

temperatures tested. The large separation between the rates of growth for streams 2 and 3 may be caused by the different species compositions of the two communities. Another possible explanation is that the temperature of 17.5°C may be the threshold above which the community is able to grow faster than it is being smothered by the heavy spring silt load.

The summer series exhibited similar trends to the spring series (Figure 18) except that high standing crops were attained in such a brief time that the last collection started to reflect the normal cycles of gain and loss of material discussed in the section on mature periphyton.

Since the chemical parameters of the Columbia River water are fairly stable annually, comparisons of the above data from different seasons may be made to give indications of the effects of light differences. Figures 19-23 show periphyton standing crop accumulation from streams with the same mean temperatures during periods of growth measurement. These data indicate that at temperatures above approximately 21°C, light increases to summer intensities will increase the rate of standing crop development. For equivalent temperatures, the spring data appear lower than might be expected, considering the high light intensities. Several factors may have affected the spring growth curves: 1) photoinhib-

Figure 19. *Periphyton standing crop accrual on bare substrates in different seasons, in 15°C streams.*

Figure 20. *Periphyton standing crop accrual on bare substrates in different seasons, in 17.5°C streams.*

Figure 21. *Periphyton standing crop accrual on bare substrates in different seasons in 20°C streams.*

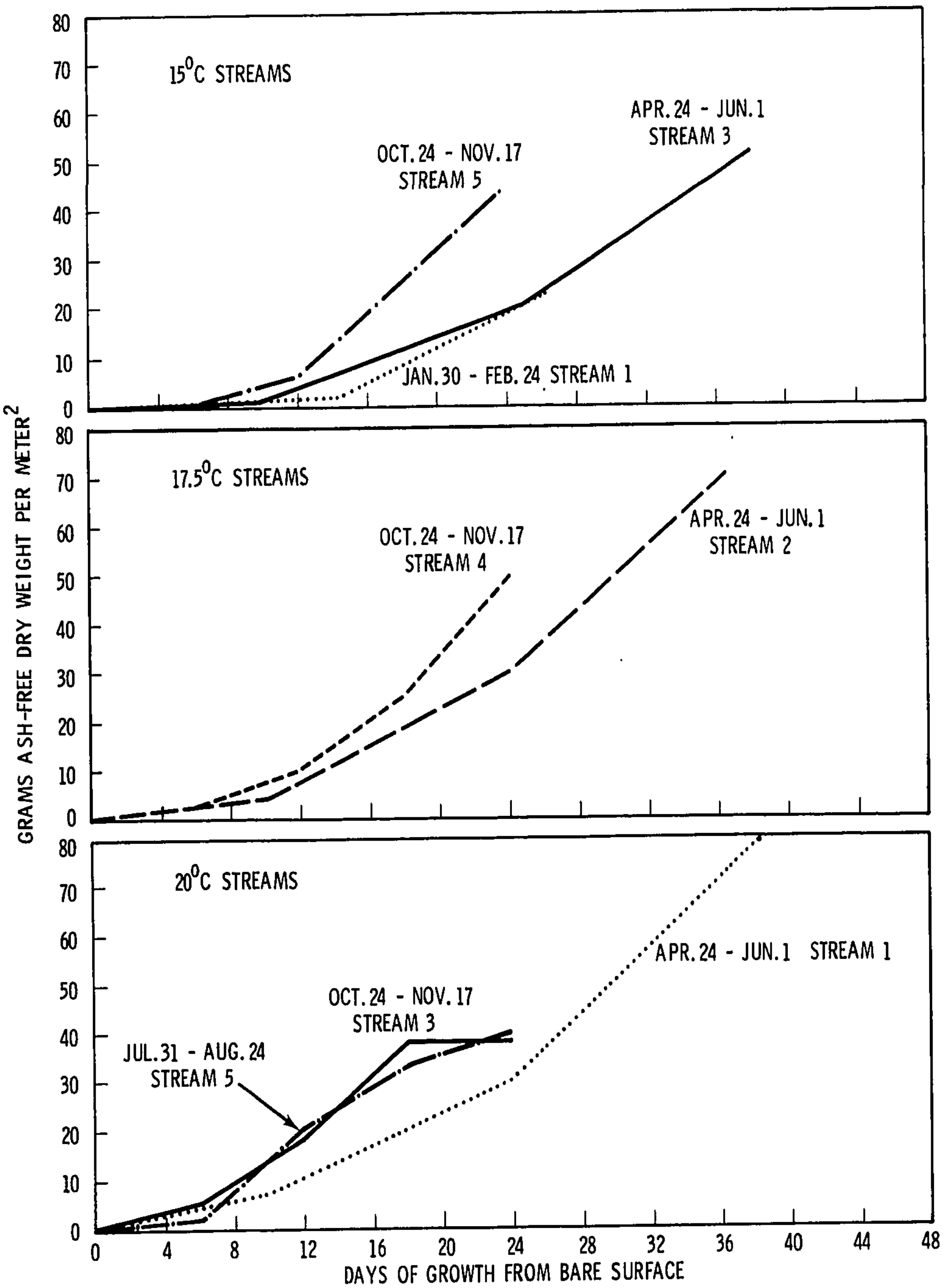
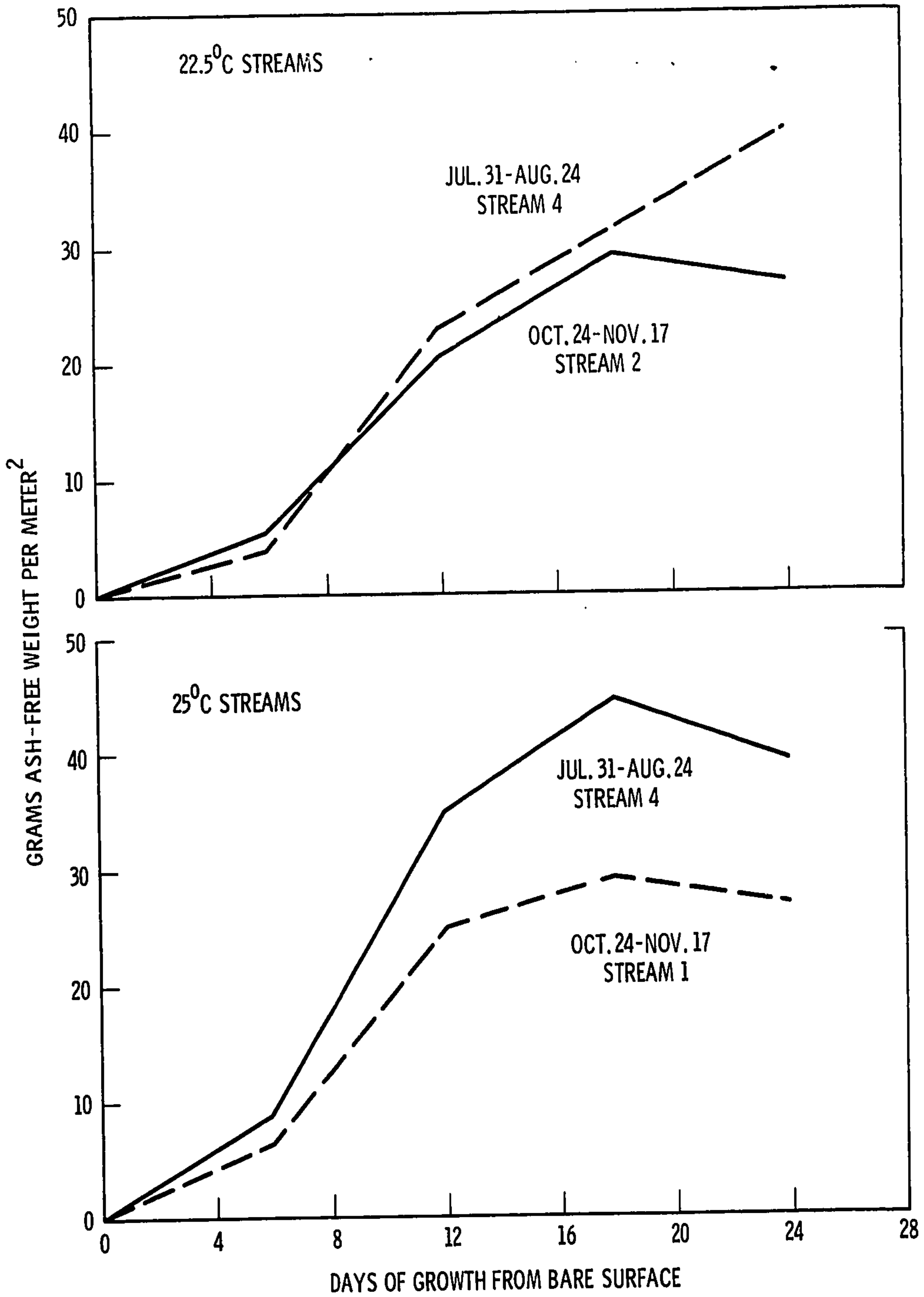

15°C STREAMS
OCT. 24 - NOV. 17 STREAM 5
APR. 24 - JUN. 1 STREAM 3
JAN. 30 - FEB. 24 STREAM 1
17.5°C STREAMS
OCT. 24 - NOV. 17 STREAM 4
APR. 24 - JUN. 1 STREAM 2
20°C STREAMS
APR. 24 - JUN. 1 STREAM 1
OCT. 24 - NOV. 17 STREAM 3
JUL. 31 - AUG. 24 STREAM 5
GRAMS ASH-FREE DRY WEIGHT PER METER²
0
10
20
30
40
50
60
70
80
0
4
8
12
16
20
24
28
32
36
40
44
48
DAYS OF GROWTH FROM BARE SURFACE

Figure 22. *Periphyton standing crop accrual on bare substrates in different seasons, in 22.5°C streams.*

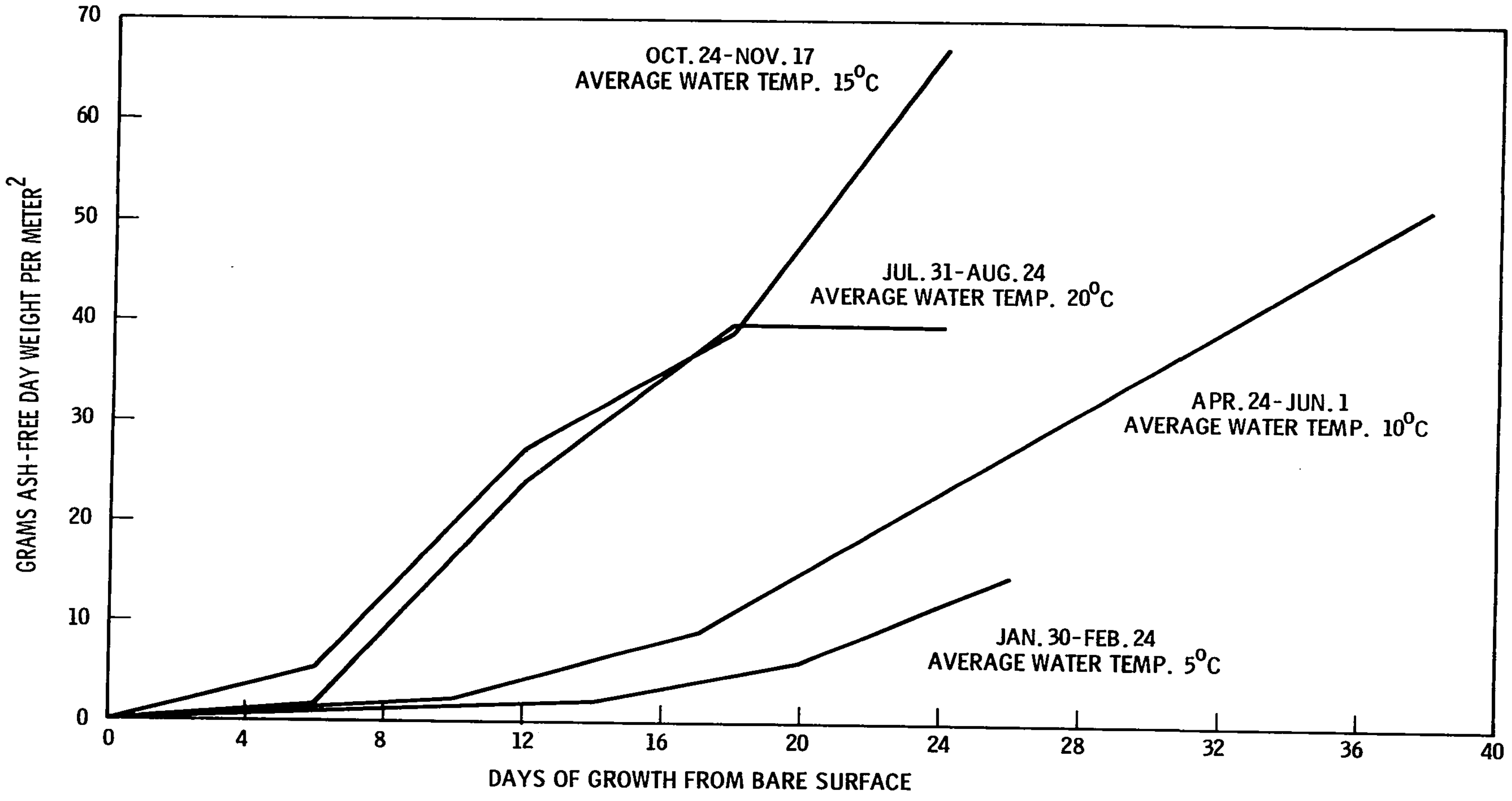
Figure 23. *Periphyton standing crop accrual on bare substrates in different seasons, in 25°C streams.*


22.5°C STREAMS
JUL. 31-AUG. 24
STREAM 4
OCT. 24-NOV. 17
STREAM 2
25°C STREAMS
JUL. 31-AUG. 24
STREAM 4
OCT. 24-NOV. 17
STREAM 1
GRAMS ASH-FREE WEIGHT PER METER²
0
10
20
30
40
50
0
4
8
12
16
20
24
28
DAYS OF GROWTH FROM BARE SURFACE

ition may have occurred, 2) heavy silt loads may have "smothered" the communities, and 3) the availability of seeding individuals may have been low due to dilution from high water, or other factors. On the other hand, the relatively high rates of periphyton accumulation of the fall cool stream communities may have resulted from a greater abundance of seeding material. Figure 24 may indicate this phenomenon also, in the light-controlled stream. However, Patrick (1967) stated that invasion rate was important to community structure, but not to the standing crop that develops. The relationship of light and temperature will be discussed in a later section.

If all factors such as river chemistry and seeding rate were stable, the data of Figure 24 would indicate that at that light level, 15°C was the optimum tested temperature for the most rapid development of a high standing crop. Compared with the data from the open channels, Figure 24 indicates that the usable light energy in stream 6 may have been higher than the natural fall and winter light. The fall and winter communities of stream 6 grew faster than the communities of equal temperature exposed to natural light. The spring and summer communities grew at nearly the same rates in both the natural light and artificial light streams of equal temperature. Pigment accrual patterns were similar to

Figure 24. *Periphyton standing crop accrual on bare substrates in different seasons in the light control stream.*


OCT. 24-NOV. 17
AVERAGE WATER TEMP. 15°C
JUL. 31-AUG. 24
AVERAGE WATER TEMP. 20°C
APR. 24-JUN. 1
AVERAGE WATER TEMP. 10°C
JAN. 30-FEB. 24
AVERAGE WATER TEMP. 5°C
GRAMS ASH-FREE DAY WEIGHT PER METER^2
0
10
20
30
40
50
60
70
0
4
8
12
16
20
24
28
32
36
40
DAYS OF GROWTH FROM BARE SURFACE

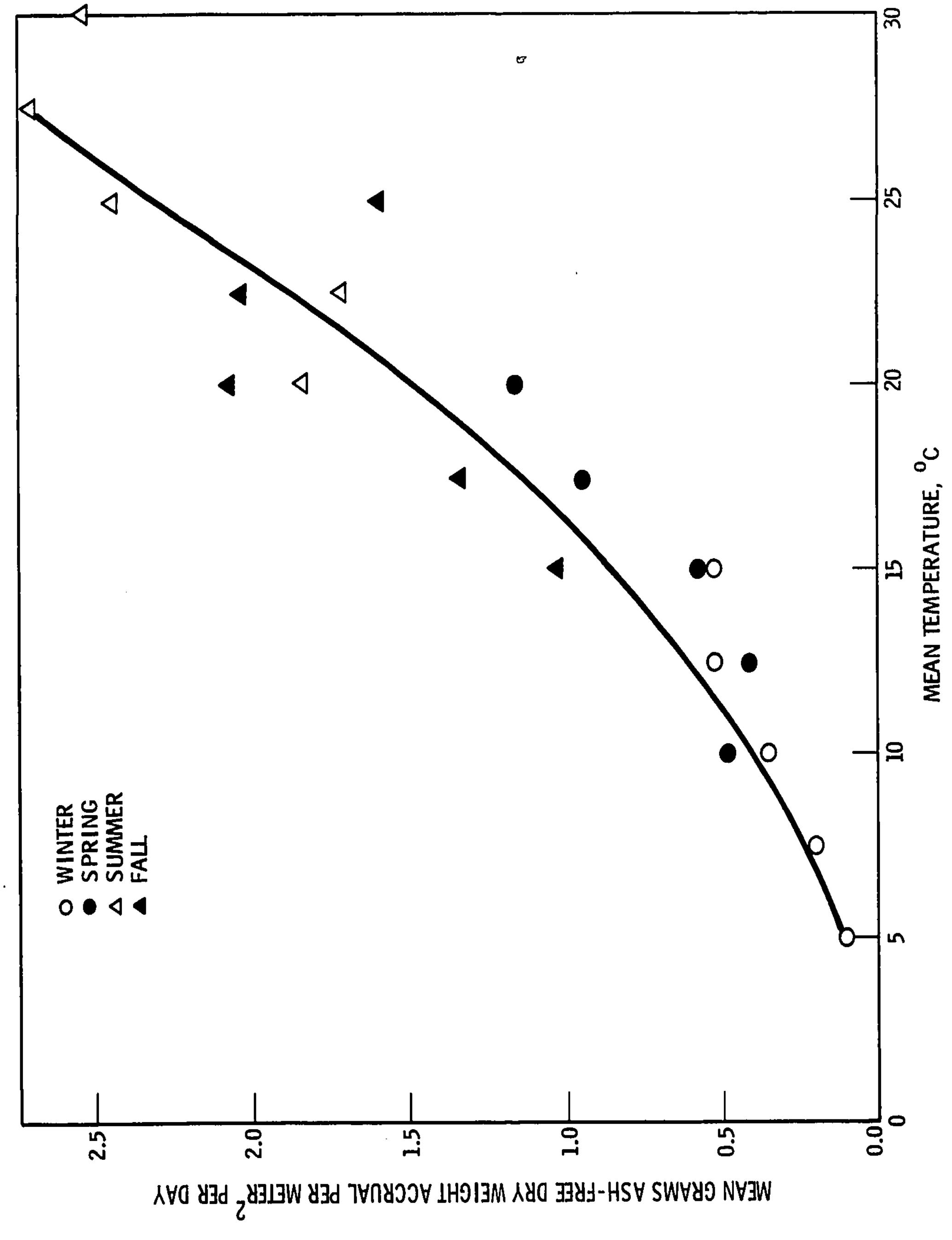
organic weight accrual during equivalent periods (Appendices 10-13). The means and standard deviations of chlorophyll *a* and carotenoids are supplied in Appendices 14 and 15. Due to the large variability and the inherent weaknesses of pigment data discussed earlier, few conclusions may be drawn from them, save that similar trends appear evident in pigment accrual as were observed for organic matter accrual.

Many investigators collect periphyton on glass slides after a set period of immersion, and use these data to estimate production (Castenholz 1961, Sladacek and Sladeckova 1964, Cushing 1967, American Public Health Service 1971). Figures 15-18 indicate that conclusions based on such a procedure could depend heavily on the immersion time. The rate of biomass accumulation is also a poor measure of net productivity, in that it does not account for biomass that has been produced and lost through grazing or physical disturbances. However, the rate of biomass accumulation may be ecologically significant to the grazers who require a certain amount of food.

Figure 25 shows the mean rate of biomass accumulation in 18 days for all the tested seasons (excluding streams 6 and 7) plotted against temperature. There is an obvious direct relationship of biomass accrual to temperature; this relationship was so strong that the

7

Figure 25. *Rate of biomass accrual on bare substrates in 18 days at different temperatures and seasons.*


○ WINTER
● SPRING
△ SUMMER
▲ FALL
MEAN TEMPERATURE, °C
0
5
10
15
20
25
30
MEAN GRAMS ASH-FREE DRY WEIGHT ACCRUAL PER METER^2 PER DAY
0.0
0.5
1.0
1.5
2.0
2.5

differing light intensities of the different seasons did not alter the trends. However, it is difficult to accurately compare biomass accumulation from different times of the year, due to the probability that any fixed immersion time would represent a different phase of the growth curves in different seasons.

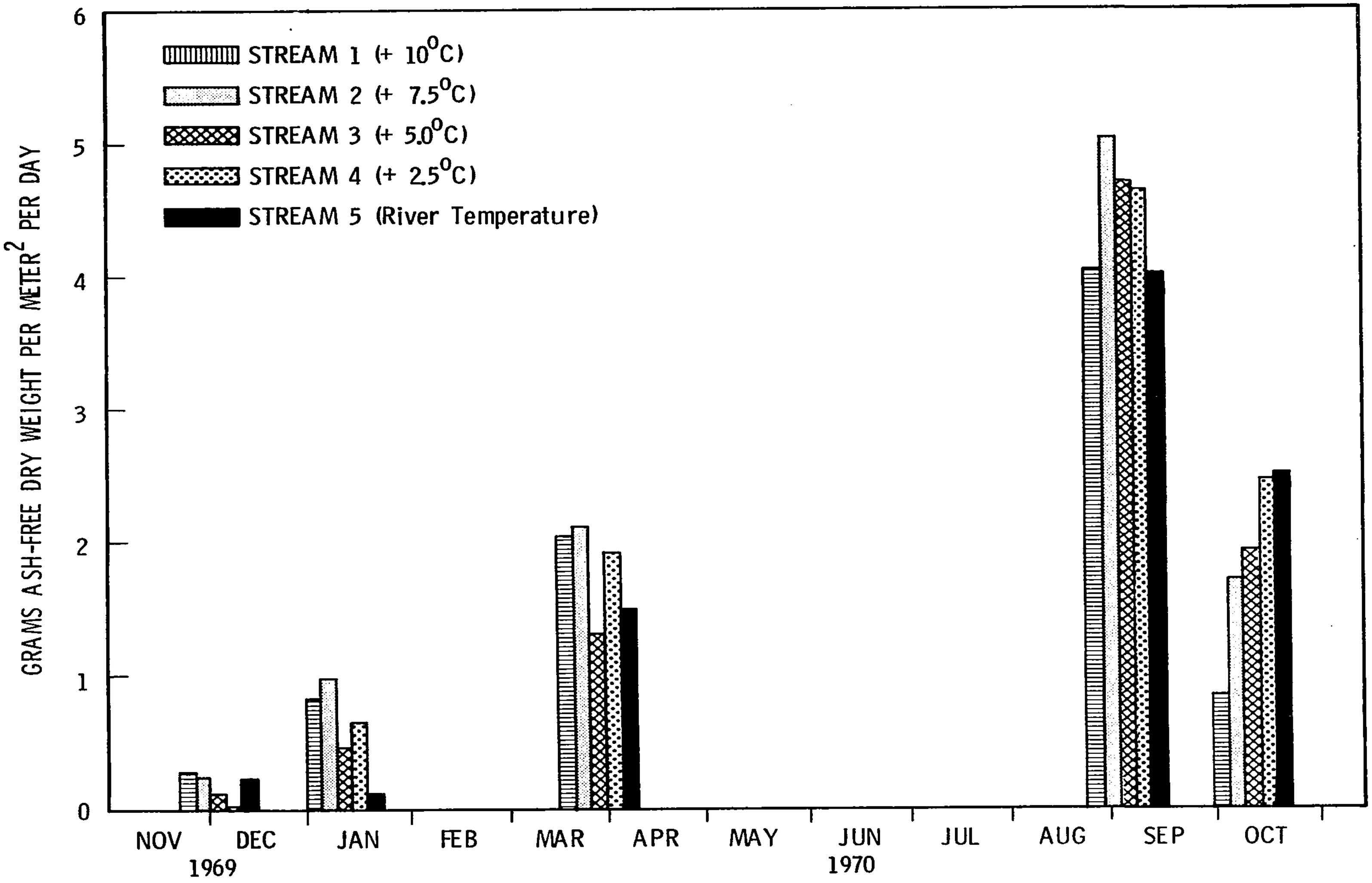
Periphyton Community Export

A certain amount of export must be a phenomenon common to all periphyton communities of moving bodies of water, and may be caused by changes in flow, scouring by particles in the water, or disturbances from grazing or moving fauna. The latter causes for export are all related to forces external to the community. However, oxygen evolution from active photosynthesis within the community may cause bubbles to form, and provide the necessary buoyancy to lift large sections of the community from the substrate. For the present study, oxygen flotation was probably the major cause of export at certain times of the year, when mats of periphyton were formed by significant populations of filamentous blue-green algae or *Cymbella affinis*. Export is not a well documented phenomenon of natural flowing waters, although McIntire (1968) observed export in experimental streams.

Figure 26 shows the rates of export of the mature periphyton communities over a year. These data are

7

Figure 26. *Rate of export of mature periphyton communities grown at different temperatures.*


STREAM 1 (+ $10^{0}C$)
STREAM 2 (+ $7.5^{0}C$)
STREAM 3 (+ $5.0^{0}C$)
STREAM 4 (+ $2.5^{0}C$)
STREAM 5 (River Temperature)
GRAMS ASH-FREE DRY WEIGHT PER $METER^2$ PER DAY
0
1
2
3
4
5
6
NOV
DEC
1969
JAN
FEB
MAR
APR
MAY
JUN
1970
JUL
AUG
SEP
OCT

sparse, due to the immature condition of the periphyton of the lower sections of the streams a majority of the time. Additional export data are supplied in Appendix 16. Note that the normal 2-3 day collection periods are not shown in all the data; in some cases the samples for several short collection periods were ashed together. These data may be compared among streams for any single period, as each stream was maintained in the same condition of disturbance. For example, there frequently were large sections that, due to recent sampling, were not mature, but these areas were equivalent for all streams. The data may not be used for comparisons among different dates, excepting those dates plotted in Figure 26.

An additional control net was used on the same water source that the streams received, as described in the Methods section. The data from this net indicated that for most of the year, the weight of trapped material amounted to less than 3% of the export measured for mature communities (Appendix 16). The material collected in the control net appeared to be mainly allochthonous detritus, although some planktonic material was present.

Short term variations in export are reflected to some degree by the export data of Appendix 16. For example, the high export recorded for the February 16-22 period was observed to be caused by bubble flotation on a sunny day that followed a long series of days with very low light. Similar phenomena were observed at intervals throughout the year. Another characteristic of the export was the tendency for large quantities (up to approximately 20% of the community) to dislodge within a few minutes, followed by a day or more with little visible export. This was apparently a chain reaction not too different from the mass windfalls of certain coniferous forests. The removal of one section of community allowed the current pressure to increase at the edge of the next downstream section, and, as well, it removed the support of the upstream portions. The net result of this phenomenon was a somewhat cyclical pattern of export and growth. The appendicized data do not indicate the latter clearly, as the collection period was often too long to permit the cycles to be seen.

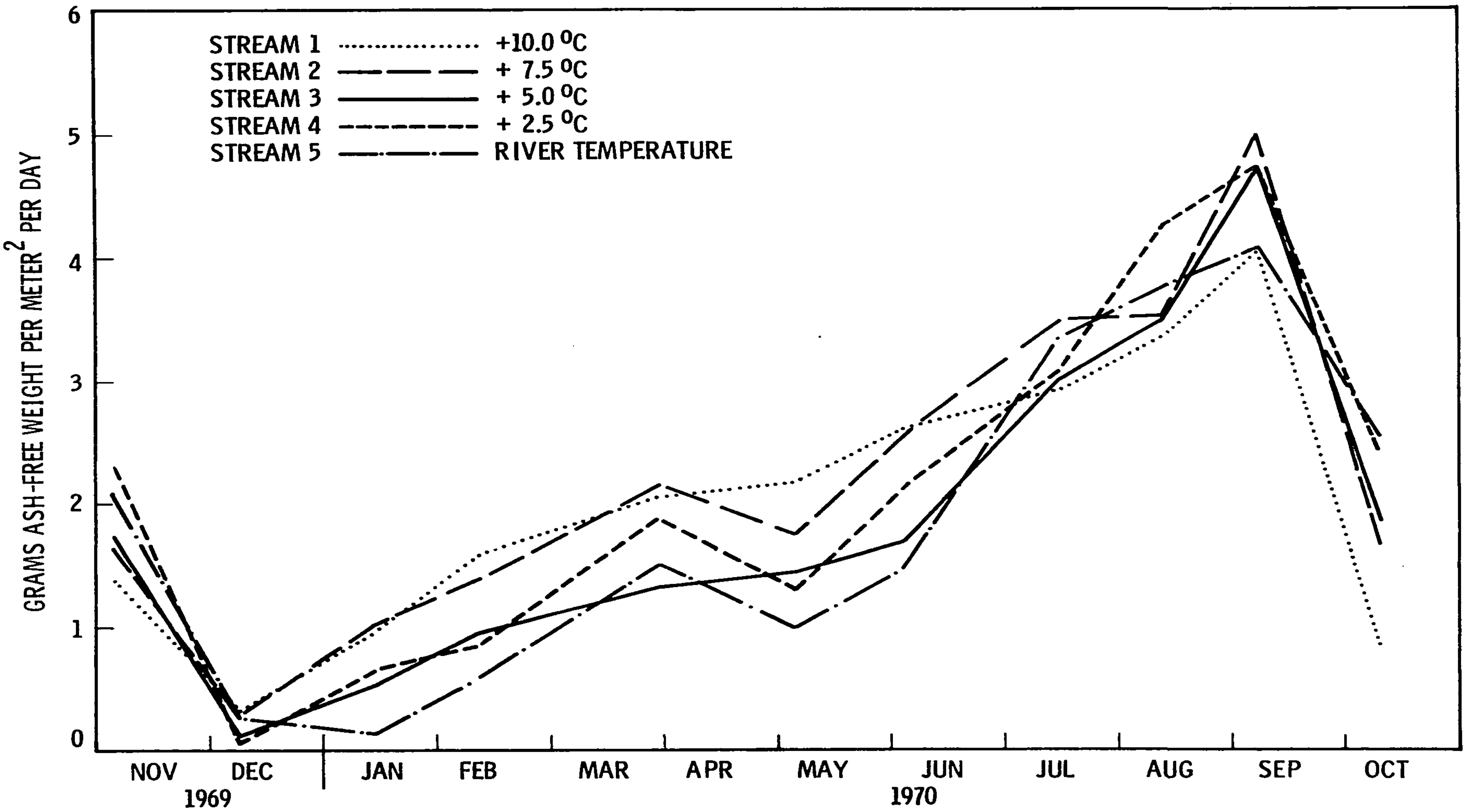
Productivity

Net primary productivity may be defined as the rate of storage of organic matter in plant tissues in excess of the respiratory utilization by the plants during the period of measurement (Odum 1971). In the present study, net community productivity was measured as the amount of primary productivity in excess of that used by heterotrophs. It was measured as the rate of change in standing crop, plus the rate of export as described in the Methods section. The productivity of the stream systems was continuously monitored with the net collections and the standing crop measurements. However, the total length of each stream had mature periphyton communities for only short periods. During other periods, there were equal areas of each stream with developing periphyton communities.

There were only six intervals during the study that were considered adequate to yield productivity data of the mature periphyton communities. As these data, and the productivity data from the periods when the majority of the streams supported immature communities appear to measure the same thing, they have been combined in Figure 27, to give one overall picture of seasonal trends. Additional justification for combining these data was the similarity of pattern of the first and last sets of data, plotted in Figure 27. This similarity indicated both that the seasonal productivity patterns may be reproducible, and that the two methods of measuring productivity were compatible (data of early November 1969 were from immature communities, data of October 1970 were from mature communities).

The patterns of productivity shown in Figure 27 do not indicate major temperature-related differences among the streams during a single collection period. All of the periphyton communities appeared to behave similarly over the course of the year. Lacking the statistical comparability of several replicate streams at each temp-

Figure 27. *Net community production of periphyton communities of experimental streams.*


STREAM 1 .... +10.0 °C
STREAM 2 — — — + 7.5 °C
STREAM 3 ——— + 5.0 °C
STREAM 4 - - - - - + 2.5 °C
STREAM 5 —·—·— RIVER TEMPERATURE
GRAMS ASH-FREE WEIGHT PER METER² PER DAY
0
1
2
3
4
5
6
NOV
DEC
1969
JAN
FEB
MAR
APR
MAY
JUN
1970
JUL
AUG
SEP
OCT

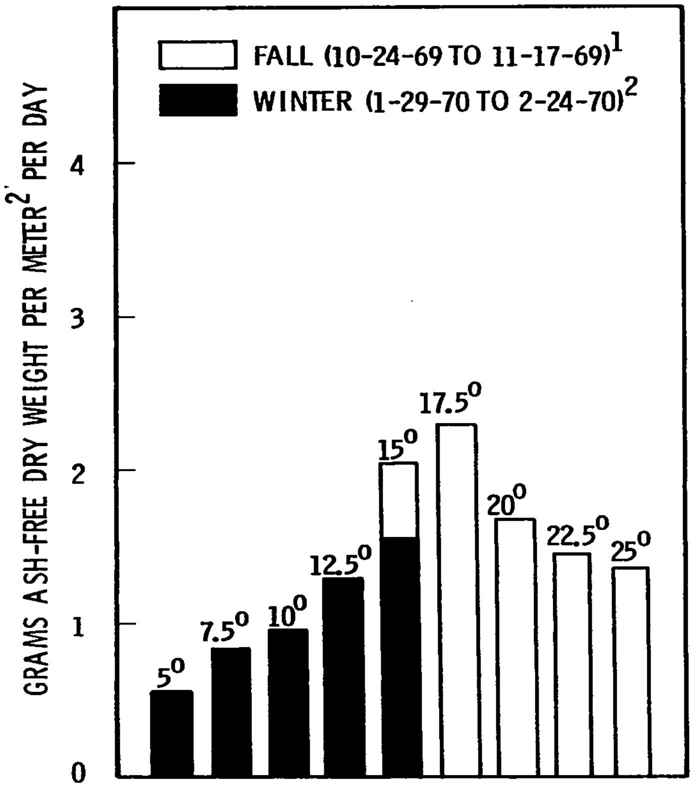
erature, one may only extrapolate the magnitude of error and/or variability from the variations in standing crop data (Appendices 5 and 9). Standard deviations of standing crop measurements varied considerably, but averaged 10% of the mean. Little error was possible in the export measurements, since total stream export was collected. It thus seems safe to assume that the error of productivity estimates closely follows those of standing crops measurements. A spread of data points of the magnitude shown among streams in spring and early fall is probably significant.

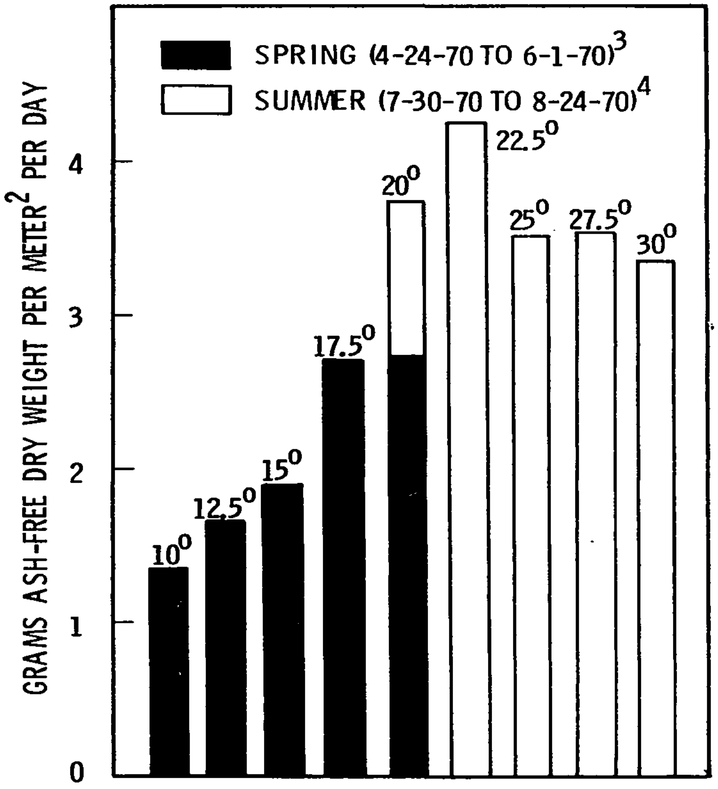
The warmer streams exhibited depressed productivities in the fall, while temperatures were high, and light was relatively low. In late winter through spring, the warmest streams out-produced the cold ones, while the light was relatively strong, and temperatures low. The enhanced spring productivity in the heated streams appears to offset the depressed fall productivity of these streams.

Figure 28 compares the productivities of periphyton communities developed under similar light conditions at different times of the year. There seems to be one temperature that is optimal for periphyton production for each light intensity. The overlap of the data for equivalent temperatures may have been due to differing availability of seeding material, or some other source of error. Nevertheless, Figure 28 indicates that for high

7

Figure 28. *Net community production of periphyton communities grown under two sets of light conditions and in two different seasons.*





1 194 LANGLEYS PER DAY MEAN INSOLATION
2 183 LANGLEYS PER DAY MEAN INSOLATION
3 598 LANGLEYS PER DAY MEAN INSOLATION
4 614 LANGLEYS PER DAY MEAN INSOLATION

light intensities (600 langleys/day) temperature operated as a limiting factor above (or below) approximately 22.5°C. At low light intensities (200 langleys/day) temperatures above 17.5°C acted as limiting factors. The accelerated respiration at higher temperatures requires more light to manufacture enough food to compensate for respiratory losses. McIntire (1968b) also noted that light could be a limiting factor when periphyton was exposed to increased temperatures.

Figure 29 further illustrates the effects of both light and temperature on the periphyton communities of this study. The features of this plot are idealized by the model that will be discussed. Figure 29 indicates that both high light and high temperature may inhibit net community production. The amount of light or heat required to inhibit this production is dependent on the temperature and light, respectively, that the community grows in.

Figure 30 shows all computed productivities of the communities in the experimental system. This includes data from streams 6 and 7, and estimates of productivity based only on accrual plus a series of data from the winter 1970-1971, not presented elsewhere. The winter data are based on accrual rates for periphyton communities grown at five temperatures from 7°C to 28.6°C. This figure represents the range of productivity likely to

Figure 29. *Periphyton net community productivity under different light and temperature conditions in experimental streams (productivity as grams of ash-free dry weight per square meter per day).*

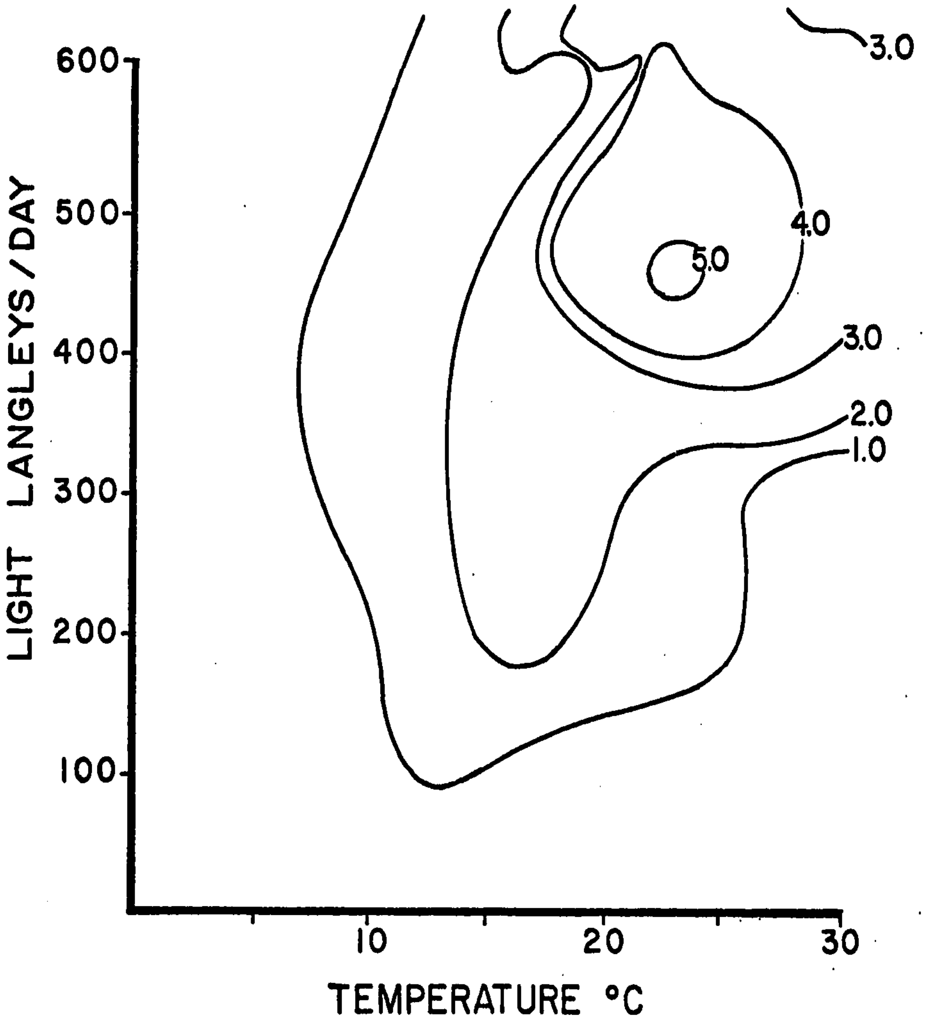
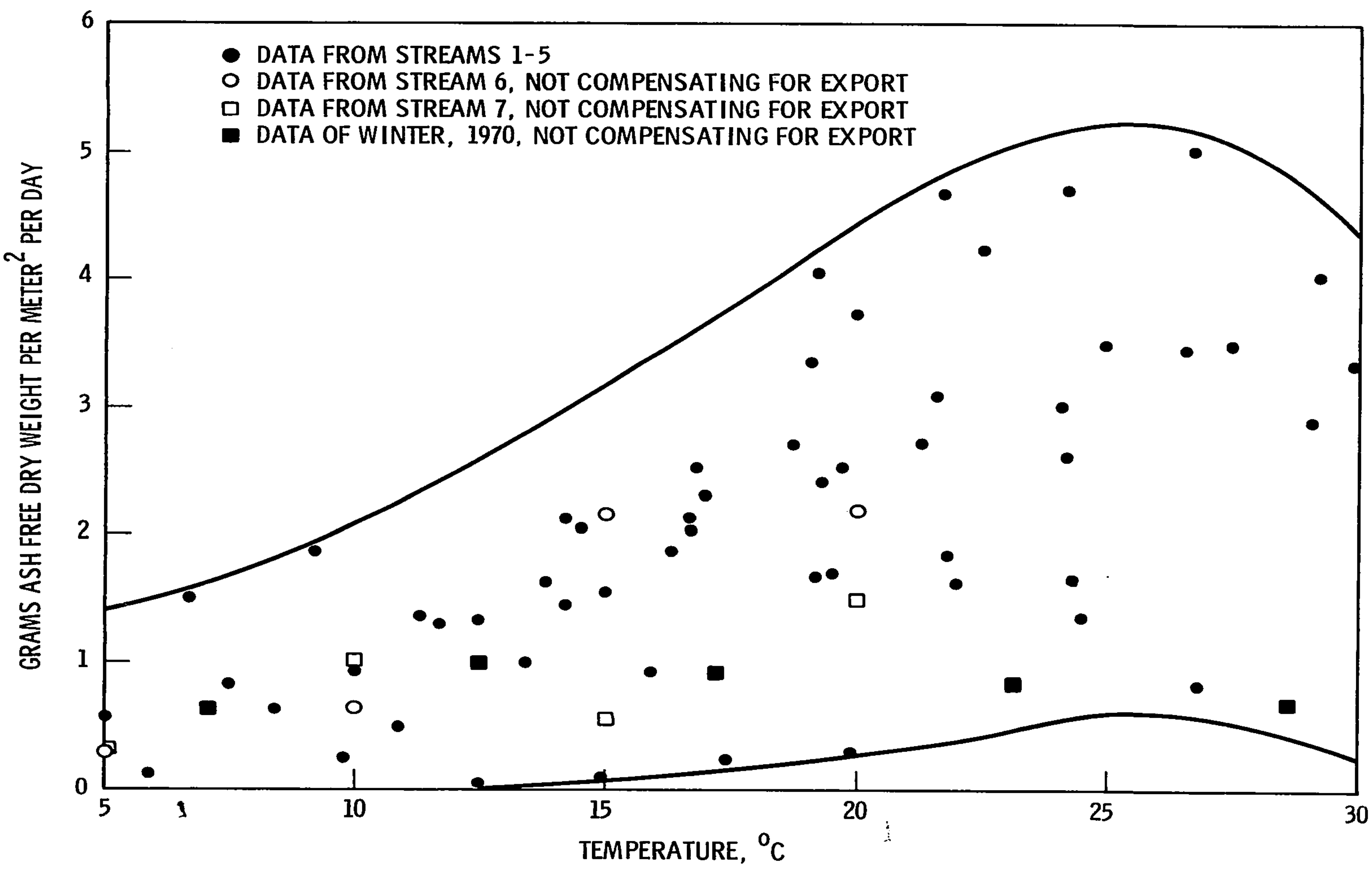

LIGHT LANGLEYS / DAY
600
500
400
300
200
100
TEMPERATURE °C
10
20
30
3.0
4.0
5.0
3.0
2.0
1.0

Figure 30. *Temperature defined limits of periphyton net community production. Based on data from all conditions encountered in the artificial stream study.*


● DATA FROM STREAMS 1-5
○ DATA FROM STREAM 6, NOT COMPENSATING FOR EXPORT
□ DATA FROM STREAM 7, NOT COMPENSATING FOR EXPORT
■ DATA OF WINTER, 1970, NOT COMPENSATING FOR EXPORT
GRAMS ASH FREE DRY WEIGHT PER METER^2 PER DAY
0
1
2
3
4
5
6
TEMPERATURE, °C
5
10
15
20
25
30

exist for all light regimes, for each temperature at the flow used in this experiment. Below 9°C there was no data from naturally illuminated communities grown at peak light intensities, although the data from stream 6 should allow prediction of performance in this range. There is an overall trend to higher productivities for increasing temperatures up to the mid-twenties. Above 25°C there appears to be a depression of the maximum productivity possible. The depression is correlated with a visible change in the structure of the periphyton community. A more mat-like and less filamentous community structure develops at these higher temperatures, accompanied by an increased abundance of blue-green algae. Above 25°C there appears to be a depression of the maximum production possible. At low temperatures, lower limits of production in Figure 30 are determined by data points from December 1969, the darkest month in the meteorological history of Hanford, and thus represent a minimum.

A comparison of the mean annual net production of periphyton communities of each stream is presented in Table 3. The means do not differ enough to draw firm conclusions. The increases in temperature do not appear to greatly modify the total amount of production in one year. The depressed productivities of the heated fall communities were offset by the enhanced spring production of these streams (Figure 27). Although the "total"

Table 3. *A comparison of three calculations of mean annual net productivity of periphyton communities of artificial streams (grams/meter^2/day).*

	STREAM				
	1	2	3	4	5
Total(a)	2.07	2.17	1.91	1.99	1.72
Mature(b)	2.01	2.35	1.93	2.20	1.93
Immature(c)	2.28	2.35	2.12	2.35	2.15

(a) Computed from the total of all export data, harvest etc. i.e. all the biomass that grew in one year, 10-24-69 to 10-27-70.

(b) Mean productivity of six periods of measurement of changes in standing crop and export data when communities were in undisturbed climax condition.

(c) Mean productivity of five periods of measurement of changes in standing crops and export data when communities (at least 2/3 of stream) were in immature stages.

net productivities (see footnote of Table 3) are considered the most realistic estimates, the other data presented indicate that judicious sampling at appropriate intervals may provide comparable data.

Finally, the productivity data for each stream and all of the accompanying environmental data were utilized to develop an empirical model of productivity. After several attempts to add additional variables into the model (river flow, chemical data) it was evident that the best predictive model was based solely on light and temperature. The model is a simple quadratic expression:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_1^2 + B_4X_2^2 + B_5X_1X_2,$$

where Y = net periphyton productivity in grams/square meter/day, X_1 = mean Centigrade temperature at which the periphyton community is grown, X_2 = light under which the community is grown, in langleys/day. The regression coefficients and their standard deviations are:

B	Mean	SD
0	-1.77962	.66982
1	.21262	.07834
2	.00878	.00230
3	.00923	.00278
4	.000022	.000004
5	.00054	.00011

The above coefficients are all very significant ($p \leq .01$) according to the *t*-test. The model accounts for 77% of the data variability.

The model performed within a tolerable range of error, except for the September and October data (Table

Table 4. *Predicted and actual net productivities of periphyton communities at temperature increments above Columbia River ambient.*

OBSERVATION		STREAM					Mean light
PERIOD		1	2	3	4	5	Langleys/day
10-24-69	A)	1.39	1.64	1.71	2.32	2.08	187.1
to	B)	1.21	1.52	1.71	1.78	1.75	
11-17-69	C)	24.86	22.30	19.76	17.26	15.10	
11-17-69	A)	.32	.28	.13	.04	.24	65.9
to	B)	-.02	.24	.36	.36	.26	
12-29-70	C)	20.04	17.32	14.73	12.29	9.86	
12-29-70	A)	.95	1.02	.50	.64	.13	89.9
to	B)	.66	.68	.61	.39	.12	
01-29-70	C)	15.95	13.64	11.20	8.50	6.34	
01-29-70	A)	1.58	1.36	.94	.83	.57	182.7
to	B)	1.66	1.53	1.28	.92	.44	
02-24-70	C)	14.91	12.54	9.88	7.48	5.03	
03-04-70	A)	2.05	2.15	1.30	1.89	1.51	397.3
to	B)	3.01	2.71	2.26	1.73	1.12	
04-24-70	C)	17.90	15.42	12.74	10.28	7.95	
04-24-70	A)	2.16	1.73	1.45	1.29	.99	585.2
to	B)	2.92	2.48	1.90	1.25	.54	
05-18-70	C)	20.31	17.85	15.25	12.86	10.59	
05-18-70	A)	2.60	2.56	1.70	2.15	1.46	598.9
to	B)	3.32	2.99	2.79	2.03	1.49	
06-20-70	C)	24.01	21.25	18.89	16.25	14.16	
07-01-70	A)	2.92	3.48	3.02	3.10	3.35	633.9
to	B)	3.48	3.37	3.15	2.80	2.36	
07-29-70	C)	28.99	26.48	24.02	21.43	19.07	
07-30-70	A)	3.36	3.52	3.49	4.24	3.74	598.1
to	B)	3.56	3.53	3.38	3.32	2.79	
08-24-70	C)	29.78	27.40	24.65	22.04	19.96	
08-24-70	A)	4.04	5.03	4.72	4.70	4.07	449.8
to	B)	3.33	3.44	3.43	3.31	3.08	
09-21-70	C)	28.32	25.93	23.30	20.80	18.44	
09-21-70	A)	.84	1.67	1.89	2.43	2.53	293.5
to	B)	2.27	2.52	2.66	2.67	2.56	
10-27-70	C)	26.83	24.28	21.70	18.87	16.57	
12-09-70	A)	.72	.86	.95	1.01	.64	107.3
to	B)	-1.91	.23	.83	.85	.37	
12-31-70	C)	28.75	23.15	17.24	12.48	7.07	

A) Net Productivity
B) Model-predicted net productivity
C) Mean temperature for given period

4). The predicted productivities were consistently low for all streams in September. However, the predicted productivities for October were 300% too high for the warmest stream, and somewhat less high for the others. This sort of systematic error indicates that a variable of significance may be missing.

Community Analysis

Table 5 presents the algal taxa that were collected from the experimental streams during the study. Several anomalous desmids and species of *Scenedesmus* were not recorded, as they were probably not part of the community. The counts that are presented (Tables 9-19) do not indicate taxonomic levels below species, as it was frequently impossible to separate variations quantitatively. This was especially true of the variations of the *Fragilaria* species which could only be determined from valve views of solitary individuals.

The total biomass contributions of all species were not well correlated to the total cell counts for respective samples. This was the result of the great range of volume of individual cells of different taxa. Volumes of the major diatom species extended over three orders of magnitude (Table 6). The volumes computed for other species were generally based on arbitrarily fixed lengths of filament, as counting individual cells was not always feasible.

Table 5. *Algal taxa collected from experimental streams from October, 1969 to November, 1970*

Cyanophyceae

Microcystis sp.
Schizothrix calcicola (Agardh.) Gomont
Oscillatoria sp.
Calothrix sp.

Chlorophyceae

Ulothrix sp.
Ulothrix zonata (Weber & Mohr) Kütz.
Stigeoclonium lubricum (Dillw.) Kütz.
Oedogonium sp.
Mougeotia sp.
Spirogyra sp.

Bacillariophyceae

Stephanodiscus astraea (Ehr.) Grun.
Stephanodiscus Hantzschii Grun.
Cyclotella Meneghiniana Kütz.
Cyclotella Kutzingiana Chauvin
Melosira granulata (Ehr.) Ralfs
Melosira granulata var.*augustissima* O. Muller
Melosira italica (Ehr.) Kütz.-and variants
Melosira varians Agardh.
Tabellaria fenestrata (Lyng.) Kütz.
Tabellaria flocculosa (Roth) Kütz.
Meridion circulare (Grev.) Agardh.
Diatoma tenue Agardh.
Diatoma vulgare Bory
Asterionella formosa Hassal
Fragilaria construens var. *binodis* (Ehr.) Grun.
Fragilaria construens var. *pumila* Grun.
Fragilaria construens var. *venter* (Ehr.) Grun
Fragilaria crotonensis Kitton
Fragilaria lepostauron (Ehr.) Hust.
Fragilaria vaucheriae (Kütz.) Peters
Fragilaria capucina Desm.
Fragilaria capucina var. *mesolepta* Rabh.
Fragilaria brevistriata Grun.
Fragilaria pinnata var. *lancettula* (Schum.) Hust.
Fragilaria pinnata var. *trigona* (Brun. & Herib.) Hust.
Synedra rumpens Kütz.
Synedra ulna (Nitz.) Ehr.
Synedra incisa Boyer
Synedra socia Wallace
Synedra pulchella var. *lacerata* Hust.
Hannaea arcus (Ehr.) Patr. comb. nov.

Table 5 continued.

Bacillariophyceae-(continued)

Cocconeis placentula Ehr.
Cocconeis pediculus Ehr.
Achnanthes lanceolata var. *dubia* Grun.
Achnanthes lanceolata (Bréb.) Grun.
Achnanthes lemmermanni Hust.
Achnanthes linearis (W. Smith) Grun.
Achnanthes linearis f.*curta* H.L. Sm.
Achnanthes minutissima Kütz.
Achnanthes clevei Grun.
Achnanthes nolii Bock
Rhoicosphenia curvata (Kütz.) Grun. ex Rabh.
Amphipleura pellucida Kütz.
Frustulia rhomboides (Ehr.) DeT.
Stauroneis nana Hust.
Stauroneis amphioxys Greg.
Diploneis elliptica (Kütz.) Cleve
Navicula cryptocephala (Kütz.)
Navicula minima Grun.
Navicula odiosa Wallace
Navicula heufleri Grun.
Pinnularia mesogongyla Ehr.
Gomphonema intricatum Kütz.
Gomphonema olivaceum (Lyng.) Kutz.
Gomphonema ventricosum Greg.
Didymosphenia geminata (Lyng.) M. Schm.
Amphora ovalis Kütz.
Cymbella affinis Kütz.
Cymbella turgida (Greg.) Cleve.
Cymbella ventricosa Kütz.
Cymbella gastroides Kütz.
Cymbella caespitosa f.*minor* A. Cleve
Cymbella sinuata Greg.
Epithemia sorex Pant.
Epithemia turgida (Ehr.) Kütz.
Epithemia zebra (Grun.) A. Mayer
Rhopalodia gibba (Ehr.) Muller
Rhopalodia gibba var. *ventricosa* (Ehr.) Grun.
Nitzschia acicularis W. Smith
Nitzschia Delognei Grun.
*Nitzschia denticula*Grun.
Nitzschia dissipata (Kütz.) Grun.
Nitzschia fonticola Grun.
Nitzschia frustulum (Kütz.) Grun. (several forms)
Nitzschia Kutzingiana Hilse
Nitzschia linearis W. Smith
Nitzschia palea (Kütz.) W. Smith (several forms)
Nitzschia subtilis Grunow

Table 5. continued

Bacillariophyceae (continued)

- *Cymatopleura solea* (Bréb.) W. Smith
- *Cymatopleura elliptica* (Balbis) W. Smith
- *Surirella angustata* Kütz.
- *Surirella linearis* W. Smith
- *Surirella ovata* Kütz. (several forms)

The cell volumes of major diatoms varied considerably among the seasons; however, there are no indications of any seasonal trends common to all species (Table 7). The data used to compute these means were highly variable. Populations of certain species included individuals with threefold differences in cell volumes. Centric diatoms exhibited the greatest variability. Although the cell sizes did not consistently vary with season, other cellular features such as chloroplast size and density appeared to follow distinct seasonal trends in some species.

Counts were replicated from streams 1, 3, and 5 once each season, the replicates being of material collected from different areas of each stream. These counts provide estimates of the total error in determining the community structure of each stream. The counts, when compared using an index of similarity (Bray and Curtis 1957) indicated that most of the replicates were over 90% similar in composition (Appendices 17-27). The least similar set of replicates were 72% alike, which still exceeded the similarity of communities of different streams for most dates by a sizeable margin.

The actual numbers of individuals counted from each community are listed in Table 8. Only diatoms are listed, as most other species could not be enumerated by cells. In most cases, several thousand individuals were counted, although as few as 700 were alive, in some cases.

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Table 6. *Mean volumes of diatom cells in cubic microns.*

SPECIES	VOLUME
Cymatopleura solea	32051
Epithemia turgida	20565
Amphipleura pellucida	11520
Rhopalodia gibba	7474
Synedra ulna	6294
Epithemia zebra	5460
Surirella linearis	4500
Melosira varians	3520
Nitzschia linearis	3156
Cymbella turgida	3043
Epithemia sorex	2158
Cymbella affinis	1663
Tabellaria fenestrata	1205
Hannaea arcus	1061
Gomphonema ventricosum	500
Nitzschia frustulum	462
Fragilaria crotonensis	458
Asterionella formosa	420
Navicula cryptocephala	406
Gomphonema olivaceum	373
Fragilaria lepostauron	354
Stauroneis nana	305
Synedra rumpens	289
Gomphonema intricatum	276
Fragilaria vaucheriae	264
Nitzschia acicularis	204
Nitzschia subtilis	190
Achnanthes lanceolata	175
Navicula odiosa	170
Fragilaria construens	168
Nitzschia palea	165
Nitzschia fonticola	161
Stephanodiscus astraea	85
Nitzschia Kutzingiana	60
Amphora ovalis	52
Navicula minima	48
Achnanthes linearis	36

Table 7. *Seasonal variation in average cell volumes (cubic microns) of select important diatoms.**

SPECIES	1-29-70	4-7-70	7-30-70	10-26-70
Stephanodiscus hantzschii	88	67	101	100
Melosira varians	3576	2654	4425	3542
Melosira italica	815	629	570	888
Tabellaria fenestrata	1062	1296	1258	--
Asterionella formosa	476	484	300	--
Fragilaria lepostauron	297	353	410	--
Fragilaria crotonensis	306	550	446	518
Fragilaria vaucheriae	277	250	295	235
Fragilaria construens	171	164	151	188
Synedra ulna	5857	5619	5332	8369
Rhopalodia gibba	8652	--	5441	8330
Nitzschia dissipata	307	266	287	306
Nitzschia Kutzingiana	40	78	71	33
Nitzschia linearis	3353	3081	2808	3308

*Based on measurements of 10-50 cells per species per season.

Table 8. *Number of diatoms actually counted in each sample.* *

	LIVE	DEAD	LIVE & DEAD	LIVE/DEAD
11-17-69				
1A	3201	1541	4742	2.1
3A	4806	2389	7195	2.0
5A	3488	1654	5142	2.1
12-12-70				
1A	4038	2662	6700	1.5
3A	3515	2066	5581	1.7
5A	6039	2275	8314	2.7
1-29-70				
1A	2987	1487	4474	2.0
1B	3071	1910	4981	1.6
3A	3765	1237	5002	3.1
3B	3158	1910	5068	1.7
5A	2006	963	2969	2.1
5B	2807	1079	3886	2.6
6A	4831	1838	6669	2.6
3-4-70				
1A	7311	3393	10704	2.2
3A	30755	2371	33126	13.0
5A	2408	1318	3726	1.8
4-7-70				
1A	2777	863	3640	3.2
1B	2578	1019	3597	2.5
3A	4285	1484	5769	2.9
3B	3401	919	4320	3.7
5A	5190	1133	6323	4.6
5B	4154	686	4840	6.1
6A	4561	1167	5728	3.9
5-14-70				
1A	2993	1703	4696	1.8
3A	3997	1927	5924	2.1
5A	2584	2364	4948	1.1

Table 8. Continued

	LIVE	DEAD	LIVE & DEAD	LIVE/DEAD
6-1-70				
1A	1388	2015	3403	0.7
3A	2024	2359	4383	0.9
5A	1282	1719	3001	0.8
7-30-70				
1A	805	1499	2304	0.6
1B	700	1997	2697	0.4
3A	2120	1598	3718	1.3
3B	2622	1927	4549	1.4
5A	2906	1646	4552	1.8
5B	2867	1312	4179	2.2
6A	3327	2230	5557	1.5
7A	1390	1366	2756	1.0
8-24-70				
1A	2813	1557	4370	1.8
3A	1535	858	2393	1.8
5A	4342	1721	6063	2.5
9-21-70				
1A	1014	1685	2699	0.6
1B	1916	1471	3387	1.3
3A	3211	1569	4780	2.1
3B	3557	2212	5769	1.6
5A	2552	1816	4368	1.4
5B	2017	689	2706	2.9
10-26-70				
1A	2493	1848	4341	1.4
3A	4910	2656	7566	1.9
5A	4591	1843	6434	2.5
6A	1736	704	2440	2.5

* Actual numbers counted prior to multiplication by constants to provide an equal areal basis for comparison; A and B are replicates.

In this study, qualitative observations indicated that the late summer communities of the artificial channels were not always dominated by the same organisms. For example, in the late summer of 1968, *Cymbella affinis* was observed as a dominant of the control channel, while 1969 and 1970 counts indicated that *Rhopalodia gibba* and *Melosira varians* were dominating. Thus, while communities in this study may be referred to by naming dominant species, no special significance has been attached to these associations. Reference will be made to the percent similarities of the communities under discussion (Appendices 17-27). These compare the communities in terms of the similarities based on biomass contribution of the various species. Unless otherwise mentioned, the following discussion will emphasize biomass data.

The November communities (Tables 9 and 20) from streams 1, 3, and 5 were all dominated by the diatoms *Melosira varians* and *Fragilaria construens*. *Melosira varians* dominated in biomass by at least one order of magnitude. There were, however, subtle differences among the three communities. The *Nitzschia* species varied among the streams; *N. dissipata* was abundant in the control channel and almost absent from the +10°C stream; *N. Kutzingiana* and *N. palea* were also abundant only in the control stream. On the other hand, the warmer channels appear to have encouraged *Navicula minima*. Indices of similarity (Appendix

17) indicate that the warm channel community was unique and the control and +5°C communities were 96% similar.

The November collection had been made before the exceptionally dark weather arrived (Figure 8). There was probably not a lot of growth from this date until the December collection was made. The control stream community was similar for the two months, although *Nitzschia frustulum* became an important biomass contributor in December (Tables 10 and 21). *N. frustulum* was abundant in stream 5, and to a lesser degree stream 3; however, the warmest channel had none of this species in evidence. Streams 1 and 2 were dominated by *Melosira varians* as in November, although *Fragilaria construens* lost importance relative to the sudden abundance of *Navicula minima*, especially in the warmest stream. *N. minima* was one of the smallest diatoms in this study (Table 6) and although by far the most numerous in stream 1, it only constituted one tenth the biomass of the dominant species, *M. varians*. The three December communities were fairly similar -- 78% or more. Stream 1 and stream 3 had communities more similar to each other than to the control channel community (Appendix 18).

Temperatures approached minimum in January, while light increased slightly. The periphyton communities collected at the end of the month indicated that the control community had changed considerably (Tables 11 and 22);

Table 9. *Numbers of diatoms in periphyton communities of experimental streams of November 17, 1969 (numbers of cells/millimeter^2).*

SPECIES	STREAM 1		STREAM 3		STREAM 5	
	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD
Stephanodiscus astraea	--	--	--	--	--	--
Stephanodiscus Hantzschii	--	1171	--	1391	--	951
Melosira granulata	439	146	439	586	146	73
Melosira italica	73	586	--	1099	--	1317
Melosira varians	5253	2103	11712	5488	11507	3077
Tabellaria fenestrata	--	5	--	42	--	--
Asterionella formosa	--	512	--	659	--	512
Fragilaria construens	6667	1748	8915	2499	11227	2233
Fragilaria crotonensis	1063	1553	946	1022	900	909
Fragilaria lepostauron	--	--	--	--	146	293
Fragilaria vaucheriae	452	112	173	191	849	182
Synedra rumpens	220	220	220	439	878	659
Synedra ulna	--	47	9	51	37	56
Hannaea arcus	--	--	--	--	--	--
Achnanthes lanceolata	--	--	73	--	146	73
Achnanthes lemmermanni	--	73	--	--	--	--
Achnanthes linearis	1903	1098	586	1830	951	1464
Navicula cryptocephala	146	--	--	146	--	--
Navicula minima	8344	4611	2489	6002	1976	2196
Navicula odiosa	659	366	146	439	73	73
Stauroneis nana	146	146	--	146	--	--
Gomphonema intricatum	--	220	--	73	--	146
Gomphonema olivaceum	--	--	--	--	--	73
Gomphonema ventricosum	--	--	--	--	--	--
Amphora ovalis	--	--	--	--	--	--
Cymbella affinis	47	119	51	131	9	19
Cymbella turgida	--	--	--	--	--	--
Cymbella ventricosa	--	--	--	--	--	73
Epithemia sorex	47	14	--	9	--	--
Epithemia turgida	3.3	6.2	.5	4.3	.4	4.6
Epithemia zebra	--	--	--	--	--	--
Rhopalodia gibba	33	19	9	5	--	--
Nitzschia acicularis	220	146	--	--	73	220
Nitzschia dissipata	73	512	586	1976	3147	2635
Nitzschia fonticola	--	--	--	--	--	--
Nitzschia frustulum	293	659	146	586	512	439
Nitzschia Kutzingiana	146	--	73	512	1464	805
Nitzschia linearis	19	9	28	5	28	19
Nitzschia palea	659	2562	586	1099	2489	1683
Nitzschia subtilis	--	--	--	--	--	--
Cymatopleura solea	4.7	5.2	--	--	--	--
Surirella angustata	9	5	--	--	23	9
Surirella linearis	--	--	--	--	--	--
Surirella ovata	--	--	--	--	--	--

Table 10. *Numbers of diatoms in periphyton communities of experimental streams of December 29, 1969 (numbers of cells/millimeter^2).*

	STREAM					
	1		3		5	
SPECIES	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD
Stephanodiscus astraea	--	73	--	--	--	146
Stephanodiscus Hantzschii	73	1903	73	1610	220	1976
Melosira granulata	--	--	--	293	366	293
Melosira italica	73	732	366	586	146	659
Melosira varians	5614	1846	5884	3557	6220	4098
Tabellaria fenestrata	23	47	9	37	--	70
Asterionella formosa	73	73	73	512	73	512
Fragilaria construens	5604	2769	5572	1879	15395	2466
Fragilaria crotonensis	695	1431	527	1035	1525	1609
Fragilaria lepostauron	--	--	--	146	--	--
Fragilaria vaucheriae	79	205	597	154	3525	392
Synedra rumpens	439	366	220	146	220	366
Synedra ulna	33	23	74	61	107	65
Hannaea arcus	--	73	--	--	--	--
Achnanthes lanceolata	--	--	--	73	73	146
Achnanthes lemmermanni	--	--	--	--	--	--
Achnanthes linearis	1464	1171	1097	732	146	1752
Navicula cryptocephala	--	73	146	73	--	146
Navicula minima	46696	37840	21509	14632	878	4672
Navicula odiosa	366	805	439	439	1317	659
Stauroneis nana	1391	951	1391	220	878	293
Gomphonema intricatum	--	--	--	73	--	146
Gomphonema olivaceum	--	--	--	--	--	73
Gomphonema ventricosum	--	--	--	--	--	--
Amphora ovalis	--	--	--	--	--	--
Cymbella affinis	--	37	5	56	9	33
Cymbella turgida	--	--	--	--	--	--
Cymbella ventricosa	--	--	--	73	--	73
Epithemia sorex	--	--	--	9	--	65
Epithemia turgida	1.3	6.4	1.6	3.6	.9	4.5
Epithemia zebra	--	--	--	--	--	--
Rhopalodia gibba	28	18	--	19	--	14
Nitzschia acicularis	--	--	--	--	73	73
Nitzschia dissipata	512	805	1171	1683	2635	5639
Nitzschia fonticola	--	--	--	--	--	--
Nitzschia frustulum	--	146	1025	73	2708	1391
Nitzschia Kutzingiana	220	73	439	439	1025	439
Nitzschia linearis	37	19	42	33	275	65
Nitzschia palea	805	1610	1317	1537	1903	2389
Cymatopleura solea	5.1	4	6.1	3	4.7	1.9
Surirella angustata	14	28	--	--	23	9
Surirella linearis	--	--	--	--	--	--
Surirella ovata	--	--	--	--	--	--

Table 11. *Numbers of diatoms in periphyton communities of experimental streams of January 29, 1970 (numbers of cells/millimeter^2).*

SPECIES	LIVE^A	DEAD	LIVE^B	DEAD	LIVE ^{A}	DEAD	LIVE ^{B}	DEAD	LIVE^A	DEAD	LIVE^B	DEAD	LIVE	DEAD
Stephanodiscus astraea	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Stephanodiscus Hantzschii	--	878	73	951	73	366	--	293	--	73	220	512	73	2123
Melosira granulata	--	--	--	73	952	220	--	--	--	--	33	47	--	--
Melosira italica	220	512	--	586	--	146	146	293	93	112	42	61	73	--
Melosira varians	5702	1753	6546	1739	3212	1464	3017	1609	825	601	1166	718	4122	3874
Tabellaria fenestrata	47	61	42	117	61	37	107	98	75	28	65	42	439	73
Asterionella formosa	--	73	--	73	--	--	--	146	73	73	--	146	146	439
Fragilaria construens	3473	1758	4205	3170	8924	2107	6299	3860	5348	1641	7306	2289	18591	6441
Fragilaria crotonensis	499	858	536	1119	1296	713	1530	1231	1464	863	1734	629	1692	3028
Fragilaria lepostauron	--	--	--	--	146	--	--	1317	--	--	439	220	--	--
Fragilaria vaucheriae	396	61	373	140	1366	121	1385	275	583	168	1669	308	203547	13028
Synedra rumpens	--	--	--	--	--	--	--	--	--	--	--	--	366	439
Synedra ulna	37	23	51	33	51	33	75	14	9	33	33	5	28	51
Hannaea arcus	73	--	--	--	73	146	--	--	--	293	220	220	146	--
Achnanthes lanceolata	73	73	146	146	732	220	220	659	73	366	220	220	--	366
Achnanthes lemmermanni	--	--	73	73	--	--	--	--	--	--	--	--	--	--
Achnanthes linearis	659	3294	439	2342	1463	512	616	440	512	439	439	146	220	366
Navicula cryptocephala	--	73	73	73	146	--	146	146	146	220	--	--	--	--
Navicula minima	48234	25397	27959	25178	29277	10174	11308	8052	4904	4392	3806	1317	1976	2854
Navicula odiosa	146	293	146	439	146	220	586	439	293	220	878	586	220	--
Stauroneis nana	4465	732	4538	1244	1683	732	3074	659	--	--	--	--	146	73
Gomphonema intricatum	--	73	--	--	--	--	73	--	--	--	--	--	--	73
Gomphonema olivaceum	--	--	--	--	--	--	--	--	--	--	146	--	73	--
Gomphonema ventricosum	--	--	--	--	--	--	73	--	--	--	--	--	--	--
Amphora ovalis	--	--	--	--	--	--	--	--	73	--	--	--	--	--
Cymbella affinis	--	146	--	--	--	73	--	--	--	--	73	--	--	--
Cymbella turgida	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cymbella ventricosa	73	146	--	--	--	--	--	--	293	--	--	73	--	146
Epithemia sorex	--	5	--	5	14	9	--	28	5	5	19	5	--	9
Epithemia turgida	.8	3.1	1	3.6	1.6	1.9	3.3	3.4	1.6	3.1	.9	2.7	--	1.4
Epithemia zebra	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rhopalodia gibba	--	19	23	14	19	33	9	33	9	--	--	9	9	--
Nitzschia acicularis	73	73	--	--	--	--	--	--	--	--	--	--	1976	805
Nitzschia dissipata	293	366	366	512	586	1464	1171	2562	4465	2928	4977	3440	951	2342
Nitzschia fonticola	220	439	659	732	1683	1025	3220	1610	1976	1830	3294	1610	351	271
Nitzschia frustulum	146	146	220	220	805	439	439	439	293	146	439	1317	293	220
Nitzschia Kutzingiana	73	73	439	146	439	220	586	73	293	146	293	73	19869	12369
Nitzschia linearis	23	9	23	5	14	--	33	19	28	37	42	5	51	51
Nitzschia palea	--	146	146	805	3074	1464	1610	805	732	1757	805	586	3162	2437
Cymatopleura solea	2.1	3.4	1	2.4	1.4	2.6	2.9	2.6	1	2.5	1.6	3.5	3	3.6
Surirella angustata	75	28	70	42	126	42	168	47	9	9	42	9	5665	2635
Surirella linearis	--	--	--	--	9	9	14	9	--	--	--	--	--	--
Surirella ovata	--	--	--	--	--	--	--	--	--	--	--	--	630	293

* A and B are replicate samples from one stream.

Table 12. *Numbers of diatoms in periphyton communities of experimental streams of March 4, 1970 (numbers of cells/millimeter^2)*

	STREAM					
	1-A		3-A		5-A	
SPECIES	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD
Stephanodiscus astraea	--	73	--	146	--	220
Stephanodiscus Hantzschii	659	2123	659	1171	146	586
Melosira granulata	146	--	146	73	--	--
Melosira italica	586	512	732	512	--	220
Melosira varians	9544	3446	2406	1357	569	331
Tabellaria fenestrata	256	615	173	289	47	135
Asterionella formosa	293	951	146	1025	--	146
Fragilaria construens	6653	1977	128216	4662	6928	2047
Fragilaria crotonensis	3264	2993	2592	1250	196	508
Fragilaria lepostauron	73	73	439	73	439	73
Fragilaria vaucheriae	382	210	5161	499	1184	1874
Synedra rumpens	293	73	220	73	--	146
Synedra ulna	79	65	61	65	14	14
Hannaea arcus	--	--	5	14	14	5
Achnanthes lanceolata	73	--	--	220	146	732
Achnanthes lemmermanni	--	--	--	--	--	--
Achnanthes linearis	951	439	805	512	293	366
Navicula cryptocephala	--	146	--	--	--	--
Navicula minima	95808	42964	37035	24885	6002	6953
Navicula odiosa	1098	732	439	732	220	366
Stauroneis nana	12882	2928	3147	1098	293	293
Gomphonema intricatum	220	--	366	--	--	--
Gomphonema olivaceum	73	366	220	659	146	732
Gomphonema ventricosum	--	--	--	--	--	--
Amphora ovalis	220	439	--	--	--	--
Cymbella affinis	--	--	--	--	--	--
Cymbella turgida	--	--	--	--	--	--
Cymbella ventricosa	220	146	1391	586	659	73
Epithemia sorex	--	14	37	14	--	5
Epithemia turgida	2	1	4	2	.4	.7
Epithemia zebra	--	--	--	--	--	--
Rhopalodia gibba	65	23	65	61	--	--
Nitzschia acicularis	73	--	--	--	146	146
Nitzschia dissipata	1391	805	1244	2269	366	2635
Nitzschia fonticola	1025	1244	16834	6075	3001	3001
Nitzschia frustulum	220	586	2049	1464	1464	3513
Nitzschia Kutzingiana	439	220	1244	220	293	293
Nitzschia linearis	112	19	23	5	9	14
Nitzschia palea	146	586	1683	805	73	293
Nitzschia subtilis	--	--	--	--	--	--
Cymatopleura solea	2	1	2	.8	.1	.7
Surirella angustata	19	75	14	5	191	14
Surirella linearis	5	9	--	--	--	--
Surirella ovata	5	--	14	--	--	--

Table 13. *Numbers of diatoms in periphyton communities of experimental streams of April 7, 1970 (numbers of cells/millimeter^2).*

SPECIES	1-A		1-B		3-A		3-B		5-A		5-B		6-A	
	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD
Stephanodiscus astraea	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Stephanodiscus Hantzschii	293	951	381	686	229	1067	610	1296	659	732	293	805	1171	3147
Melosira granulata	--	--	--	305	--	--	--	--	--	--	--	--	--	--
Melosira italica	659	586	686	381	457	1220	991	1296	1317	1025	659	586	2854	2123
Melosira varians	4224	970	4354	1183	1160	431	1218	390	205	326	168	75	998	555
Tabellaria fenestrata	73	439	152	305	534	457	305	762	146	512	73	366	1098	732
Asterionella formosa	293	586	457	991	--	991	305	686	220	659	586	586	586	1683
Fragilaria construens	4439	1138	4896	1923	17729	4091	5140	874	11908	1865	6737	909	16395	3367
Fragilaria crotonensis	783	653	828	944	1661	950	2156	863	1072	592	1086	559	3735	1674
Fragilaria lepostauron	--	--	--	--	229	381	76	--	--	146	--	--	512	73
Fragilaria vaucheriae	895	154	606	303	2914	874	9978	1748	8560	839	9637	932	177636	11711
Synedra rumpens	73	146	152	152	381	915	76	--	73	--	220	--	146	293
Synedra ulna	28	28	17	47	41	58	64	87	242	112	182	61	247	103
Hannaea arcus	--	--	--	--	--	76	--	--	73	439	293	73	146	366
Achnanthes lanceolata	--	--	--	--	--	229	--	--	366	878	146	73	--	73
Achnanthes lemmermanni	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Achnanthes linearis	293	73	366	73	146	146	73	73	73	220	73	73	1830	2635
Navicula cryptocephala	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Navicula minima	25398	5782	33815	6368	4172	4904	2562	2489	146	439	293	220	439	659
Navicula odiosa	146	220	152	152	152	305	76	76	--	73	--	146	--	73
Stauroneis nana	2196	878	2135	534	--	--	--	--	--	73	--	73	293	73
Gomphonema intricatum	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Gomphonema olivaceum	73	220	76	229	229	457	--	762	1903	1098	2123	439	1903	1025
Gomphonema ventricosum	--	--	--	--	--	--	--	--	293	73	512	73	73	732
Amphora ovalis	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cymbella affinis	--	--	--	--	--	--	--	--	73	--	--	--	--	--
Cymbella turgida	19	19	17	23	12	17	23	12	51	19	42	9	--	--
Cymbella ventricosa	--	73	--	152	--	381	76	610	366	878	220	293	659	878
Epithemia sorex	--	--	--	6	17	6	--	6	--	--	--	5	--	--
Epithemia turgida	6.1	4.1	5.8	1.8	1.3	.4	1.2	.8	.3	.5	.3	.5	.6	2.3
Epithemia zebra	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rhopalodia gibba	177	89	221	163	82	47	23	6	5	--	--	--	--	--
Nitzschia acicularis	--	--	--	--	--	--	--	--	--	--	--	--	146	--
Nitzschia dissipata	220	586	76	534	305	1144	457	305	366	73	--	73	586	1391
Nitzschia fonticola	2123	878	2342	878	6148	8344	5416	4465	20421	13248	13980	3220	17859	6441
Nitzschia frustulum	439	220	839	152	991	3202	534	1067	659	586	512	293	439	586
Nitzschia Kutzingiana	146	146	229	--	152	229	534	610	3952	878	2049	1464	7100	4172
Nitzschia linearis	--	--	12	23	6	6	6	--	5	--	5	--	121	51
Nitzschia palea	73	73	146	73	146	146	146	73	1098	659	732	146	4465	1610
Cymatopleura solea	.3	.3	.4	.4	.6	1.6	.7	1	.7	.8	.8	.6	3	2.3
Surirella angustata	5	9	--	23	6	6	17	12	9	--	9	--	73	586
Surirella linearis	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Surirella ovata	--	--	--	--	--	--	--	--	173	23	135	23	--	73

Table 14. *Numbers of diatoms in periphyton communities of experimental streams of May 14, 1970 (numbers of cells/millimeter^2).*

	STREAM					
	1		3		5	
SPECIES	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD
Stephanodiscus astraea	--	--	--	--	--	
Stephanodiscus Hantzschii	--	1647	--	2562	--	2489
Melosira granulata	--	--	--	--	--	--
Melosira italica	14272	46294	17566	12992	12516	12955
Melosira varians	4301	1364	1208	462	312	173
Tabellaria fenestrata	128	501	275	284	186	210
Asterionella formosa	2562	5489	4209	1830	1537	3001
Fragilaria construens	11085	6912	14011	9173	8590	8824
Fragilaria crotonensis	4919	2681	3683	2716	2611	2296
Fragilaria lepostauron	--	--	--	366	146	146
Fragilaria vaucheriae	1935	653	10758	2203	11504	3846
Synedra rumpens	183	366	--	366	--	146
Synedra ulna	128	105	186	89	75	107
Hannaea arcus	12	35	5	14	12	175
Achnanthes lanceolata	--	--	--	--	--	439
Achnanthes lemmermanni	--	--	--	--	--	--
Achnanthes linearis	732	146	549	183	220	220
Navicula cryptocephala	--	--	--	--	--	--
Navicula minima	65690	12077	46294	22141	3733	4904
Navicula odiosa	--	--	--	--	--	--
Stauroneis nana	9881	7136	4392	3843	73	--
Gomphonema intricatum	--	--	--	--	--	--
Gomphonema olivaceum	--	366	--	183	73	2342
Gomphonema ventricosum	--	--	--	--	--	--
Amphora ovalis	--	--	--	--	--	--
Cymbella affinis	--	--	--	--	--	--
Cymbella turgida	--	--	--	--	--	--
Cymbella ventricosa	--	--	--	915	--	512
Epithemia sorex	186	105	988	107	12	--
Epithemia turgida	6	2	19	3	.4	1
Epithemia zebra	--	--	--	--	--	--
Rhopalodia gibba	781	653	247	84	--	--
Nitzschia acicularis	--	--	--	--	--	--
Nitzschia dissipata	--	1464	366	366	73	659
Nitzschia fonticola	3843	4940	10613	10979	16981	33376
Nitzschia frustulum	549	1281	366	915	878	3879
Nitzschia Kutzingiana	549	366	183	183	805	1903
Nitzschia linearis	--	--	--	--	5	5
Nitzschia palea	366	549	183	549	--	220
Cymatopleura solea	.8	.7	.4	.6	.5	2
Surirella angustata	--	--	5	5	5	14
Surirella linearis	--	--	--	--	--	--
Surirella ovata	35	35	47	33	221	408

Table 15. *Numbers of diatoms in periphyton communities of experimental streams of June 1, 1970 (numbers of cells/millimeter^2).*

SPECIES	STREAM 1A LIVE	 DEAD	 3A LIVE	 DEAD	 5A LIVE	 DEAD
Stephanodiscus astraea	--	--	--	--	--	--
Stephanodiscus Hantzschii	220	3586	146	4465	439	5354
Melosira granulata	--	--	--	--	--	--
Melosira italica	3733	32351	5636	20347	4245	15297
Melosira varians	1133	415	340	131	153	135
Tabellaria fenestrata	146	1391	439	732	242	182
Asterionella formosa	293	2562	1098	4026	659	2415
Fragilaria construens	2879	2739	3963	3138	2093	2420
Fragilaria crotonensis	1247	7203	1623	2928	1198	1674
Fragilaria lepostauron	--	--	--	--	--	--
Fragilaria vaucheriae	1387	991	1776	979	606	452
Synedra rumpens	146	73	73	146	293	146
Synedra ulna	84	168	149	182	289	140
Hannaea arcus	--	--	--	--	5	42
Achnanthes lanceolata	--	--	--	146	--	73
Achnanthes lemmermanni	--	--	--	--	--	--
Achnanthes linearis	659	732	146	1464	732	1830
Navicula cryptocephala	--	--	--	--	--	--
Navicula minima	1098	878	220	1098	--	--
Navicula odiosa	--	73	--	73	73	146
Stauroneis nana	73	73	--	73	--	--
Gomphonema intricatum	--	--	--	--	--	--
Gomphonema olivaceum	--	73	146	659	--	146
Gomphonema ventricosum	--	146	730	2196	28	42
Amphora ovalis	--	73	--	146	--	366
Cymbella affinis	--	--	--	--	--	--
Cymbella turgida	--	--	--	--	--	--
Cymbella ventricosa	--	146	73	586	28	51
Epithemia sorex	233	98	79	61	--	--
Epithemia turgida	.39	.39	2	1.5	.7	1.2
Epithemia zebra	28	9	--	--	--	--
Rhopalodia gibba	2056	718	280	14	--	--
Nitzschia acicularis	--	--	--	--	--	--
Nitzschia dissipata	146	293	73	220	72	220
Nitzschia fonticola	2854	5563	2781	4977	2342	3586
Nitzschia frustulum	73	293	--	293	--	293
Nitzschia Kutzingiana	586	586	1903	4684	220	2196
Nitzschia linearis	--	--	--	--	23	5
Nitzschia palea	146	220	2781	4977	732	439
Nitzschia subtilis	--	--	--	--	--	--
Cymatopleura solea	.2	1	1	2	1	2.3
Surirella angustata	5	33	19	37	9	19
Surirella linearis	--	--	--	--	--	--
Surirella ovata	37	326	186	275	532	159

Table 16. *Numbers of diatoms in periphyton communities of experimental streams of July 30, 1970 (numbers of cells/millimeter^2).*

SPECIES	1-A		1-B		3-A		3-B		5-A		5-B		6-A		7-A	
	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD
Stephanodiscus astraea	--	--	--	--	--	586	--	--	73	439	--	220	--	--	--	--
Stephanodiscus Hantzschii	--	146	--	293	--	1391	73	951	73	1171	--	805	73	3147	73	1098
Melosira granulata	--	--	--	--	--	--	--	73	--	--	--	--	--	--	--	--
Melosira italica	659	5416	512	4831	439	7246	293	7539	1976	5563	1025	4172	3001	8563	177	909
Melosira varians	191	131	303	340	3641	872	4457	1096	5007	825	4467	592	3860	853	1156	294
Tabellaria fenestrata	28	657	33	853	280	774	210	713	499	737	368	522	373	1058	14	275
Asterionella formosa	--	33	--	146	--	659	73	439	146	732	73	512	220	805	73	146
Fragilaria construens	186	518	242	1124	2098	811	4418	4429	3856	1609	7833	2424	8817	3469	3259	3287
Fragilaria crotonensis	410	3935	326	5534	2285	3170	1860	3324	1753	2774	2257	2387	1664	3100	322	713
Fragilaria lepostauron	--	--	--	--	--	--	--	--	73	146	73	--	73	73	73	--
Fragilaria vaucheriae	84	98	--	75	168	121	504	191	326	56	340	135	173	214	23	112
Synedra rumpens	--	--	--	--	72	512	293	220	366	73	731	293	73	732	220	220
Synedra ulna	--	19	9	28	47	65	42	65	84	191	65	103	33	117	47	23
Hannaea arcus	--	--	--	--	--	--	--	--	--	--	--	--	--	14	--	9
Achnanthes lanceolata	--	--	--	--	--	293	--	--	--	73	--	73	--	73	73	--
Achnanthes lemmermanni	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Achnanthes linearis	586	878	439	731	586	1171	586	1025	805	951	952	1464	805	1903	293	1244
Navicula cryptocephala	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Navicula minima	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Navicula odiosa	--	--	--	--	73	146	73	220	73	73	73	--	146	146	--	--
Stauroneis nana	--	293	--	293	--	--	--	73	--	--	--	--	--	73	--	--
Gomphonema intricatum	--	--	--	73	--	--	--	--	--	--	--	--	--	--	--	146
Gomphonema olivaceum	--	73	--	--	--	220	--	--	--	146	--	--	--	366	--	--
Gomphonema ventricosum	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Amphora ovalis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cymbella affinis	--	73	--	--	--	--	--	73	--	--	--	--	--	--	--	--
Cymbella turgida	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cymbella ventricosa	--	73	--	--	--	--	--	146	--	--	--	73	--	--	--	--
Epithemia sorex	--	23	--	9	200	79	284	121	601	270	1161	340	5	14	685	214
Epithemia turgida	.5	2.2	.7	3.7	1.6	5.1	6.7	5.3	12.6	5.8	14.9	5.6	1.1	4.3	11	3.1
Epithemia zebra	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rhopalodia gibba	2569	811	1991	681	1035	448	2611	569	359	149	532	112	9	9	154	33
Nitzschia acicularis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Nitzschia dissipata	--	73	--	--	--	--	--	--	73	146	--	220	146	366	--	--
Nitzschia fonticola	--	--	--	--	73	73	--	73	--	146	73	73	293	1025	293	512
Nitzschia frustulum	--	--	--	--	--	--	--	146	146	146	73	146	146	146	--	73
Nitzschia Kutzingiana	--	73	220	293	878	512	220	293	366	146	295	586	146	586	73	293
Nitzschia linearis	--	73	--	--	5	5	--	--	28	--	5	--	19	5	--	9
Nitzschia palea	293	1317	731	2415	1025	805	586	805	731	659	951	805	220	586	439	586
Cymatopleura solea	.3	.6	.1	.7	.3	.7	.1	1.1	1.1	1.4	1.1	1.6	1.9	2.1	.3	.9
Surirella angustata	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Surirella linearis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-
Surirella ovata	--	--	--	--	--	9	--	--	9	5	--	14	--	33	--	--

Table 17. *Numbers of diatoms in periphyton communities of experimental streams of August 24, 1970 (numbers of cells/millimeter^2).*

SPECIES	STREAM 1 LIVE	 DEAD	 3 LIVE	 DEAD	 5 LIVE	 DEAD
Stephanodiscus astraea	--	--	--	--	--	--
Stephanodiscus Hantzschii	--	1171	--	1025	73	1610
Melosira granulata	--	--	--	--	--	73
Melosira italica	146	1610	--	1464	73	1903
Melosira varians	9432	1082	2797	620	8765	1408
Tabellaria fenestrata	79	536	65	214	84	420
Asterionella formosa	293	3440	73	1025	366	3586
Fragilaria construens	732	1063	1436	1063	2895	2187
Fragilaria crotonensis	704	1226	937	807	2037	1304
Fragilaria lepostauron	--	--	--	--	--	--
Fragilaria vaucheriae	611	522	261	56	3124	1184
Synedra rumpens	293	1464	366	1171	512	1391
Synedra ulna	9	65	33	23	65	93
Hannaea arcus	--	9	--	9	--	--
Achnanthes lanceolata	--	--	--	--	--	--
Achnanthes lemmermanni	--	--	--	--	--	--
Achnanthes linearis	293	951	366	878	878	512
Navicula cryptocephala	--	--	--	--	--	--
Navicula minima	586	439	--	--	--	--
Navicula odiosa	73	73	--	--	--	--
Stauroneis nana	73	73	--	146	--	--
Gomphonema intricatum	--	--	--	--	--	--
Gomphonema olivaceum	--	--	--	73	--	--
Gomphonema ventricosum	--	--	--	--	--	146
Amphora ovalis	--	--	--	--	--	--
Cymbella affinis	186	182	--	5	--	9
Cymbella turgida	--	--	--	--	--	--
Cymbella ventricosum	--	73	--	--	--	--
Epithemia sorex	5	79	312	84	1786	79
Epithemia turgida	--	11.2	3.2	4.9	12.7	8.2
Epithemia zebra	--	--	--	--	--	--
Rhopalodia gibba	956	555	1021	270	625	182
Nitzschia acicularis	--	--	--	--	--	--
Nitzschia dissipata	--	--	--	--	146	146
Nitzschia fonticola	--	--	--	--	--	--
Nitzschia frustulum	73	--	--	146	--	73
Nitzschia Kutzingiana	146	366	439	439	512	878
Nitzschia linearis	9	14	--	14	28	5
Nitzschia palea	2196	9588	732	2708	512	1171
Cymatopleura solea	.2	.8	.3	.4	.6	.4
Surirella angustata	--	--	--	--	--	--
Surirella linearis	--	--	--	--	--	--
Surirella ovata	--	9	--	9	--	9

Table 18. *Numbers of diatoms in periphyton communities of experimental streams of September 21, 1970 (numbers of cells/millimeter^2).*

SPECIES	1-A LIVE	1-A DEAD	1-B LIVE	1-B DEAD	3-A LIVE	3-A DEAD	3-B LIVE	3-B DEAD	5-A LIVE	5-A DEAD	5-B LIVE	5-B DEAD
Stephanodiscus astraea	--	--	--	--	--	--	--	--	--	--	--	--
Stephanodiscus Hantzschii	73	5416	512	8563	366	3733	146	3220	805	2196	146	3733
Melosira granulata	439	--	--	951	220	659	659	293	--	293	146	146
Melosira italica	586	6880	1391	5343	878	2708	878	4098	1317	3074	366	1464
Melosira varians	9661	5855	13614	6514	6066	2695	6938	2294	12881	5489	10247	3879
Tabellaria fenestrata	--	1830	--	1683	73	512	--	1464	--	951	220	439
Asterionella formosa	73	3513	439	3806	366	1903	--	659	439	1171	146	512
Fragilaria construens	1958	2294	3040	988	3338	499	4164	3166	4597	2350	4602	839
Fragilaria crotonensis	382	499	280	699	792	877	597	1417	821	1012	886	396
Fragilaria lepostauron	--	--	--	73	--	--	--	--	--	--	--	--
Fragilaria vaucheriae	396	611	1231	998	2993	741	1585	597	1734	631	1949	294
Synedra rumpens	203	486	293	146	146	732	146	586	293	1171	293	1025
Synedra ulna	37	140	56	145	37	51	37	47	70	103	112	75
Hannaea arcus	--	73	--	--	--	73	--	--	--	--	--	--
Achnanthes lanceolata	--	73	--	--	--	--	--	--	--	--	--	7
Achnanthes lemmermanni	--	--	--	--	--	--	--	--	--	--	--	--
Achnanthes linearis	1024	3950	4538	3806	9076	3952	11198	4318	3001	3074	2123	1756
Navicula cryptocephala	73	586	439	439	146	293	73	73	146	73	220	73
Navicula minima	--	--	--	--	--	--	--	--	--	--	--	--
Navicula odiosa	--	293	293	878	146	73	73	73	146	73	220	73
Stauroneis nana	--	220	--	586	--	293	73	--	220	220	146	146
Gomphonema intricatum	--	439	--	146	--	73	--	--	--	--	--	--
Gomphonema olivaceum	--	73	--	146	--	--	--	73	--	--	--	--
Gomphonema ventricosum	--	--	--	--	--	--	--	--	--	--	--	--
Amphora ovalis	--	--	--	--	--	--	--	--	--	--	--	--
Cymbella affinis	1244	1025	805	1683	--	--	--	73	--	--	--	--
Cymbella turgida	--	--	--	--	--	--	--	--	--	--	--	--
Cymbella ventricosa	--	146	--	293	--	73	--	73	--	--	--	73
Epithemia sorex	--	293	--	366	439	659	354	303	4538	3147	4684	2781
Epithemia turgida	2.3	27.3	1.8	22.6	9.3	13.5	25.6	13.8	41.3	12.6	23.1	14.5
Epithemia zebra	--	--	--	--	--	--	--	--	--	--	--	--
Rhopalodia gibba	891	871	2629	1548	671	867	667	821	366	951	42	145
Nitzschia acicularis	--	--	--	--	--	--	--	--	--	--	--	--
Nitzschia dissipata	73	1830	--	732	439	951	73	439	366	293	1244	586
Nitzschia fonticola	--	220	--	220	73	220	146	439	146	220	146	366
Nitzschia Kutzingiana	220	366	146	366	439	512	366	512	293	585	366	512
Nitzschia linearis	--	--	--	--	--	--	--	--	--	--	--	--
Nitzschia palea	1903	10906	4099	15736	586	1610	659	805	586	659	1317	1025
Nitzschia subtilis	146	146	--	146	73	293	--	73	--	--	--	--
Cymatopleura solea	.4	1.6	.7	1.1	2.6	2.3	.9	1.1	.7	1.4	.9	.9
Surirella angustata	--	--	--	73	--	--	--	--	--	--	--	--
Surirella linearis	--	--	--	--	--	--	--	--	--	--	--	--
Surirella ovata	--	--	--	--	--	--	--	--	--	--	--	--

Table 19. *Numbers of diatoms in periphyton communities of experimental streams of October 26, 1970 (numbers of cells/millimeter^2).*

SPECIES	1-A		3-A		5-A		6-A	
	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD
Stephanodiscus astraea	--	--	--	--	--	--	--	--
Stephanodiscus Hantzschii	146	3806	73	6734	293	4099	512	6002
Melosira granulata	--	293	220	805	146	73	--	--
Melosira italica	439	1464	220	1537	293	1610	512	1683
Melosira varians	3003	1571	7861	2406	5548	3017	2555	737
Tabellaria fenestrata	14	131	--	107	--	112	5	163
Asterionella formosa	--	805	146	732	146	951	146	439
Fragilaria construens	3571	1837	8546	4047	9311	1870	3562	881
Fragilaria crotonensis	1180	1324	1497	988	1888	788	863	326
Fragilaria lepostauron	--	--	--	--	--	--	366	--
Fragilaria vaucheriae	476	205	2382	1389	2355	550	331	117
Synedra rumpens	--	732	73	366	512	586	220	805
Synedra ulna	145	103	163	173	182	98	84	47
Hannaea arcus	--	--	--	5	--	--	--	--
Achnanthes lanceolata	--	--	--	73	--	--	--	73
Achnanthes lemmermanni	366	146	--	--	--	--	--	--
Achnanthes linearis	1464	1098	9369	6148	2196	3513	2708	3294
Navicula cryptocephala	220	220	--	--	--	73	220	--
Navicula minima	6002	4318	--	--	--	--	--	--
Navicula odiosa	1025	220	512	293	1244	293	220	220
Stauroneis nana	586	366	73	73	73	73	732	220
Gomphonema intricatum	--	73	--	73	--	--	--	--
Gomphonema olivaceum	--	73	--	293	--	73	--	--
Gomphonema ventricosum	--	--	--	--	--	--	--	--
Amphora ovalis	--	--	--	--	--	--	--	--
Cymbella affinis	1893	811	61	75	--	--	--	--
Cymbella turgida	--	--	--	--	--	--	--	--
Cymbella ventricosa	--	--	--	--	--	146	--	73
Epithemia sorex	9	107	597	489	681	559	9	19
Epithemia turgida	.9	15.7	7	12.3	10.8	10.8	1.2	3
Epithemia zebra	--	293	--	--	5	5	--	--
Rhopalodia gibba	149	438	322	564	79	79	--	42
Nitzschia acicularis	--	--	--	--	--	--	220	--
Nitzschia dissipata	73	366	146	951	951	439	220	512
Nitzschia fonticola	--	293	146	146	293	146	732	659
Nitzschia frustulum	--	73	73	--	--	220	--	--
Nitzschia Kutzingiana	439	146	512	146	586	366	805	146
Nitzschia linearis	5	5	19	5	76	14	37	5
Nitzschia palea	3879	3220	3367	3147	3513	2196	951	586
Nitzschia subtilis	366	220	659	1025	366	73	--	--
Cymatopleura solea	.3	2.1	2.2	2	1.7	.9	1.8	.3
Surirella linearis	--	--	--	--	--	--	--	--
Surirella ovata	--	--	--	--	--	--	--	--
Amphipleura pellucida	--	--	--	--	--	--	14	9

Table 20. *Species biovolumes of experimental stream periphyton communities of November 17, 1969 (cubic microns/millimeter^2).*

Species	1-A	3-A	5-A
Microcystis sp.	220	--	--
Schizothrix calcicola	69	24	50
Oscillatoria sp.	--	--	--
Anabaena sp.	--	--	--
Calothrix sp.	--	--	--
Stephanodiscus astraea	--	--	--
Stephanodiscus Hantzschii	--	--	--
Melosira granulata	435	435	145
Melosira italica	42	--	--
Melosira varians	18561	40617	39906
Tabellaria fenestrata	--	--	--
Asterionella formosa	--	--	--
Fragilaria construens	1133	1516	1909
Fragilaria crotonensis	325	289	275
Fragilaria lepostauron	--	--	43
Fragilaria vaucheriae	125	48	235
Synedra rumpens	55	55	220
Synedra ulna	--	53	217
Hannaea arcus	--	--	--
Achnanthes lanceolata	--	9	17
Achnanthes lemmermanni	--	--	--
Achnanthes linearis	84	26	70
Navicula cryptocephala	51	--	--
Navicula minima	367	110	87
Navicula odiosa	108	24	12
Stauroneis nana	45	--	--
Gomphonema intricatum	--	--	--
Gomphonema olivaceum	--	--	--
Gomphonema ventricosum	--	--	--
Amphora ovalis	--	--	--
Cymbella affinis	25	27	5
Cymbella turgida	--	--	--
Cymbella ventricosa	--	--	--
Epithemia sorex	82	--	--
Epithemia turgida	67	10	8
Epithemia zebra	--	--	--
Rhopalodia gibba	180	49	--
Nitzschia acicularis	45	--	15
Nitzschia dissipata	22	180	603
Nitzschia fonticola	--	--	--
Nitzschia frustulum	199	99	347
Nitzschia Kutzingiana	6	3	59
Nitzschia linearis	64	94	94
Nitzschia palea	122	108	460
Nitzschia subtilis	--	--	--
Cymatopleura solea	149	138	148
Surirella angustata	9	--	22
Surirella linearis	--	--	--
Surirella ovata	--	--	--
Ulothrix sp.	--	--	--
Stigeoclonium lubricum	--	--	--
Oedogonium sp.	--	--	--
Mougeotia sp.	--	--	--
Spirogyra sp.	--	--	--

Table 21. *Species biovolumes of experimental stream periphyton communities of December 29, 1969 (cubic microns/millimeter^2).*

Species	1-A	3-A	5-A
Microcystis sp.	--	--	--
Schizothrix calcicola	121	37	11
Oscillatoria sp.	380	--	--
Anabaena sp.	--	--	--
Calothrix sp.	--	--	--
Stephanodiscus astraea	--	--	--
Stephanodiscus Hantzschii	6	6	19
Melosira granulata	--	--	363
Melosira italica	59	298	119
Melosira varians	20076	21041	22243
Tabellaria fenestrata	24	10	--
Asterionella formosa	35	35	35
Fragilaria construens	958	953	2633
Fragilaria crotonensis	222	169	487
Fragilaria lepostauron	--	--	--
Fragilaria vaucheriae	22	165	976
Synedra rumpens	110	55	55
Synedra ulna	193	433	627
Hannaea arcus	--	--	--
Achnanthes lanceolata	--	--	10
Achnanthes lemmermanni	--	--	--
Achnanthes linearis	64	48	6
Navicula cryptocephala	--	51	--
Navicula minima	2055	946	42
Navicula odiosa	60	72	216
Stauroneis nana	427	427	270
Gomphonema intricatum	--	--	--
Gomphonema olivaceum	--	--	--
Gomphonema ventricosum	--	--	--
Amphora ovalis	--	--	--
Cymbella affinis	--	3	5
Cymbella turgida	--	--	--
Cymbella ventricosa	--	--	--
Epithemia sorex	--	--	--
Epithemia turgida	27	33	19
Epithemia zebra	--	--	--
Rhopalodia gibba	242	--	--
Nitzschia acicularis	--	--	15
Nitzschia dissipata	157	359	809
Nitzschia fonticola	--	--	--
Nitzschia frustulum	--	695	1836
Nitzschia Kutzingiana	9	18	41
Nitzschia linearis	124	141	922
Nitzschia palea	149	244	352
Nitzschia subtilis	--	--	--
Cymatopleura solea	163	196	151
Surirella angustata	13	--	22
Surirella linearis	15	--	--
Surirella ovata	--	--	--
Ulothrix sp.	--	--	--
Stigeoclonium lubricum	--	--	--
Oedogonium sp.	--	--	--
Mougeotia sp.	--	--	--
Spirogyra sp.	--	--	--

Table 22. *Species biovolumes of experimental stream periphyton communities of January 29, 1970 (cubic microns/millimeter^2).*

Species	1-A	1-B	3-A	3-B	5-A	5-B	6-A
Microcystis sp.	--	--	--	--	--	--	--
Schizothrix calcicola	124	161	32	50	37	8	29
Oscillatoria sp.	925	925	--	--	--	--	--
Anabaena sp.	--	--	--	--	--	--	--
Calothrix sp.	--	--	--	--	--	--	--
Stephanodiscus astraea	--	--	--	--	--	--	--
Stephanodiscus Hantzschii	--	6	6	--	--	2	6
Melosira granulata	--	--	943	--	--	33	--
Melosira italica	179	--	--	119	76	34	59
Melosira varians	20390	23408	11486	10789	2956	4170	14295
Tabellaria fenestrata	50	42	65	114	80	69	466
Asterionella formosa	--	--	--	--	35	--	69
Fragilaria construens	594	719	1526	1077	915	1249	3179
Fragilaria crotonensis	153	164	397	471	448	531	563
Fragilaria lepostauron	--	--	43	--	--	130	--
Fragilaria vaucheriae	110	103	378	384	161	462	56383
Synedra rumpens	--	--	--	--	--	--	92
Synedra ulna	217	299	299	439	53	193	164
Hannaea arcus	82	--	82	--	--	248	164
Achnanthes lanceolata	10	19	97	29	10	29	--
Achnanthes lemmermanni	--	3	--	--	--	--	--
Achnanthes linearis	29	19	64	27	23	19	10
Navicula cryptocephala	--	26	51	51	51	--	--
Navicula minima	2122	1230	1288	498	216	167	87
Navicula odiosa	24	24	24	96	48	144	36
Stauroneis nana	1371	1393	539	944	--	--	45
Gomphonema intricatum	--	--	--	20	--	--	--
Gomphonema olivaceum	--	--	--	--	--	54	27
Gomphonema ventricosum	--	--	--	77	--	--	--
Amphora ovalis	--	--	--	--	4	--	--
Cymbella affinis	--	--	--	--	--	--	--
Cymbella turgida	--	--	--	--	--	--	--
Cymbella ventricosa	37	--	--	--	147	--	--
Epithemia sorex	--	--	25	--	9	33	--
Epithemia turgida	17	21	33	69	33	19	--
Epithemia zebra	--	--	--	--	--	--	--
Rhopalodia gibba	--	199	164	78	78	--	3
Nitzschia acicularis	--	--	15	--	--	--	403
Nitzschia dissipata	90	112	180	359	1371	1528	292
Nitzschia fonticola	41	122	311	596	366	610	65
Nitzschia frustulum	99	149	546	298	199	298	199
Nitzschia Kutzingiana	3	18	18	23	12	12	788
Nitzschia linearis	77	77	47	111	94	141	171
Nitzschia palea	--	27	135	298	135	149	585
Nitzschia subtilis	--	--	--	--	--	--	--
Cymatopleura solea	67	32	45	93	32	51	96
Surirella angustata	72	67	121	162	9	40	5455
Surirella linearis	--	--	41	63	--	--	--
Surirella ovata	--	--	--	--	--	40	1519
Ulothrix sp.	--	--	--	--	--	--	--
Stigeoclonium lubricum	--	--	--	--	--	--	--
Oedogonium sp.	--	--	--	--	--	--	--
Mougeotia sp.	--	--	--	--	--	--	--
Spirogyra sp.	--	--	--	--	--	--	120

Table 23. *Species biovolumes of experimental stream periphyton communities of March 3, 1970 (cubic microns/millimeter^2).*

Species	1-A	3-A	5-A
Microcystis sp.	--	--	--
Schizothrix calcicola	181	118	--
Oscillatoria sp.	790	--	--
Anabaena sp.	--	--	--
Calothrix sp.	--	--	--
Stephanodiscus astraea	--	--	--
Stephanodiscus Hantzschii	44	44	10
Melosira granulata	145	145	--
Melosira italica	369	460	--
Melosira varians	25330	6386	1510
Tabellaria fenestrata	332	224	61
Asterionella formosa	142	71	71
Fragilaria construens	1118	21027	1136
Fragilaria crotonensis	1795	1426	108
Fragilaria lepostauron	26	155	155
Fragilaria vaucheriae	113	1290	349
Synedra rumpens	74	55	--
Synedra ulna	444	343	79
Hannaea arcus	--	6	16
Achnanthes lanceolata	10	--	19
Achnanthes lemmermanni	--	--	--
Achnanthes linearis	42	35	13
Navicula cryptocephala	--	--	--
Navicula minima	4216	1630	264
Navicula odiosa	180	72	36
Stauroneis nana	3903	954	89
Gomphonema intricatum	61	101	--
Gomphonema olivaceum	25	75	50
Gomphonema ventricosum	--	--	--
Amphora ovalis	11	--	--
Cymbella affinis	--	--	--
Cymbella turgida	--	--	--
Cymbella ventricosa	110	696	330
Epithemia sorex	--	65	--
Epithemia turgida	41	82	8
Epithemia zebra	--	--	--
Rhopalodia gibba	125	125	--
Nitzschia acicularis	15	--	30
Nitzschia dissipata	370	331	97
Nitzschia fonticola	190	3114	555
Nitzschia frustulum	149	1389	993
Nitzschia Kutzingiana	42	119	28
Nitzschia linearis	345	71	28
Nitzschia palea	24	311	14
Nitzschia subtilis	--	--	--
Cymatopleura solea	64	64	3
Surirella angustata	18	13	18
Surirella linearis	23	--	--
Surirella ovata	12	34	--
Ulothrix sp.	--	--	--
Stigeoclonium lubricum	--	--	--
Oedogonium sp.	--	--	--
Mougeotia sp.	--	--	--
Spirogyra sp.	--	--	--

Table 24. *Species biovolumes of experimental stream periphyton communities of April 7, 1970 (cubic microns/millimeter^2).*

Species	1-A	1-B	3-A	3-B	5-A	5-B	6-A
Microcystis sp.	--	--	--	--	--	--	--
Schizothrix calcicola	103	118	51	36	--	--	83
Oscillatoria sp.	345	494	--	--	--	--	--
Anabaena sp.	--	--	--	--	--	--	--
Calothrix sp.	--	--	--	--	--	--	--
Stephanodiscus astraea	--	--	--	--	--	--	--
Stephanodiscus Hantzschii	20	26	15	41	44	20	78
Melosira granulata	--	--	--	--	--	--	--
Melosira italica	415	431	289	623	828	415	1795
Melosira varians	11210	11556	3079	3233	544	446	2649
Tabellaria fenestrata	95	197	692	395	189	95	1423
Asterionella formosa	142	221	--	148	106	284	284
Fragilaria construens	728	803	2908	843	1953	1105	2689
Fragilaria crotonensis	431	455	914	1186	590	597	2054
Fragilaria lepostauron	--	--	81	27	--	--	181
Fragilaria vaucheriae	224	152	729	2495	2140	2409	44409
Synedra rumpens	18	38	96	19	18	55	37
Synedra ulna	157	96	230	360	1360	1023	1388
Hannaea arcus	--	--	--	--	73	292	146
Achnanthes lanceolata	--	--	--	--	101	40	--
Achnanthes lemmermanni	--	--	--	--	--	--	--
Achnanthes linearis	13	16	6	3	3	3	81
Navicula cryptocephala	--	--	--	--	--	--	--
Navicula minima	1118	1488	184	113	6	13	19
Navicula odiosa	24	25	25	12	--	--	--
Stauroneis nana	665	647	--	--	--	--	89
Gomphonema intricatum	--	--	--	--	--	--	--
Gomphonema olivaceum	25	26	78	--	649	724	649
Gomphonema ventricosum	--	--	--	--	308	538	77
Amphora ovalis	--	--	--	--	--	--	--
Cymbella affinis	--	--	--	--	39	--	--
Cymbella turgida	58	52	37	70	155	128	--
Cymbella ventricosa	--	--	--	38	183	110	330
Epithemia sorex	--	--	30	--	--	--	--
Epithemia turgida	128	122	27	25	6	6	13
Epithemia zebra	--	--	--	--	--	--	--
Rhopalodia gibba	341	425	158	44	10	--	--
Nitzschia acicularis	--	--	--	--	--	--	15
Nitzschia dissipata	59	20	81	122	97	--	156
Nitzschia fonticola	393	433	1137	1002	3778	2586	3304
Nitzschia frustulum	298	569	672	362	447	347	298
Nitzschia Kutzingiana	14	22	15	51	379	197	682
Nitzschia linearis	--	37	18	18	15	15	373
Nitzschia palea	14	27	27	27	203	135	719
Nitzschia subtilis	--	--	--	--	--	--	--
Cymatopleura solea	10	13	19	23	22	25	96
Surirella angustata	5	--	6	16	9	9	70
Surirella linearis	--	--	--	--	--	--	--
Surirella ovata	--	--	--	--	417	325	--
Ulothrix sp.	--	--	--	--	--	--	--
Stigeoclonium lubricum	--	--	157	222	427	404	222
Oedogonium sp.	--	--	--	--	--	--	--
Mougeotia sp.	--	--	--	--	--	--	--
Spirogyra sp.	--	--	--	--	--	--	--

Table 25. *Species biovolumes of experimental stream periphyton communities of May 14, 1970 (cubic microns/millimeter^2).*

Species	1-A	3-A	5-A
Microcystis sp.	--	--	--
Schizothrix calcicola	392	380	15
Oscillatoria sp.	494	--	--
Anabaena sp.	--	--	--
Calothrix sp.	--	--	--
Stephahodiscus astraea	--	--	--
Stephanodiscus Hantzschii	--	--	--
Melosira granulata	--	--	--
Melosira italica	8977	11049	7873
Melosira varians	11415	3206	828
Tabellaria fenestrata	166	356	241
Asterionella formosa	1240	2037	744
Fragilaria construens	1818	2298	1409
Fragilaria crotonensis	2705	2026	1436
Fragilaria lepostauron	--	--	52
Fragilaria vaucheriae	484	2690	2876
Synedra rumpens	46	--	--
Synedra ulna	719	1045	421
Hannaea arcus	12	5	12
Achnanthes lanceolata	--	--	--
Achnanthes lemmermanni	--	--	--
Achnanthes linearis	32	24	10
Navicula cryptocephala	--	--	--
Navicula minima	2890	2037	164
Navicula odiosa	90	90	--
Stauroneis nana	2994	1331	22
Gomphonema intricatum	--	--	--
Gomphonema olivaceum	--	--	25
Gomphonema ventricosum	--	--	--
Amphora ovalis	--	10	--
Cymbella affinis	--	--	--
Cymbella turgida	--	--	--
Cymbella ventricosa	--	--	--
Epithemia sorex	326	1734	21
Epithemia turgida	126	400	8
Epithemia zebra	--	--	--
Rhopalodia gibba	1503	475	--
Nitzschia acicularis	--	--	--
Nitzschia dissipata	--	97	19
Nitzschia fonticola	711	1963	3141
Nitzschia frustulum	372	248	595
Nitzschia Kutzingiana	53	18	77
Nitzschia linearis	--	--	15
Nitzschia palea	68	34	--
Nitzschia subtilis	--	--	--
Cymatopleura solea	26	13	16
Surirella angustata	--	5	5
Surirella linearis	--	--	--
Surirella ovata	87	116	548
Ulothrix sp.	--	--	--
Stigeoclonium lubricum	--	--	--
Oedogonium sp.	--	--	--
Mougeotia sp.	--	--	--
Spirogyra sp.	--	--	--

Table 26. *Species biovolumes of experimental stream periphyton communities of June 1, 1970 (cubic microns/millimeter^2).*

Species	1-A	3-A	5-A
Microcystis sp.	--	--	--
Schizothrix calcicola	739	265	--
Oscillatoria sp.	296	--	--
Anabaena sp.	950	--	--
Calothrix sp.	--	--	--
Stephanodiscus astraea	--	--	--
Stephanodiscus Hantzschii	22	15	44
Melosira granulata	--	--	--
Melosira italica	2128	3213	2420
Melosira varians	5014	1505	681
Tabellaria fenestrata	184	552	789
Asterionella formosa	88	329	198
Fragilaria construens	435	598	316
Fragilaria crotonensis	556	724	534
Fragilaria lepostauron	--	--	--
Fragilaria vaucheriae	409	524	179
Synedra rumpens	37	18	74
Synedra ulna	448	794	1541
Hannaea arcus	--	--	5
Achnanthes lanceolata	--	--	--
Achnanthes lemmermanni	--	--	--
Achnanthes linearis	29	6	27
Navicula cryptocephala	--	--	--
Navicula minima	48	10	--
Navicula odiosa	--	--	12
Stauroneis nana	22	--	--
Gomphonema intricatum	--	--	--
Gomphonema olivaceum	--	59	--
Gomphonema ventricosum	--	767	29
Amphora ovalis	--	--	--
Cymbella affinis	--	--	--
Cymbella turgida	--	--	--
Cymbella ventricosa	--	37	14
Epithemia sorex	409	139	--
Epithemia turgida	8	41	14
Epithemia zebra	153	--	--
Rhopalodia gibba	11187	1523	--
Nitzschia acicularis	--	--	--
Nitzschia dissipata	42	21	21
Nitzschia fonticola	528	514	433
Nitzschia frustulum	49	--	--
Nitzschia Kutzingiana	42	135	16
Nitzschia linearis	--	--	69
Nitzschia palea	27	41	135
Nitzschia subtilis	--	--	--
Cymatopleura solea	6	32	32
Surirella angustata	5	18	9
Surirella linearis	--	--	--
Surirella ovata	89	448	1283
Ulothrix sp.	--	--	7186
Stigeoclonium lubricum	--	--	--
Oedogonium sp.	--	--	--
Mougeotia sp.	--	--	--
Spirogyra sp.	6434	--	--

Table 27. *Species biovolumes of experimental stream periphyton communities of July 30, 1970 (Cubic microns/millimeter^2).*

	1-A	1-B	3-A	3-B	5-A	5-B	6-A	7-A
Microcystis sp.	32	13	--	8	4	6	--	--
Schizothrix calcicola	143	86	373	466	194	172	--	108
Oscillatoria sp.	--	--	--	--	--	--	--	--
Anabaena sp.	663	30	75	166	75	105	--	196
Calothrix sp.	476	359	63	64	40	17	--	--
Stephanodiscus astraea	--	--	--	--	73	--	--	--
Stephanodiscus Hantzschii	--	--	--	7	7	--	7	7
Melosira granulata	--	--	--	--	--	--	--	--
Melosira italica	376	292	250	167	1126	584	1711	101
Melosira varians	845	1341	16111	19722	22156	19766	17081	5115
Tabellaria fenestrata	35	42	352	264	628	486	469	18
Asterionella formosa	--	--	--	22	44	22	66	22
Fragilaria construens	28	37	317	667	582	1183	1331	492
Fragilaria crotonensis	182	145	1019	830	782	1007	742	144
Fragilaria lepostauron	--	--	--	--	30	30	30	30
Fragilaria vaucheriae	25	--	50	149	96	100	51	7
Synedra rumpens	--	--	18	74	92	183	18	55
Synedra ulna	29	48	251	253	448	347	176	251
Hannaea arcus	--	--	--	--	--	--	--	--
Achnanthes lanceolata	--	--	--	--	--	--	--	9
Achnanthes lemmermanni	--	--	--	--	--	--	--	--
Achnanthes linearis	22	16	22	22	30	35	30	11
Navicula cryptocephala	--	--	--	--	--	--	--	--
Navicula minima	--	--	--	--	--	--	--	--
Navicula odiosa	--	--	12	12	12	12	24	--
Stauroneis nana	--	--	--	--	--	--	--	--
Gomphonema intricatum	--	--	--	--	--	--	--	--
Gomphonema olivaceum	--	--	--	--	--	--	--	--
Gomphonema ventricosum	--	--	--	--	--	--	--	--
Amphora ovalis	--	--	--	--	--	--	--	--
Cymbella affinis	--	--	--	--	--	--	--	--
Cymbella turgida	--	--	--	--	--	--	--	--
Cymbella ventricosa	--	--	--	--	--	--	--	--
Epithemia sorex	--	--	351	498	1055	2038	9	1202
Epithemia turgida	10	14	124	136	256	303	202	224
Epithemia zebra	--	--	--	--	--	--	--	--
Rhopalodia gibba	13978	10833	5631	14206	1953	2895	49	838
Nitzschia acicularis	--	--	--	--	--	--	--	--
Nitzschia dissipata	--	--	--	--	21	--	42	21
Nitzschia fonticola	--	--	14	--	--	14	54	54
Nitzschia frustulum	--	--	--	--	99	49	99	--
Nitzschia Kutzingiana	--	16	62	16	26	21	10	5
Nitzschia linearis	--	--	14	--	79	14	53	--
Nitzschia palea	40	100	140	80	100	130	41	81
Nitzschia subtilis	--	--	--	--	--	--	--	--
Cymatopleura solea	10	3	10	3	34	34	61	10
Surirella angustata	--	--	--	--	--	--	--	--
Surirella linearis	--	--	--	--	--	--	--	--
Surirella ovata	--	--	--	--	22	--	--	--
Ulothrix sp.	--	--	--	--	--	--	--	--
Stigeoclonium lubricum	--	--	--	--	--	--	--	79
Oedogonium sp.	436	177	--	--	--	--	--	--
Mougeotia sp.	--	--	--	--	--	--	122	--
Spirogyra sp.	--	--	--	--	--	--	--	--

Table 28. *Species biovolumes of experimental stream periphyton communities of August 24, 1970 (cubic microns/millimeter^2).*

Species	1-A	3-A	5-A
Microcystis sp.	17	--	--
Schizothrix calcicola	100	115	93
Oscillatoria sp.	--	--	--
Anabaena sp.	45	136	45
Calothrix sp.	10	9	3
Stephanodiscus astraea	--	--	--
Stephanodiscus Hantzschii	--	--	7
Melosira granulata	--	--	--
Melosira italica	83	--	42
Melosira varians	41737	12377	37032
Tabellaria fenestrata	99	82	106
Asterionella formosa	88	22	110
Fragilaria construens	111	217	437
Fragilaria crotonensis	314	418	909
Fragilaria lepostauron	--	--	--
Fragilaria vaucheriae	180	77	922
Synedra rumpens	74	92	129
Synedra ulna	48	176	347
Hannaea arcus	--	--	--
Achnanthes lanceolata	--	--	--
Achnanthes lemmermanni	--	--	--
Achnanthes linearis	13	14	32
Navicula cryptocephala	--	--	--
Navicula minima	26	--	--
Navicula odiosa	12	--	--
Stauroneis nana	22	--	--
Gomphonema intricatum	--	--	--
Gomphonema olivaceum	--	--	--
Gomphonema ventricosum	--	--	--
Amphora ovalis	--	--	--
Cymbella affinis	100	--	--
Cymbella turgida	--	--	--
Cymbella ventricosa	--	--	--
Epithemia sorex	9	548	3134
Epithemia turgida	--	65	258
Epithemia zebra	--	--	--
Rhopalodia gibba	5202	5555	3401
Nitzschia acicularis	--	--	--
Nitzschia dissipata	--	--	42
Nitzschia fonticola	--	--	--
Nitzschia frustulum	49	--	--
Nitzschia Kutzingiana	10	31	36
Nitzschia linearis	25	--	79
Nitzschia palea	301	100	70
Nitzschia subtilis	--	--	--
Cymatopleura solea	6	9	19
Surirella angustata	--	--	--
Surirella linearis	--	--	--
Surirella ovata	--	--	--
Ulothrix sp.	--	--	--
Stigeoclonium lubricum	--	--	--
Oedogonium sp.	--	--	--
Mougeotia sp.	--	--	--
Spirogyra sp.	--	--	--

Table 29. *Species biovolumes of experimental stream periphyton communities of September 21, 1970 (cubic microns/millimeter^2).*

Species	1-A	1-B	3-A	3-B	5-A	5-B
Microcystis sp.	98	137	2	15	--	--
Schizothrix calcicola	514	717	789	681	807	771
Oscillatoria sp.	3690	9995	--	--	--	--
Anabaena sp.	--	--	--	--	60	90
Calothrix sp.	--	--	--	--	--	--
Stephanodiscus astraea	--	--	--	--	--	--
Stephanodiscus Hantzschii	7	52	37	15	81	15
Melosira granulata	318	--	160	478	--	106
Melosira italica	520	1235	780	780	1169	325
Melosira varians	34219	48221	21486	24574	45625	36295
Tabellaria fenestrata	--	--	92	--	--	277
Asterionella formosa	22	132	110	--	132	44
Fragilaria construens	368	572	628	783	864	865
Fragilaria crotonensis	198	145	410	309	425	459
Fragilaria lepostauron	--	--	--	--	--	--
Fragilaria vaucheriae	93	289	703	174	140	459
Synedra rumpens	74	74	37	37	74	74
Synedra ulna	310	469	310	310	586	937
Hannaea arcus	--	--	--	--	--	--
Achnanthes lanceolata	--	--	--	--	--	--
Achnanthes lemmermanni	--	--	--	--	--	--
Achnanthes linearis	36	159	318	392	105	74
Navicula cryptocephala	34	202	67	34	--	34
Navicula minima	--	--	--	--	--	--
Navicula odiosa	--	52	27	13	26	39
Stauroneis nana	--	--	--	133	400	265
Gomphonema intricatum	--	--	--	--	--	--
Gomphonema olivaceum	--	--	--	--	--	--
Gomphonema ventricosum	77	--	--	--	--	--
Amphora ovalis	--	--	--	--	--	--
Cymbella affinis	2227	1441	--	--	--	--
Cymbella turgida	--	--	--	--	--	--
Cymbella ventricosa	--	--	--	--	--	--
Epithemia sorex	--	--	1124	906	11617	11911
Epithemia turgida	47	37	189	521	841	470
Epithemia zebra	--	--	--	--	--	--
Rhopalodia gibba	7422	21900	6260	5556	532	350
Nitzschia acicularis	--	--	--	--	--	--
Nitzschia dissipata	22	--	134	22	105	381
Nitzschia fonticola	--	--	14	27	27	27
Nitzschia frustulum	--	--	--	--	49	99
Nitzschia Kutzingiana	16	10	31	26	21	26
Nitzschia linearis	--	--	--	--	--	--
Nitzschia palea	314	676	97	109	97	217
Nitzschia subtilis	27	--	14	--	--	--
Cymatopleura solea	14	22	83	29	22	29
Surirella angustata	--	--	--	--	--	--
Surirella linearis	--	--	--	--	--	--
Surirella ovata	--	--	--	--	--	--
Ulothrix sp.	--	--	--	--	--	--
Stigeoclonium lubricum	--	--	--	--	--	--
Oedogonium sp.	11	2	--	--	--	--
Mougeotia sp.	--	--	--	--	--	--
Spirogyra sp.	--	--	--	--	--	--

Table 30. *Species biovolumes of experimental stream periphyton communities of October 26, 1970 (cubic microns/millimeter^2).*

Species	1-A	3-A	5-A	6-A
Microcystis sp.	131	--	--	--
Schizothrix calcicola	717	843	377	79
Oscillatoria sp.	--	--	--	99
Anabaena sp.	--	--	75	--
Calothrix sp.	--	--	--	--
Stephanodiscus astraea	--	--	--	--
Stephanodiscus Hantzschii	15	7	30	52
Melosira granulata	--	160	106	--
Melosira italica	390	195	260	1814
Melosira varians	10637	27844	19651	9050
Tabellaria fenestrata	18	--	--	6
Asterionella formosa	--	44	44	44
Fragilaria construens	671	1607	1750	670
Fragilaria crotonensis	611	775	977	447
Fragilaria lepostauron	--	--	--	150
Fragilaria vaucheriae	112	560	553	78
Synedra rumpens	--	21	147	63
Synedra ulna	1214	1364	1523	703
Hannaea arcus	--	--	--	--
Achnanthes lanceolata	--	--	--	--
Achnanthes lemmermanni	13	--	--	--
Achnanthes linearis	261	328	77	95
Navicula cryptocephala	101	--	--	101
Navicula minima	210	--	--	--
Navicula odiosa	180	90	219	39
Amphipleura pellucida	--	--	--	161
Stauroneis nana	1064	133	133	1329
Gomphonema intricatum	--	--	--	--
Gomphonema olivaceum	--	--	--	--
Gomphonema ventricosum	--	--	--	--
Amphora ovalis	--	--	--	--
Cymbella affinis	339	109	--	--
Cymbella turgida	--	--	--	--
Cymbella ventricosa	--	--	--	--
Epithemia sorex	23	1528	1743	23
Epithemia turgida	18	142	219	24
Epithemia zebra	--	--	21	--
Rhopalodia gibba	1241	2682	658	--
Nitzschia acicularis	--	--	--	44
Nitzschia dissipata	22	45	291	67
Nitzschia fonticola	--	27	54	135
Nitzschia frustulum	--	18	--	--
Nitzschia Kutzingiana	14	17	19	27
Nitzschia linearis	17	63	251	122
Nitzschia palea	718	623	650	157
Nitzschia subtilis	68	122	27	--
Cymatopleura solea	9	71	53	59
Surirella angustata	--	--	5	--
Surirella linearis	--	--	--	--
Surirella ovata	--	--	--	--
Ulothrix sp.	--	--	--	--
Stigeoclonium lubricum	--	--	--	--
Oedogonium sp.	--	--	--	--
Mougeotia sp.	--	--	--	--
Spirogyra sp.	--	--	--	--

having only 34% in common with the December community of the same channel. *Melosira varians* was less abundant, although still dominant in biomass, and *Nitzschia dissipata* became the second most important species. Streams 1 and 3 remained essentially unchanged from December, although *Stauroneis nana* became more abundant. The increase in *N. dissipata* was limited to the control channel. Stream 6, the light control, developed large populations of *Fragilaria vaucheriae, Cymatopleura solea, Surirella ovata* and *Nitzschia Kutzingiana*. These species were less important in the natural light control community, indicating that they were light limited. Indices of similarity (Appendix 19) show that stream 6 periphyton only remotely resembled stream 5 (12-17%), although it was slightly more similar to stream 1 (28-29%) and stream 3 (28-29%). Clearly, this indicates that light is an important factor in determining species composition at this time of year.

During February, water temperatures remained at the lowest yearly levels, and light increased to November levels. The March 4 collection indicates that the cooler temperature channels responded greatly to the light increases (Tables 12 and 23). *Navicula minima* continued to increase in abundance in the warmer channels, while *Melosira varians* decreased in the control channel, but maintained its dominance. *Fragilaria* species all increased, and collectively produced the most biomass of any genus in streams

3 and 5. The outstanding abundance of *Fragilaria construens* in channel 3 was real, and confirmed by additional counts. *Fragilaria crotonensis*, a major phytoplankter of the Columbia River (Williams 1964, Cushing 1964) increased somewhat in the warmest stream. The relatively greater total numbers of this species in the warmest channel may indicate it was growing here and not just passively accumulating from plankton precipitation. *Stauroneis nana* increased considerably in the warmer streams, although it did not develop much of a population in the control channel. In summary, in February the warmest community changed relatively little, while the cooler ones were modified greatly; the end result was three communities with virtually no similarities to each other (Appendix 20).

The April 7 collection (Tables 13 and 24) represented communities that had grown at low temperatures, and medium light intensity. Each stream again developed a distinctive community. The control community became dominated by *Fragilaria* and *Nitzschia* species, while *Melosira varians* became even less abundant than in March. *Melosira italica*, however, increased slightly in all streams, perhaps reflecting an increased importance of this species in the potamoplankton of the Columbia River. In the control channel *Synedra ulna* became important, while *Navicula minima* almost disappeared. *Nitzschia fonticola* became the dominant species in the control channel, but achieved lesser status in the heated streams. *Fragilaria construens* lost its dominance in stream 3, although there was disagreement between the replicate counts as to how abundant the species was. The community of stream 1 was somewhat similar to that of March, although *Stauroneis nana* and *Navicula minima* were less important in April. The April communities were dissimilar to each other (Appendix 21). Stream 6 was more similar to stream 5 than it had been in January, although *Fragilaria vaucheriae* was disproportionately abundant in stream 6. The increased natural light compared to the January period probably made environmental conditions for stream 5 similar to those of the light-control channel, thus resulting in more similar communities.

The May 14 collections (Tables 14 and 25) represented communities grown under high light intensities and low water temperatures. The control stream community was similar to that of the previous month, except that *Melosira italica* assumed dominance. This species also became dominant in stream 3, and important in stream 1. The ecological status of *M. italica* in each community is, however, not certain. The count data indicate that great numbers of this species were present in each community, but that in the warmest, many individuals were dead. The filaments were generally observed to be short and broken. Thus it seems plausible to assume this species was largely planktonic in origin, and not actually reproducing to any extent in the channels. The significant amount of organic material entering the streams in May (Appendix 16 -- control net data) may further substantiate this hypothesis. *Asterionella formosa* also became abundant in all streams, but it was probably also planktonic in origin. Streams 1 and 3 were not greatly different from the previous month, except as noted. The three communities became more similar to each other than they had been the previous month (Appendix 22).

The communities collected June 1 were not very similar to the previous month's communities. The light regime was near maximum , but temperatures were still low. The turbidity of the water, due to spring runoff, probably created additional stress on each community. *Nitzschia fonticola* was no longer very abundant in the control stream, and *Ulothrix* sp. became very important. Areas of the river were also observed to support *Ulothrix* at this time (see "Succession" section). *Navicula minima* and *Stauroneis nana* practically disappeared from all streams, while *Rhopalodia gibba* became dominant in stream 1, although it was absent from the control community. *Surirella ovata* became important in the control channel; less so in the warmer streams. *Spirogyra* sp. appeared in stream 1, and was very important. The June 1 communities were all rather distinct, and the maximum similarity among communities was 48% (Appendix 23).

The July 30 collection represented growth over a period of near-maximum temperatures, and maximum light conditions. The communities all developed small populations of blue-green algae. *Epithemia sorex* and *Rhopalodia gibba* became important in stream 5. *Melosira varians* dwindled to very low levels in stream 1, and developed into the dominant in streams 3 and 5. In the heated channels, this species declined in relation to *Rhopalodia gibba* as the temperature was increased. Stream 6 was similar to the control channel (80%), but completely lacked the *Epithemia sorex* and *Rhopalodia gibba* and blue-green populations characteristic of stream 5. Presumably these taxa were stimulated by the higher light environment present in stream 5. The community of stream 7, the river control channel, included the latter "high light" species, and was about equally similar to streams 5 and 6 (45%, 41%). The warmest channel community was 45% similar to stream 3, and much less similar to the others (Appendix 24).

The communities collected August 24 were very low in diversity (discussed later), and rather similar to each other (Tables 17, 28). One unique feature of these communities was the greater similarity between the communities of streams 1 and 5 (78%) than between either of the latter and stream 3(Appendix 25). This was apparently due to the lower population of *Melosira varians* in stream 3. Nevertheless, all streams were dominated by *M. varians* with *Rhopalodia gibba* next in significance. In stream 5, *Epithemia sorex* was also very important. The low populations of *Epithemia* species in streams 1 and 3 is the only outstanding difference among these three communities. Under the high light conditions of mid-summer, the temperature additions appear to influence community structure very little.

The September 21 communities were not greatly different from those of August 24 (Appendix 26). Although the temperatures remained near maximum, light intensity had decreased considerably. Several subtle changes in the communities may have been attributable to this. Although *Melosira varians* dominated all communities, the co-dominants differed. The control stream was dominated secondarily by *Epithemia sorex,* which was much less important in stream 3, and completely absent from stream 1. *Rhopalodia gibba* continued to be more important in the warmer streams than in the control. The most distinguishing features of the warmest channel were the importance of *Oscillatoria* sp. and *Cymbella affinis,* neither of which even appeared in the other communities.

By October 26, the temperatures had dropped somewhat, and light was low. The communities of streams 1, 3, and 5 had changed somewhat in the month (36%, 82%, 59% similar, respectively, to the previous month). There were slight increases in *Synedra ulna, Nitzschia,* and

Fragilaria species. The communities of streams 3 and 5 resembled those of July 30 (Appendix 27). The warmest stream lost its *Oscillatoria* and *Cymbella affinis* populations. *Melosira varians* still dominated all of the communities. The community of stream 6 lacked the *Epithemia sorex* population of stream 5, but had a greater population of *Stauroneis nana*. Nevertheless, streams 5 and 6 were 54% similar.

Physiognomy

One aspect of community structure that merits discussion is its physiognomy, or gross morphology. Periphyton of natural or experimental systems tends to grow to a thickness exceeding several millimeters. The communities of the present study frequently developed mats of growth two centimeters thick. Although no quantitative data are available, visual observations indicate that during the latter third of each year, the communities became stratified. At the base of the community, next to the substrate, a thin layer of blue-green algae developed. These algae were largely filamentous, and intertwined with some bacteria and the bases of the filamentous diatoms. This same periphyton structure was observed in the Columbia River during the fall season.

The vertical stratification described is likely caused by environmental gradients that are a result of the thickness of growth. Both nutrient and light gradients are directly related to the thickness of growth. These factors are highly significant to the community (Whitford 1960), and result in the stratification of species as well as the death of unfit species that become buried. The death of the lower strata cells is likely one cause for the export (see "Periphyton Community Export"). The higher metabolic rates of the warmer communities probably considerably increased the environmental requirements (e.g. nutrients, light, oxygen) of the living cells of the warmer streams. Thus, the cells of the lower strata would be additionally stressed. This may have been the reason that the warmer streams were unable to develop high standing crops in the high temperature-low light environment in the fall.

Succession

The section describing the composition of the mature periphyton communities of various seasons has the underlying assumption that the species structures present represented conditions similar to those of terrestrial climax communities. During the summer growing season, there is a rapid turnover of periphyton material, which along with the seasonally induced changes in species makes the concept of climax difficult to apply. However, there exists a typical community-type that may be expected if no disturbances occur. The structure of this community will change with season, following a definite pattern.

The periphyton communities of the present study did not develop species compositions in proportion to the seeding species populations. Some within-season succession therefore had to occur before the mature stage. Rather than continuously monitor these changes to decide when maturity was reached, the colonization and growth studies were terminated when relatively stable standing crops were attained. This was determined by observation at the time when large amounts of the community started to be exported and replaced by new growth. Qualitative examination of the permanent microscope slides made during the colonization and growth studies indicates that succession had occurred prior to the first collection. One major exception was the spring series of April 24 to June 1, 1970. During this period the control stream was the slowest to develop a mature community; it was consequently selected for a more detailed study of succession, as follows.

The Columbia River potamoplankton of late April was collected on millipore filters. The five most abundant taxa in order of relative abundance by cell count were:

Melosira varians
Fragilaria crotonensis
Tabellaria fenestrata
Synedra ulna
Asterionella formosa

This was the major seed material for the streams. Tables 31 and 32 compare the periphyton counts and species biomasses of May 4 and May 11 with the mature community of May 14. The collection of May 4 represented ten days of

Table 31. *Diatom counts of successional periphyton communities vs. a mature periphyton community; numbers per millimeter^2.*

	5-4-70		5-11-70		5-14-70	
SPECIES	LIVE	DEAD	LIVE	DEAD	LIVE	DEAD
Stephanodiscus astraea	--	--	--	--	--	--
Stephanodiscus Hantzschii	13	37	55	256	--	2489
Melosira granulata	--	--	--	--	--	--
Melosira italica	80	89	3367	3001	12516	12955
Melosira varians	3	2	12	15	312	173
Tabellaria fenestrata	1	2	23	28	186	210
Asterionella formosa	6	18	219	256	1537	3001
Fragilaria construens	4	6	383	174	8590	8824
Fragilaria crotonensis	--	1	444	115	2611	2296
Fragilaria lepostauron	--	--	--	--	146	146
Fragilaria vaucheriae	29	6	114	64	1504	3846
Synedra rumpens	3	--	--	--	--	146
Synedra ulna	10	2	22	5	75	107
Hannaea arcus	167	1	17	19	12	175
Achnanthes lanceolata	10	1	18	18	--	439
Achnanthes lemmermanni	--	--	--	--	--	--
Achnanthes linearis	13	39	73	183	220	220
Navicula cryptocephala	--	--	--	--	--	--
Navicula minima	--	--	--	--	3733	4904
Navicula odiosa	--	--	--	--	--	--
Stauroneis nana	--	--	--	--	73	--
Gomphonema intricatum	--	--	--	1	--	--
Gomphonema olivaceum	58	1	21	7	73	2342
Gomphonema ventricosum	8	1	33	12	--	--
Amphora ovalis	--	--	--	--	--	--
Cymbella affinis	--	--	--	--	--	--
Cymbella turgida	--	--	--	--	--	--
Cymbella ventricosa	12	1	7	5	--	512
Epithemia sorex	--	--	--	--	12	--
Epithemia turgida	.1	.6	1.3	1.3	.4	1
Epithemia zebra	--	--	--	--	--	--
Rhopalodia gibba	.3	--	.1	1	--	--
Nitzschia acicularis	8	13	--	--	--	--
Nitzschia dissipata	3	3	37	18	73	659
Nitzschia fonticola	118	39	567	403	16981	33376
Nitzschia frustulum	8	10	37	--	878	3879
Nitzschia Kutzingiana	175	13	1299	604	805	1903
Nitzschia linearis	.3	--	2	1	5	5
Nitzschia palea	10	8	18	18	--	220
Cymbatopleura solea	.4	.1	1.6	.5	.5	2
Surirella angustata	--	--	--	--	5	14
Surirella linearis	--	--	--	--	--	--
Surirella ovata	12	.3	57	15	221	408

Table 32. *Species biomass of successional vs. mature periphyton communities; cubic microns per millimeter*^{2}.

SPECIES	5-4-70	5-11-70	5-14-70
Microcystis sp.	--	--	--
Schizothrix calcicola	--	--	15
Oscillatoria sp.	--	--	--
Anabaena sp.	--	--	--
Calothrix sp.	--	--	--
Stephanodiscus astraea	--	--	--
Stephanodiscus Hantzschii	1	6	--
Melosira granulata	--	--	--
Melosira italica	46	1919	7873
Melosira varians	13	52	828
Tabellaria fenestrata	1	29	241
Asterionella formosa	2	66	744
Fragilaria construens	1	58	1409
Fragilaria crotonensis	--	198	1436
Fragilaria lepostauron	2	--	52
Fragilaria vaucheriae	9	34	2876
Synedra rumpens	1	--	--
Synedra ulna	53	117	421
Hannaea arcus	166	17	12
Achnanthes lanceolata	1	2	--
Achnanthes lemmermanni	--	--	--
Achnanthes linearis	--	3	10
Navicula cryptocephala	--	--	--
Navicula minima	--	1	164
Navicula odiosa	--	--	--
Stauroneis nana	1	--	22
Gomphonema intricatum	--	--	--
Gomphonema olivaceum	23	8	25
Gomphonema ventricosum	8	34	--
Amphora ovalis	--	--	--
Cymbella affinis	--	--	--
Cymbella turgida	--	--	--
Cymbella ventricosa	--	3	--
Epithemia sorex	1	--	21
Epithemia turgida	2	--	8
Epithemia zebra	--	--	--
Rhopalodia gibba	2	1	--
Nitzschia acicularis	2	--	--
Nitzschia dissipata	1	10	19
Nitzschia fonticola	22	105	3141
Nitzschia frustulum	5	25	595
Nigzschia Kutzingiana	12	92	77
Nitzschia linearis	1	7	15
Nitzschia palea	2	3	--
Nitzschia subtilis	--	--	--
Cymatopleura solea	13	51	16
Surirella angustata	--	--	5
Surirella linearis	--	--	--
Surirella ovata	29	138	548
Ulothrix sp.	208	751	--
Stigeoclonium lubricum	--	--	--
Oedogonium sp.	--	--	--
Mougeotia sp.	--	--	--
Spirogyra sp.	--	--	--

undisturbed growth at high light intensity, and temperatures averaging approximately 9°C. There are two obvious successional species in this community -- *Hannaea arcus* and *Ulothrix* sp. (probably *U. zonata)*. *Nitzschia Kutzingiana* and *Gomphonema olivaceum* may also be successional; both were represented by large numbers of individuals in the May 4 collection. *N. Kutzingiana* was numerically the most abundant alga, although due to its small size, contributed little to the community biomass. The species structure of the May 4 community does not reflect the proportions of available seed species. With the exception of *Synedra ulna,* which thrives in benthic communities (Owen 1966), the abundant potamoplankton species were rare in the periphyton. Clearly the May 4 community does not represent a passive collection of planktonic species, but rather a distinctive community of species that have grown on the substrate. The physiognomy of this community lends further credence to the latter statement. The counts were made of whole mounts of the undisturbed community. This revealed that many of the non-motile species populations dispersed in radiating clumps; presumably representing the descendents of initial seed organisms.

The May 11 community was more similar to the mature community. *Melosira italica* had assumed biomass dominance, although *Fragilaria vaucheriae* had not developed a significant population. *Ulothrix* sp. was still important, although it was absent from the May 14 community. The May 11 community was very similar, however, to that of June. This indicates that although there were many dissimilarities compared to the mature May 14 community, the May 11 community probably represented a mature stage itself. Thus, the high populations of *Fragilaria vaucheriae, Nitzschia fonticola* and *N. frustulum* in the May 14 community likely represented remnant populations from an earlier period of optimal conditions. (Recall that the May 14 collection was taken from the undisturbed section of the stream, and did not represent a stage of the growth and colonization communities). The high counts of dead individuals of the two *Nitzschia* may confirm that they represented senescent populations.

In natural systems, "pioneer" species such as *Hannaea arcus* and *Ulothrix* sp. may provide the necessary habitat for the colonization of the "climax" species. *Ulothrix* especially may function in this manner. In the Columbia River, substrate areas that were temporarily disturbed developed luxuriant growths of *Ulothrix* which were later succeeded by diatom species. Areas where deer waded into the river for water provided constant examples of this situation -- the hoof-marks were demarcated by green patches of *Ulothrix*. Examination of several stages of the succession from *Ulothrix* to diatoms indicated that the *Ulothrix* filaments were gradually covered by diatoms until all the inter-filament space was filled. The *Ulothrix* then gradually became senescent and disappeared. This process generally took nearly a month in the river, which may indicate that the June 1 counts showing that *Ulothrix* sp. was still important may have been misleading -- succession may not have been completed. The *Ulothrix* succession is strictly a spring and early summer phenomenon in the Columbia River. No marked succession occurred in other seasons, although *Cladophora*-dominated communities developed in late summer on certain rocks in the river. The latter condition was never duplicated in the artificial channels; *Cladophora* never colonized the artificial substrates.

Dead Diatoms of the Community

The number of dead or empty diatoms encountered in this study averaged 46-51% of the numbers of live diatoms (Tables 8 and 33). The significance of empty diatoms is difficult to assess, as their origin may not be readily determined. Several factors may be responsible for large numbers of empty frustules: 1) a natural selection against certain species may have occurred due to seasonal environmental factors, 2) certain species may not have been able to grow rapidly enough to compete with others, and died from lack of light or nutrients, as it was buried in the thick mat of growth, 3) individuals may have been imported from outside the community and

Table 33. *Percentage of intact frustules that are empty within the periphyton communities of artificial streams.*

	STREAM										
		1			3			5		6	7
DATE	A	x	B	A	x	B	A	x	B	A	A
11-17-69	41.7	--	--	49.0	--	--	35.8	--	--	--	--
12-29-69	45.2	--	--	42.0	--	--	43.7	--	--	--	--
1-29-70	36.4	41.2	45.9	27.6	34.8	42.0	41.5	38.0	34.4	16.4	--
3-4-70	32.1	--	--	19.4	--	--	52.9	--	--	--	--
4-7-70	25.7	24.8	23.9	45.0	41.3	37.6	32.4	27.3	22.2	16.3	--
5-14-70	44.1	--	--	39.1	--	--	57.8	--	--	--	--
6-1-70	76.3	--	--	73.5	--	--	70.9	--	--	--	--
7-30-70	74.0	76.4	78.7	60.6	59.4	58.1	50.2	46.6	42.9	57.5	57.8
8-24-70	59.5	--	--	57.5	--	--	45.0	--	--	--	--
9-21-70	71.9	67.6	63.3	48.3	47.8	47.2	46.1	43.7	41.3	--	--
10-26-70	33.3	--	--	45.0	--	--	40.3	--	--	50.8	--
Annual mean*		51.0			48.8			46.3			

*3-4-70 data are nonrepresentative due to chironomid grazing; annual means computed without these data.

been unable to survive the new environment, and 4) empty frustules may have been imported.

The first factor may be seen in the count tables -- species that had passed their seasonal peak abundance and were rare were still frequently encountered as empty frustules. These empty frustules probably remained after the species declined in numbers. Although a complete turnover of material theoretically occurred within half a month to several months, depending on the season (based on biomass and export data), the community probably lost and replaced material most rapidly near the upper strata. Thus, empty diatoms could be retained in the lower strata for several months.

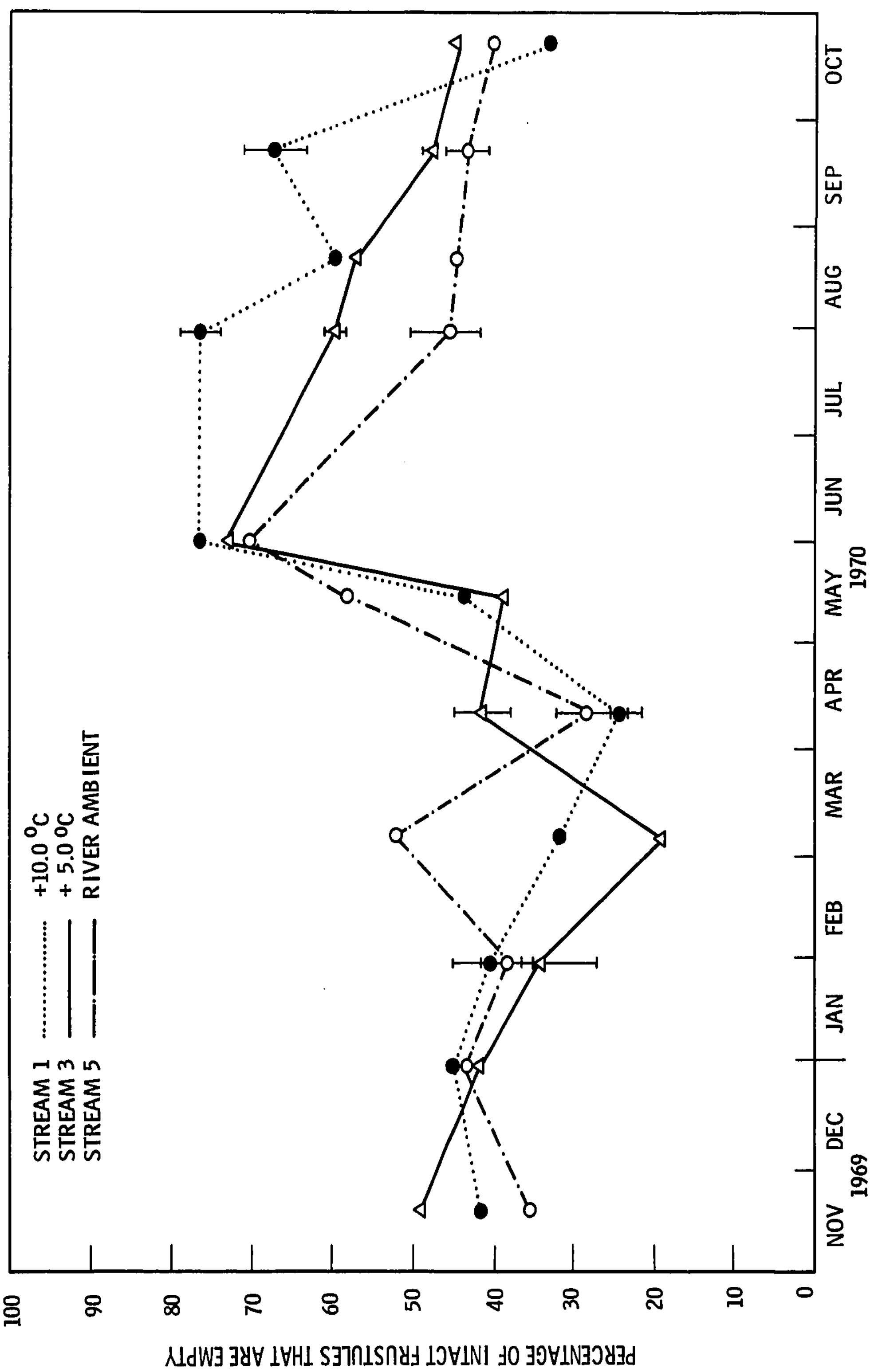
Species that are unable to compete successfully may include certain successional forms such as *Hannaea arcus*. The data from May indicate several species were able to thrive only in the absence of strong competition (Table 32). One species of considerable importance was *Fragilaria crotonensis*, which, although generally regarded as a planktonic species, was observed growing in the early stages of succession in May. However, as succession occurred it too became most commonly observed as empty frustules.

The final reason for finding empty diatoms in periphyton samples is that they were of external origin. Their upstream origin is indeterminable, as individuals could drift hundreds of miles from their origin in tributaries or lakes. Conceivably, diatom frustules could even be representatives of ancient floras dug up from old sediments. These possibilities were the reasons for not counting species that were only present as empty frustules in this study.

There appears to have been a trend of increased numbers of dead diatoms for the three streams (Figure 31) during the summer months. This trend would have been more obvious if the March data were not considered. Stream 5 was heavily grazed in this count, and the high percentage of dead diatoms was attributable to the material having been at least partly digested. The sharp rise in the numbers of dead diatoms in May and June was likely attributable to the following factors: 1) the spring runoff produced heavy siltation, which tended to bury the diatoms rapidly, 2) the temperature and light regimes were favorable to faster growth, which also probably caused many cells to die from being buried under the massive new growths, 3) the runoff probably increased the input of empty frustules scoured from upstream, and 4) there may have been a high number of phytoplankters entering the system.

The spring runoff, which had tapered off by late July (Appendix 3) probably masked what would otherwise

Figure 31. *Percentages of intact frustules that are empty in periphyton communities of experimental streams (ranges shown for replicate samples).*

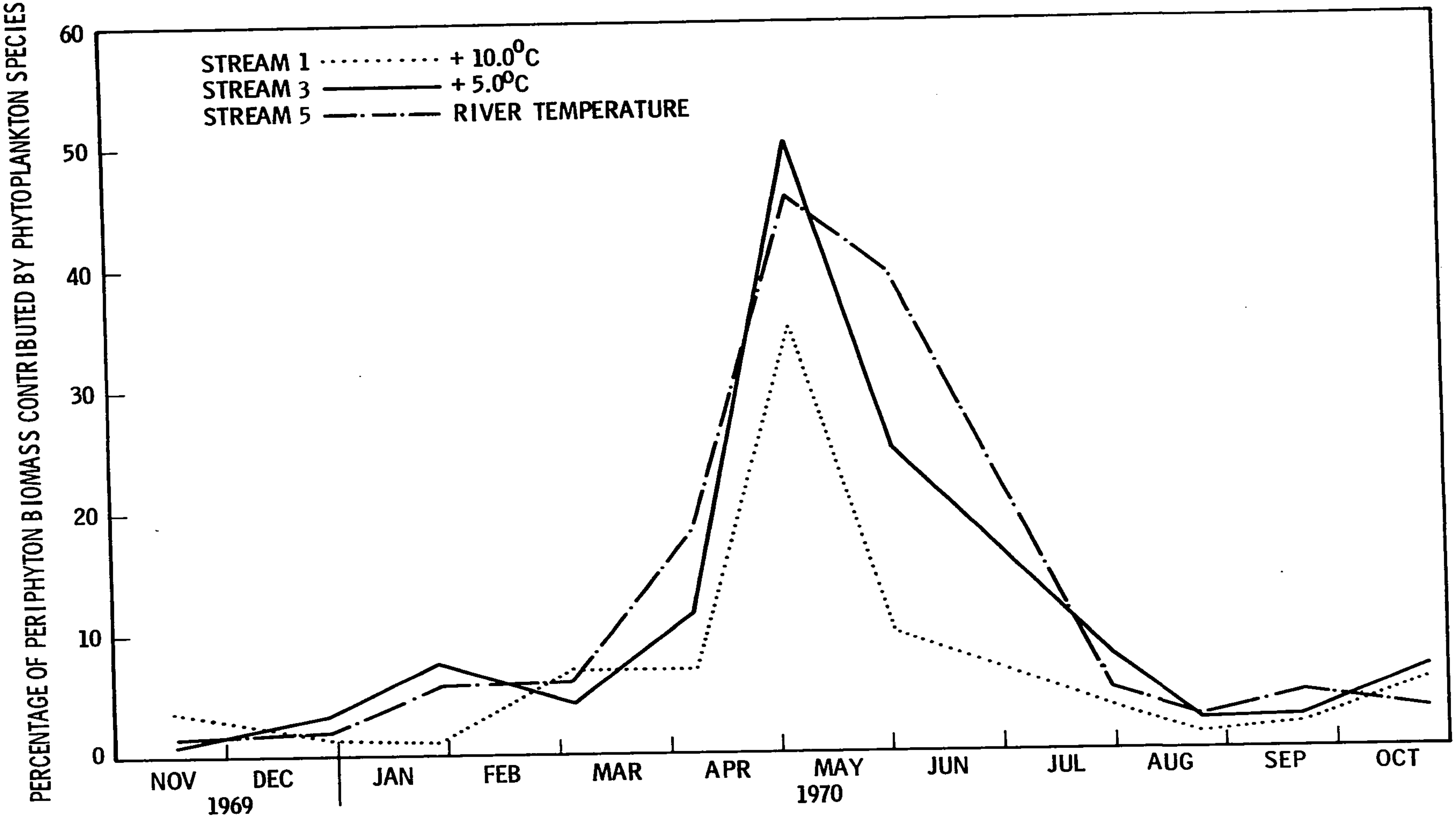

STREAM 1 +10.0 °C
STREAM 3 + 5.0 °C
STREAM 5 RIVER AMBIENT
PERCENTAGE OF INTACT FRUSTULES THAT ARE EMPTY
100
90
80
70
60
50
40
30
20
10
0
NOV
1969
DEC
JAN
FEB
MAR
APR
MAY
1970
JUN
JUL
AUG
SEP
OCT

be a positive correlation of productivity to numbers of empty diatoms. The correlation would not be perfect, however, as the additional factor of externally contributed diatoms was not constant. Cushing (1964b) showed several peaks in abundances of major live phytoplankters throughout the year.

The biomass contribution of species that are suspected to be planktonic in origin (based on literature) is separated from the rest of the community in Figure 32. Most of these "planktonic" species tended to be represented in the counts by a very high proportion of empty individuals (Tables 9-19), indicating that they were unable to thrive as part of an actively growing periphyton community. If consistent, this criterion may be a valid means of separating the euplanktonic species. However, it is likely that most of the species are capable of growth and reproduction in both communities under certain conditions. The very abundant *Fragilaria crotonensis* considered by Cushing (1964b) to be a major plankter in the Columbia River was observed to be reproducing in the periphyton in early May.

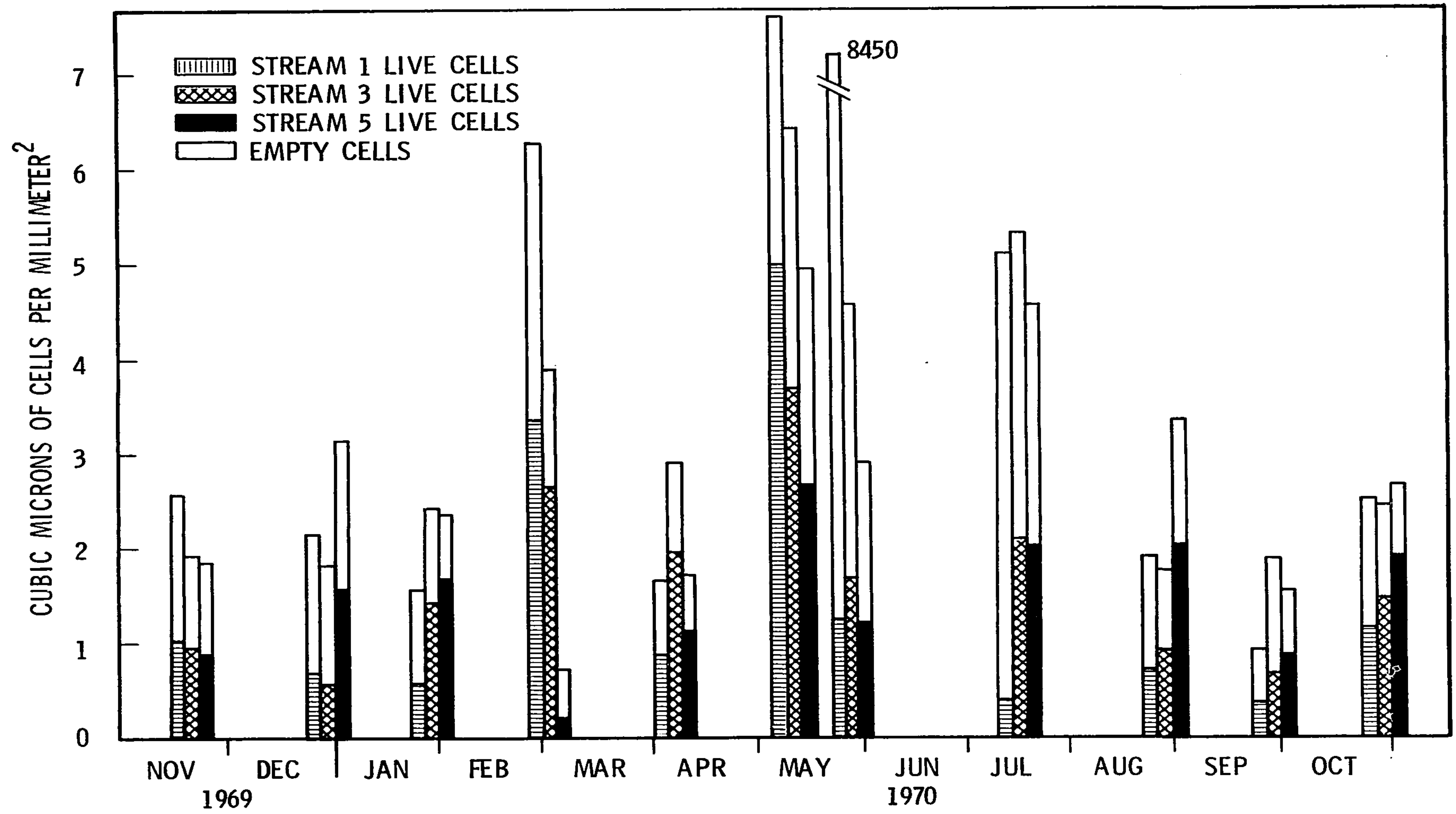
The counts of live and dead *Fragilaria crotonensis* cells are plotted in Figure 33. With the exceptions of March (when heavy siltation slowed the cooler streams' productivities) the total of live and dead *F. crotonensis* cells was usually similar, indicating the diatom may have entered the system from outside. Based on the assumption

Figure 32. *Percentage contribution of phytoplankton species to total periphyton biomass in experimental streams.*


PERCENTAGE OF PERIPHYTON BIOMASS CONTRIBUTED BY PHYTOPLANKTON SPECIES
60
50
40
30
20
10
0
STREAM 1 + 10.0°C
STREAM 3 + 5.0°C
STREAM 5 RIVER TEMPERATURE
NOV
DEC
1969
JAN
FEB
MAR
APR
MAY
1970
JUN
JUL
AUG
SEP
OCT

7

Figure 33. *Numbers of live and dead* Fragilaria crotonensis *cells in experimental streams.*


CUBIC MICRONS OF CELLS PER MILLIMETER^2
0
1
2
3
4
5
6
7
STREAM 1 LIVE CELLS
STREAM 3 LIVE CELLS
STREAM 5 LIVE CELLS
EMPTY CELLS
8450
NOV
1969
DEC
JAN
FEB
MAR
APR
MAY
JUN
1970
JUL
AUG
SEP
OCT

that this species is imported to, and retained in, equal numbers by each stream, the low proportion of live to dead individuals in the early summer indicates that these river populations are apparently unable to live for long periods of time at 10°C above their acclimation temperature.

Diversity

The Shannon diversity index was used to compute the species diversities of the periphyton communities (see Methods). The two components of diversity are richness (number of species) and evenness or equitability (J' index). High diversity may be a function of either high richness or a very even distribution of individuals among species. The theoretical maximum evenness is a J' index of 1.0, representing an equal number of individuals in each species.

Diversity indices were applied to the community data in terms of counts of diatoms, both live and dead, and live only, and biomass of diatoms and of all taxa. It was of interest in this study to see if lesser portions as well as the total community could yield representative information.

The diversities of the communities, based on the biomass contributions of each species were distinctly dissimilar for most months (Figure 34). Although the ranges of the replicate data were small (Appendix 28) the paired *t*-test failed to show significant differences among the annual mean diversities (the indices were 1.94, 2.24, and 2.33, for streams 1, 3, and 5, respectively). The data nevertheless indicate a possible trend of lower diversity with higher temperatures.

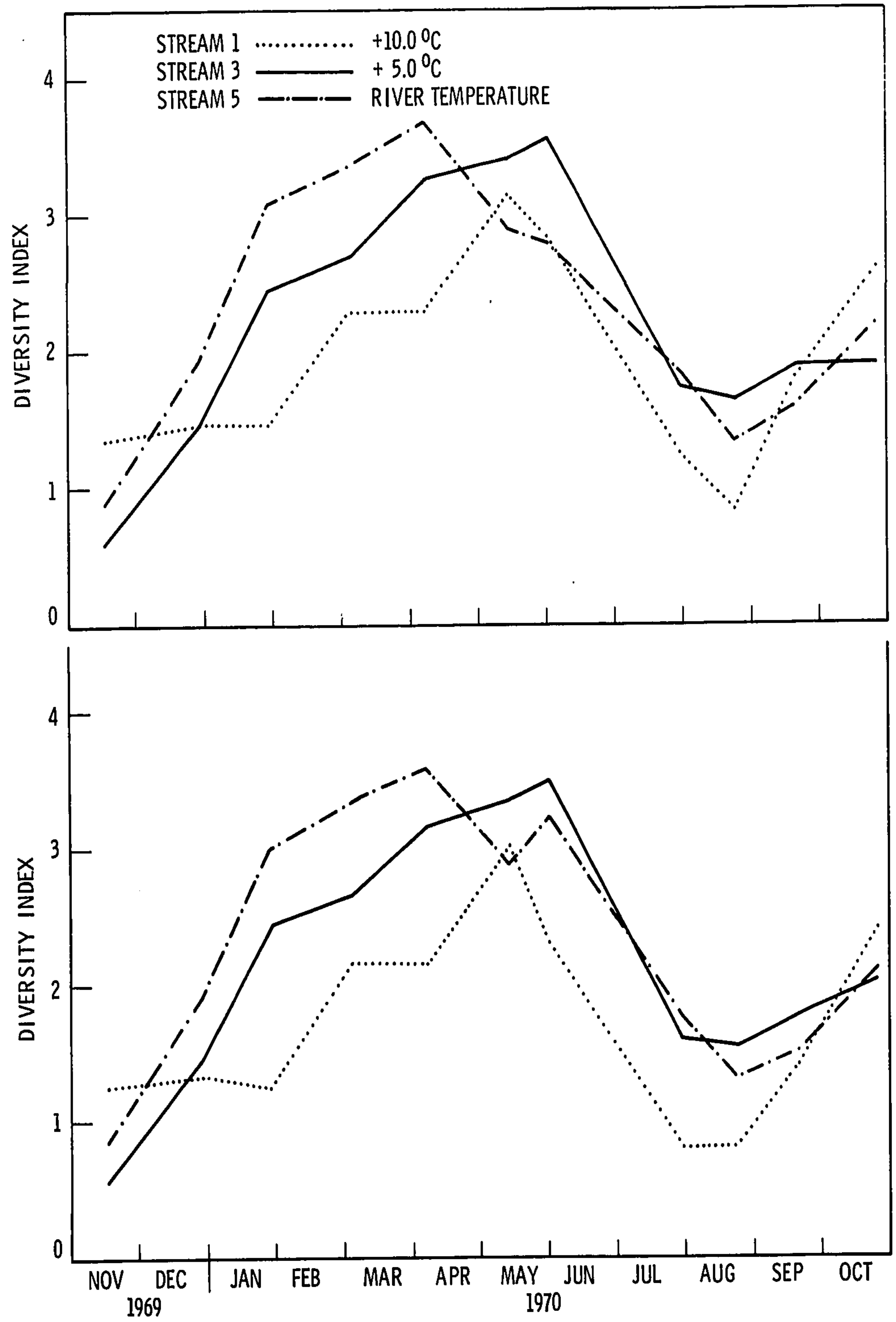
The seasonal changes of diversity shown in figure 34 are very significantly ($p \leq .01$) negatively correlated to the water temperatures ($r = -.53$) and to net productivity ($r = -.35$). The inverse correlation with productivities is most pronounced in stream 5 (Appendix 29). The two times the warmest stream developed communities of greater diversity than the cooler streams, it had exceptionally low productivity. This inverse correlation or productivity to community diversity is considered by Margalef (1965) as having predictive utility.

The biomass contributions of diatoms alone were used to compute the diversity indices of the communities plotted in Figure 35. The results were very similar to those shown in Figure 34; all major trends were evident. This may only reflect the fact that diatoms were the major biomass component of these communities. The mean annual diversities were again inversely related to the temperature -- 1.73, 2.17, and 2.33 for streams 1, 3, and 5, respectively.

Diversity indices were also computed from counts of

Figure 34. *Periphyton species diversity in experimental streams, computed from biomass contributions of each species.*

Figure 35. *Periphyton species diversity in experimental streams, computed from biomass contributions of each diatom species.*


STREAM 1 ············ +10.0 °C
STREAM 3 ———— + 5.0 °C
STREAM 5 —·—·— RIVER TEMPERATURE
DIVERSITY INDEX
0
1
2
3
4
DIVERSITY INDEX
0
1
2
3
4
NOV
DEC
1969
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
1970

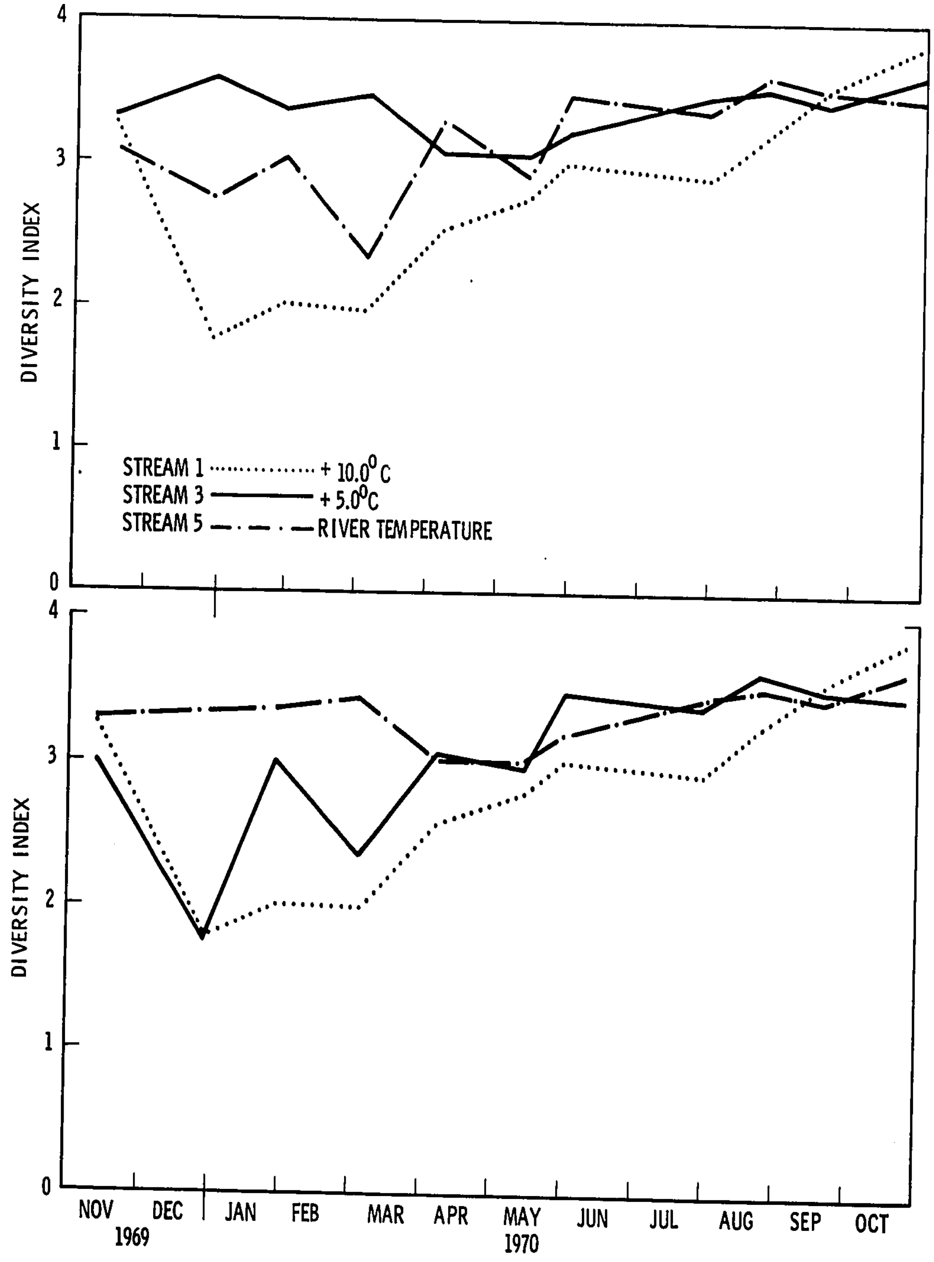
diatoms (Figure 36). The number of cells was not determined for many species of other groups (see Methods). There are no obvious differences among the streams. The mean annual diversities for the three streams was 2.48, 2.73, and 3.03 for streams 1, 3, and 5, respectively. Diversity indices computed from counts of live and dead cells (Figure 37) are similar to the diversities of live diatoms. This may indicate that dead cells tended to accumulate in similar proportions at all three temperatures. The annual means of these diversity indices was 2.81, 3.18, and 3.37 for streams 1, 3, and 5.

All of the diversity values show an annual trend toward higher diversity in the cooler streams. Although the differences are small, this may represent a biologically significant trend. The ecological maxim of greater diversity representing greater community stability is easily demonstrated in the plankton community. Great biomass fluctuations accompany blooms of single species of phytoplankton. In periphyton communities, however, such examples are lacking. In the present study, a greater short-term fluctuation in biomass has been observed in the warmest streams in late summer (see "export" section). Although this occurred in the period of lowest diversity, there is little evidence to attribute the lack of structural stability to low diversity.

The observed trends in diversity were not caused by

Figure 36. *Periphyton species diversity in experimental streams, computed from counts of live diatoms.*

Figure 37. *Periphyton species diversity in experimental streams, computed from counts of live and dead diatoms.*

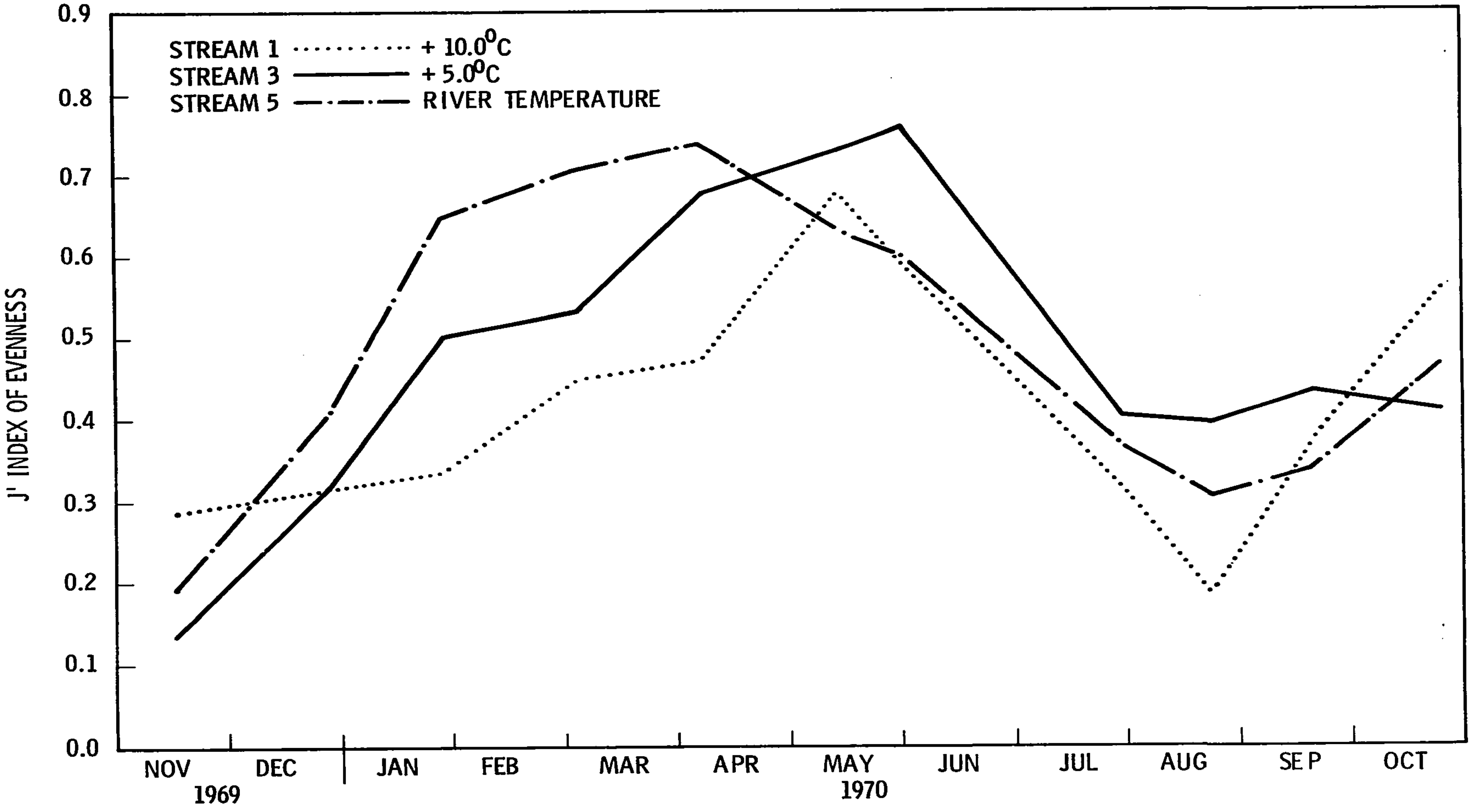

4
3
2
1
0
DIVERSITY INDEX
STREAM 1 ·············· + 10.0°C
STREAM 3 ———— + 5.0°C
STREAM 5 — · — · — RIVER TEMPERATURE
4
3
2
1
0
DIVERSITY INDEX
NOV
DEC
1969
JAN
FEB
MAR
APR
MAY
1970
JUN
JUL
AUG
SEP
OCT

major fluctuations in the numbers of species present (Appendix 28). The J' index measures the relative abundance or evenness component of the Shannon-Weaver diversity index. A plot of the J' index (Figure 38) demonstrates that the diversity differences are almost exclusively attributable to differences in evenness.

Diversity indices computed from biomass may be more useful in elucidating community trends than those obtained from counts. It may be argued that each cell represents a genetic entity of unit value in the population pool of the species, and therefore count data (where filaments and other colonials are counted as individuals) are the best means of obtaining a measure of the informational diversity of a community. However, conclusions based on the latter reasoning may not be valid, as it is never possible to determine how many cells represent truly different genetic entities. In the cryptogamic world, the turnover of living matter is usually extremely rapid, and the number of individuals present at any time should be sufficient to supply a very broad genetic spectrum. Ideally, one should be able to use the rate at which biomass is being manufactured by a species (productivity) as a means of evaluating its true functional energy in the community (Whittaker 1966). Dickman (1968) found that productivity per species provided the best diversity information in a community which includes several trophic levels (plankton). For the

Figure 38. *Periphyton community evennes (J' index) computed from species biomass contributions.*

7


STREAM 1 + 10.0°C
STREAM 3 + 5.0°C
STREAM 5 RIVER TEMPERATURE
J' INDEX OF EVENNESS
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NOV
1969
DEC
JAN
FEB
MAR
APR
MAY
1970
JUN
JUL
AUG
SEP
OCT

present study, it was not possible to estimate the productivity of each species, although it was assumed to be closely related to the standing crop.

The pigment diversity ratios D4300/D6650 (Margalef 1965) and D4800/D6650 were computed for all collection dates. Both ratios failed to provide meaningful information on community structure. The D4300/D6650 ratio was not positively correlated with the Shannon diversity indices, nor was it negatively correlated with productivity as found by Margalef (1965). Winner (1969) also found no consistent relationship between seasonal changes in plankton diversity, and Margalef's pigment ratio. Winner (1972) further studied the application of this ratio to lakes, and arrived at the conclusion that it contributed no meaningful information about other characteristics of the ecosystem. He also found that the ratio D4800/D6650 was no more useful in evaluating lake ecosystems.

Species Performances in Mature Communities

In this section the individual performances of each species will be discussed, both to further elucidate the temperature effects, and to provide some autecological data on these species. Table 34 presents a summary of the data on species performances. *Fragilaria vaucheriae* had the highest maximum biomass value, although this occurred in the light control channel. Among the three major sunlit streams compared, *Melosira varians* had the highest

Table 34. *Algal species performances in periphyton communities of artificial streams, November 17, 1969 to October 24, 1970.*

	BIOMASS		COUNTS		PERCENT PRESENCE
	Max.value	Av.value	Max.value	Av.value	
	microns^3/mm^2		no. individuals/mm^2		
Microcystis sp.	220	14	--	--	24
Schizothrix calcicola	843	227	--	--	90
Oscillatoria sp.	9995	368	--	--	22
Anabaena sp.	950	54	--	--	28
Calothrix sp.	476	21	--	--	18
Stephanodiscus astraea	73	2	73	2	2
Stephanodiscus Hantzschii	81	16	805	183	70
Melosira granulata	943	79	952	100	28
Melosira italica	11049	1088	17566	1704	88
Melosira varians	48221	16172	13614	4730	100
Tabellaria fenestrata	1423	198	534	123	80
Asterionella formosa	2037	146	4209	349	72
Fragilaria construens	21027	1489	128216	8687	100
Fragilaria crotonensis	2705	665	4919	1389	100
Fragilaria lepostauron	181	23	439	51	30
Fragilaria vaucheriae	56383	2514	11504	2205	98
Synedra rumpens	220	51	878	201	76
Synedra ulna	1541	474	289	74	98
Hannaea arcus	292	23	293	17	26
Achnanthes lanceolata	101	8	732	55	28
Achnanthes lemmermanni	13	1	366	10	4
Achnanthes linearis	392	58	11198	1463	100
Navicula cryptocephala	202	17	439	41	26
Navicula minima	4216	473	95808	11913	60
Navicula odiosa	219	44	1317	257	76
Amphipleura pellucida	161	3	--	--	2
Stauroneis nana	3903	393	12882	1197	54
Gomphonema intricatum	101	4	366	15	6
Gomphonema olivaceum	724	49	2123	116	26
Gomphonema ventricosum	767	37	730	36	14
Amphora ovalis	11	1	220	7	6
Cymbella affinis	2227	86	1893	97	22
Cymbella turgida	155	10	51	4	12
Cymbella ventricosa	696	41	1391	76	22
Epithemia sorex	11911	811	4684	384	56
Epithemia turgida	841	110	41	6	96
Epithemia zebra	153	4	28	1	4
Rhopalodia gibba	21900	2559	2629	481	78
Nitzschia acicularis	403	12	220	15	18
Nitzschia dissipata	1528	176	4977	638	80
Nitzschia fonticola	3778	526	20421	2729	68
Nitzschia frustulum	1836	244	2708	377	66
Nitzschia Kutzingiana	788	67	3952	560	98
Nitzschia linearis	922	76	275	22	68
Nitzschia palea	719	188	4099	1116	96
Nitzschia subtilis	122	5	659	36	10
Cymatopleura solea	196	48	6	1	100
Surirella angustata	5455	124	191	20	52
Surirella linearis	63	3	14	1	8
Surirella ovata	1519	99	532	31	26
Ulothrix sp.	7186	144	--	--	2
Stigeoclonium lubricum	427	30	--	--	12
Oedogonium sp.	436	13	--	--	8
Mougeotia sp.	122	2	--	--	2
Spirogyra sp.	6434	131	--	--	4

maximum biomass value for any collection, with *Rhopalodia gibba* and *Fragilaria construens* almost tied for second place. *M. varians* maintained the highest mean biomass over the year, having nearly six times the mean value of the next most important biomass contributors, *R. gibba* and *F. vaucheriae.*

Navicula minima had the highest average density of individuals (11,900cells/mm^2) over the year of study, although the species was only present (in live condition) in 60% of the counts. *Fragilaria construens* had the greatest numbers of individuals in any single count (128,000 cells/mm^2). *Cymatopleura solea* was one of the five species present in all counts, but averaged only 1.3 cells/mm^2.

The five species present in every sample were: *Melosira varians, Fragilaria construens, F. crotonensis, Achnanthes linearis,* and *Cymatopleura solea.* Neither *A. linearis* nor *C. solea* contributed large biomasses over the year, in spite of their universal presence.

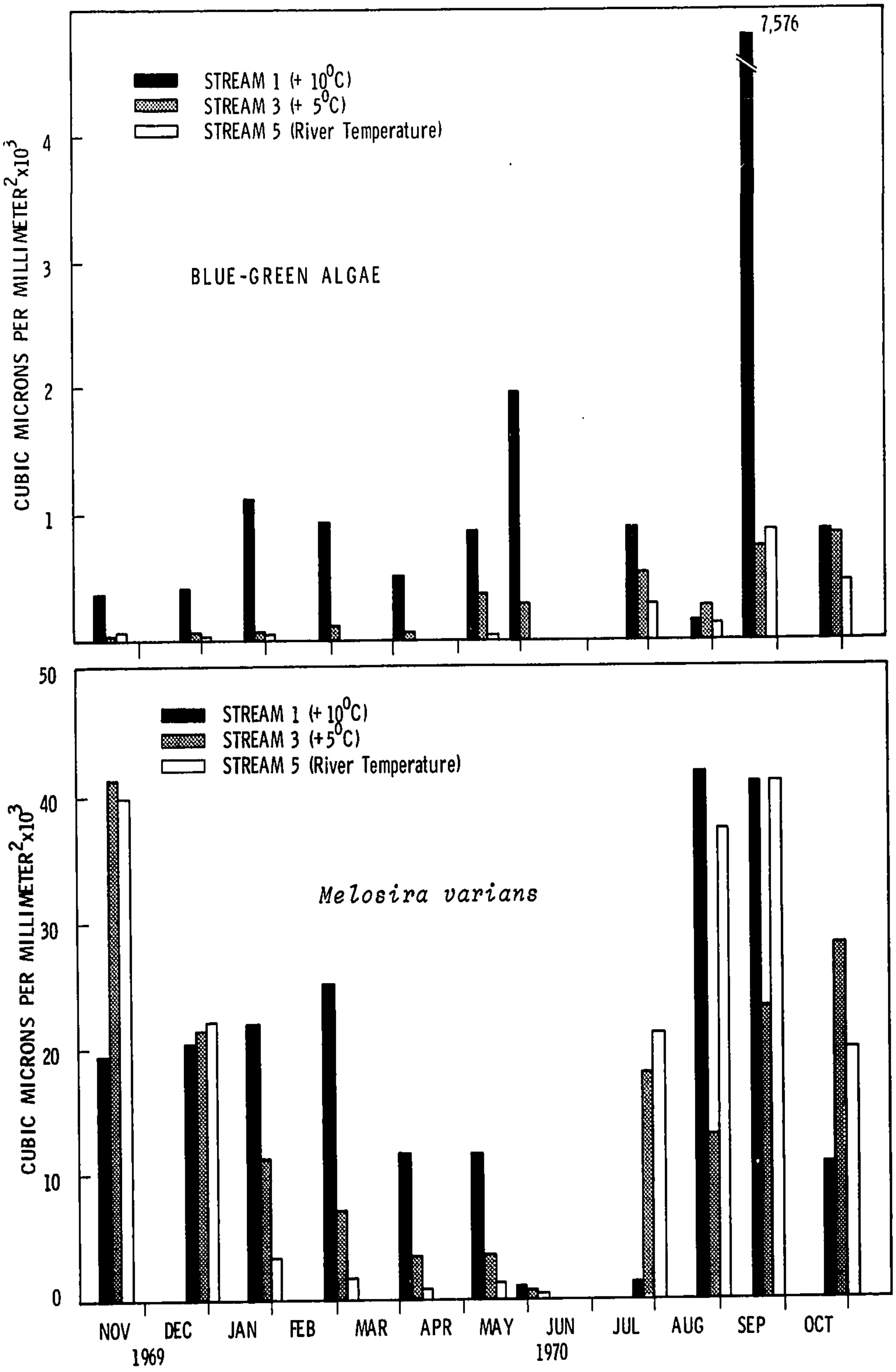
There is an evident tendency for blue-green algal standing crops to increase in the heated streams (Figure 39), although only in September did they become a very important part of the community. Increased blue-green algal standing crops in heated waters has been noted by other authors (Cairns 1956, Trembley 1960, Churchill and Wojtalik 1969, Patrick, Crum and Coles 1969).

Melosira varians, quantitatively the most important

7

Figure 39. *Blue-green algal biomass in periphyton communities of experimental streams.*

Figure 40. Melosira varians *biomass in periphyton communities of experimental streams.*


7,576
STREAM 1 (+ 10°C)
STREAM 3 (+ 5°C)
STREAM 5 (River Temperature)
BLUE-GREEN ALGAE
CUBIC MICRONS PER MILLIMETER^{2}x10^3
1
2
3
4
50
40
30
20
10
0
STREAM 1 (+10°C)
STREAM 3 (+5°C)
STREAM 5 (River Temperature)
Melosira varians
CUBIC MICRONS PER MILLIMETER^{2}x10^3
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
1969
1970

7

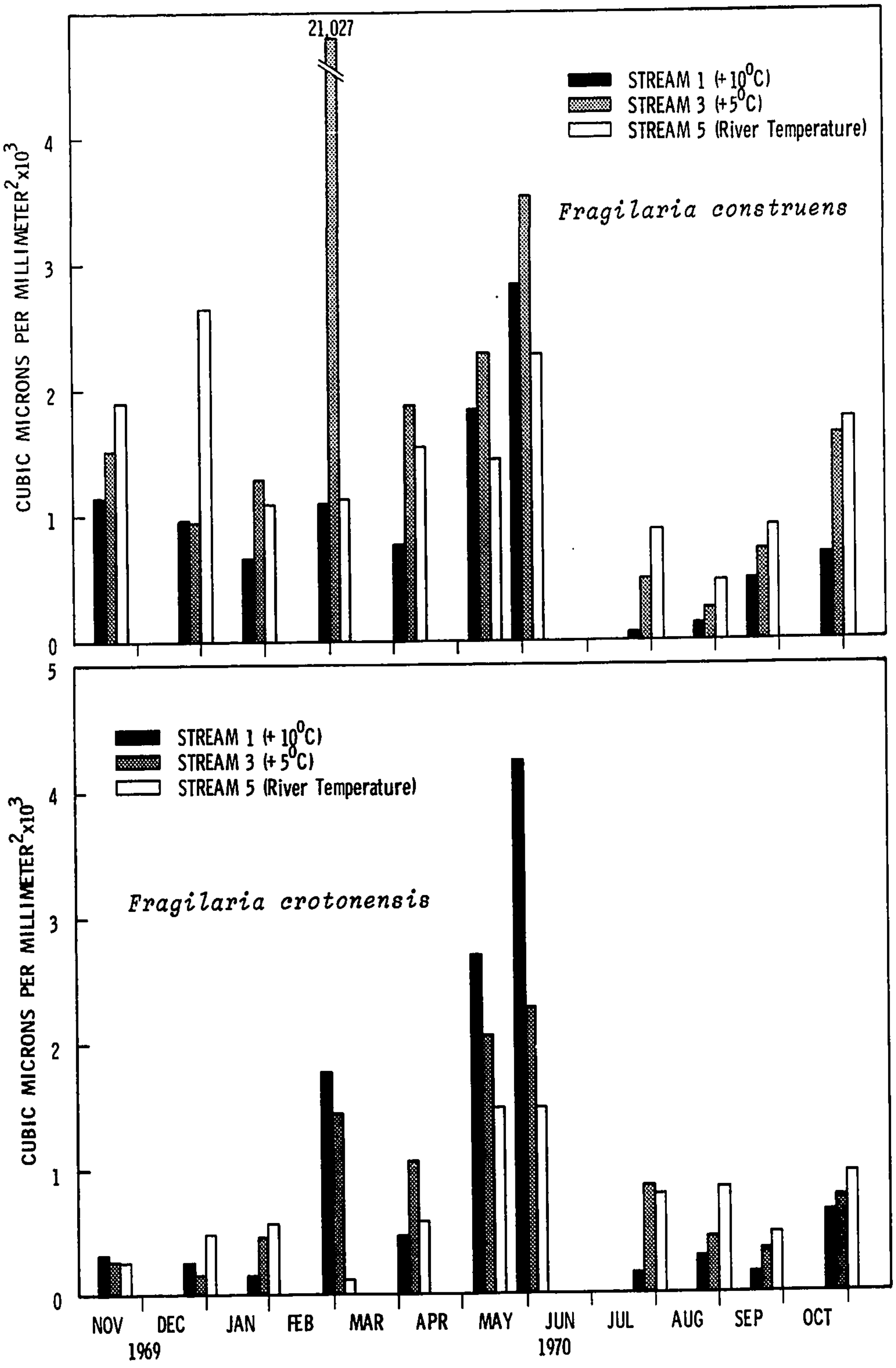
species of the present study, is normally the dominant diatom from July through December in the control community (Figure 40). However, in the heated streams, *M. varians* continues to be very important until late spring, representing a very significant change in community structure.

Fragilaria construens is a very important diatom in most of the communities studied (Figure 41). From July through December, standing crops of this species are lower in the heated streams. The gigantic peak in March may indicate that optimal conditions were present at this time. In channel 6, *F. construens* was common in the cool seasons and less common in the July and October collections. *F. construens* thus appears to be somewhat indifferent to light conditions, and possibly prefers cool to intermediate temperatures.

Fragilaria crotonensis may be largely planktonic in origin in some months (see "Dead Diatoms"). The biomass contributions of this species are illustrated in Figure 42. There are no outstanding trends in biomass contributions of this species among the streams for each date, except for the greater standing crops in the heated streams in spring. Growth of this species in the benthic community is apparent this time of year (see "Succession" section). The remainder of the year, there are usually similar total numbers of cells in each community, possibly signifying passive accumulation from the phytoplankton community,

Figure 41. Fragilaria construens *biomass in periphyton communities of experimental streams.*

Figure 42. Fragilaria crotonensis *biomass in periphyton communities of experimental streams.*


21,027
STREAM 1 (+10°C)
STREAM 3 (+5°C)
STREAM 5 (River Temperature)
Fragilaria construens
CUBIC MICRONS PER MILLIMETER²x10³
0
1
2
3
4
5
STREAM 1 (+10°C)
STREAM 3 (+5°C)
STREAM 5 (River Temperature)
Fragilaria crotonensis
CUBIC MICRONS PER MILLIMETER²x10³
0
1
2
3
4
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
1969
1970

or that temperature is not having a differential effect. If the former is true, then the slightly greater numbers of dead individuals in the heated communities may indicate increased mortality of this important phytoplankter at increased temperatures.

The biomass of *Fragilaria vaucheriae* was generally greatest in the control stream, and was usually reduced in the +10°C channel (Figure 43). This species was very abundant in channel 6 in January and April, and uncommon in July and October, further indicating a preference for cool temperatures.

Navicula minima, because of its small size (Table 6) developed large populations without developing large biomasses. Figure 44 illustrates clearly that this diatom was stimulated by the increased temperatures in streams 1 and 3. In stream 5, *N. minima* was never abundant. Apparently the combination of increased temperatures and low to moderate light of winter and spring stimulated this species.

Epithemia sorex (Figure 45) was severely affected by the thermal additions in streams 1 and 3. It was a very important diatom in the control community in late summer to early fall, but was nearly absent from the warmest channel during this period. The slight development of an *E. sorex* population in stream 3 in May lends credence to the hypothesis that this diatom has a very

Figure 43. Fragilaria vaucheriae *biomass in periphyton communities of experimental streams.*

Figure 44. Navicula minima *biomass in periphyton communities of experimental streams.*

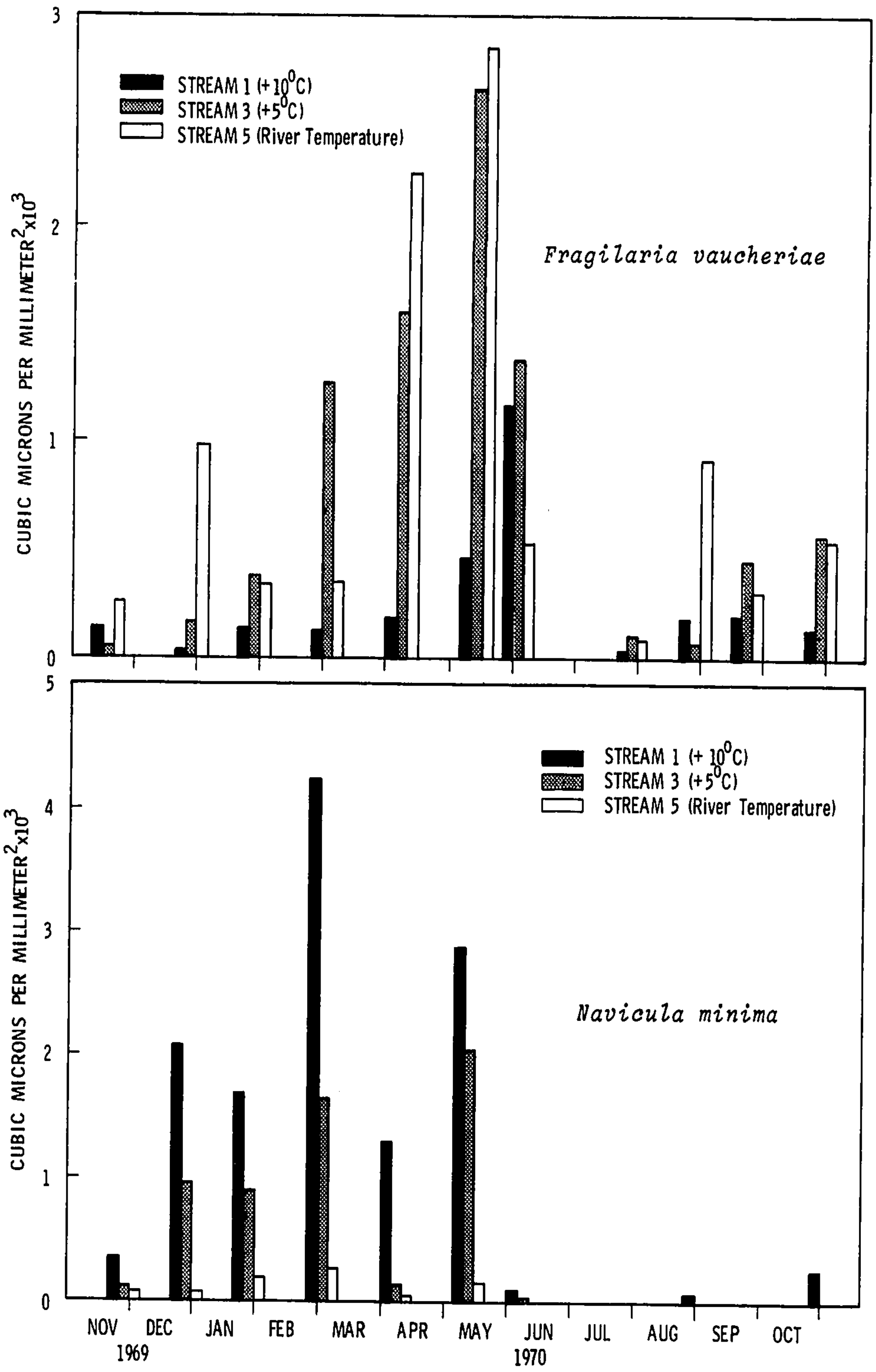
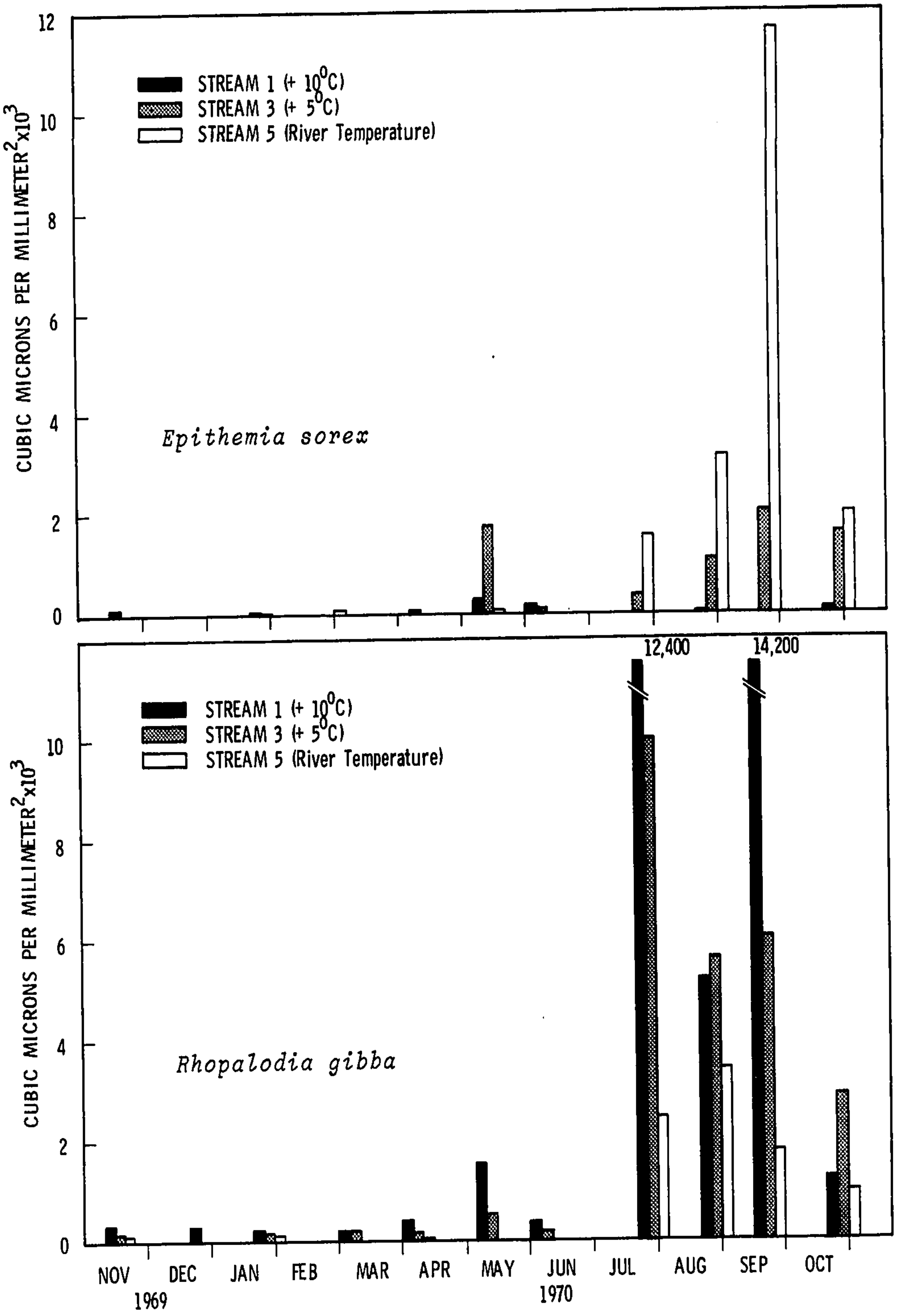

3
2
1
0
CUBIC MICRONS PER MILLIMETER^{2}x10^3
STREAM 1 (+10^{0}C)
STREAM 3 (+5^{0}C)
STREAM 5 (River Temperature)
Fragilaria vaucheriae
5
4
3
2
1
0
CUBIC MICRONS PER MILLIMETER^{2}x10^3
STREAM 1 (+ 10^{0}C)
STREAM 3 (+5^{0}C)
STREAM 5 (River Temperature)
Navicula minima
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
1969
1970

Figure 45. Epithemia sorex *biomass in periphyton communities of experimental streams.*

Figure 46. Rhopalodia gibba *biomass in periphyton communities of experimental streams.*


12
10
8
6
4
2
0
CUBIC MICRONS PER MILLIMETER^{2}x10^3
STREAM 1 (+ 10°C)
STREAM 3 (+ 5°C)
STREAM 5 (River Temperature)
Epithemia sorex
12,400
14,200
Rhopalodia gibba
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
1969
1970

narrow temperature range (15-20°C). The conspicuous absence of *E. sorex* from channel 6, when it was abundant in the control stream, indicates a preference for high light intensities.

Rhopalodia gibba displayed a pattern of seasonality similar to that of *E. sorex* (Figure 46). However, this important diatom was apparently stimulated by the addition of heat, and thus had greatest biomass in the warmer streams. *R. gibba* was almost absent from the light control channel in July, when it was abundant in stream 5, indicating a preference for high light intensities.

Figures 47 through 50 show the population fluctuations of four *Nitzschia* species. *N. fonticola* and *N. dissipata* are important winter and spring species. In most counts, *N. dissipata* was considerably less abundant in the heated communities, indicating a preference for low temperatures. *N. fonticola* responded similarly, although it appeared later in the season. *N. palea* developed a population peak in fall and early winter, but was reasonably common in all collections. In the light of the reputation of pollution tolerance that this species has acquired, the broad spectrum of environmental conditions it tolerated in the present study are not surprising. *N. Kutzingiana* also responded little to the spectrum of environmental conditions over the year.

Surirella ovata (Figure 51) is a species that

Figure 47. Nitzschia fonticola *biomass in periphyton communities of experimental streams.*

Figure 48. Nitzschia dissipata *biomass in periphyton communities of experimental streams.*

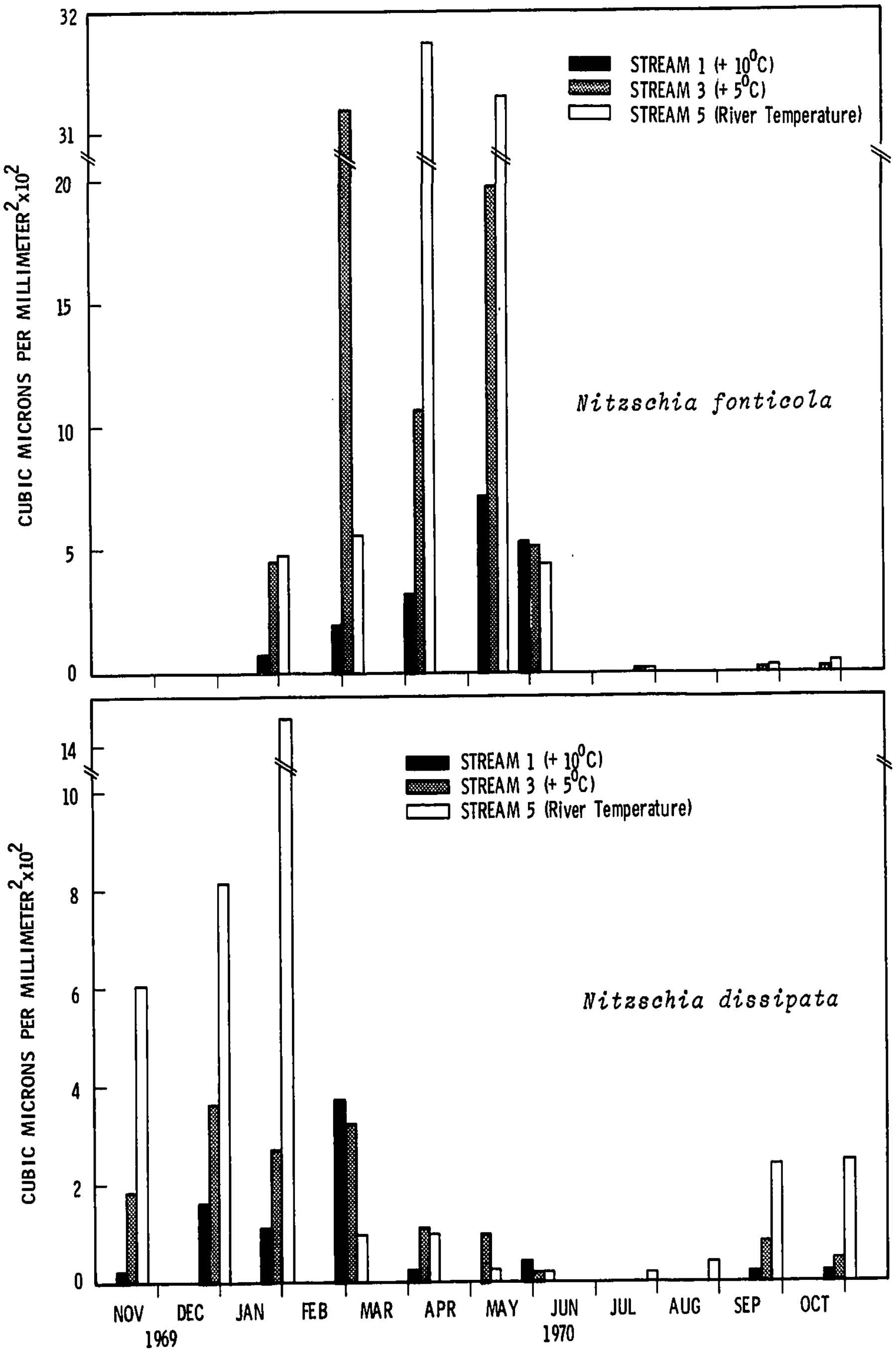
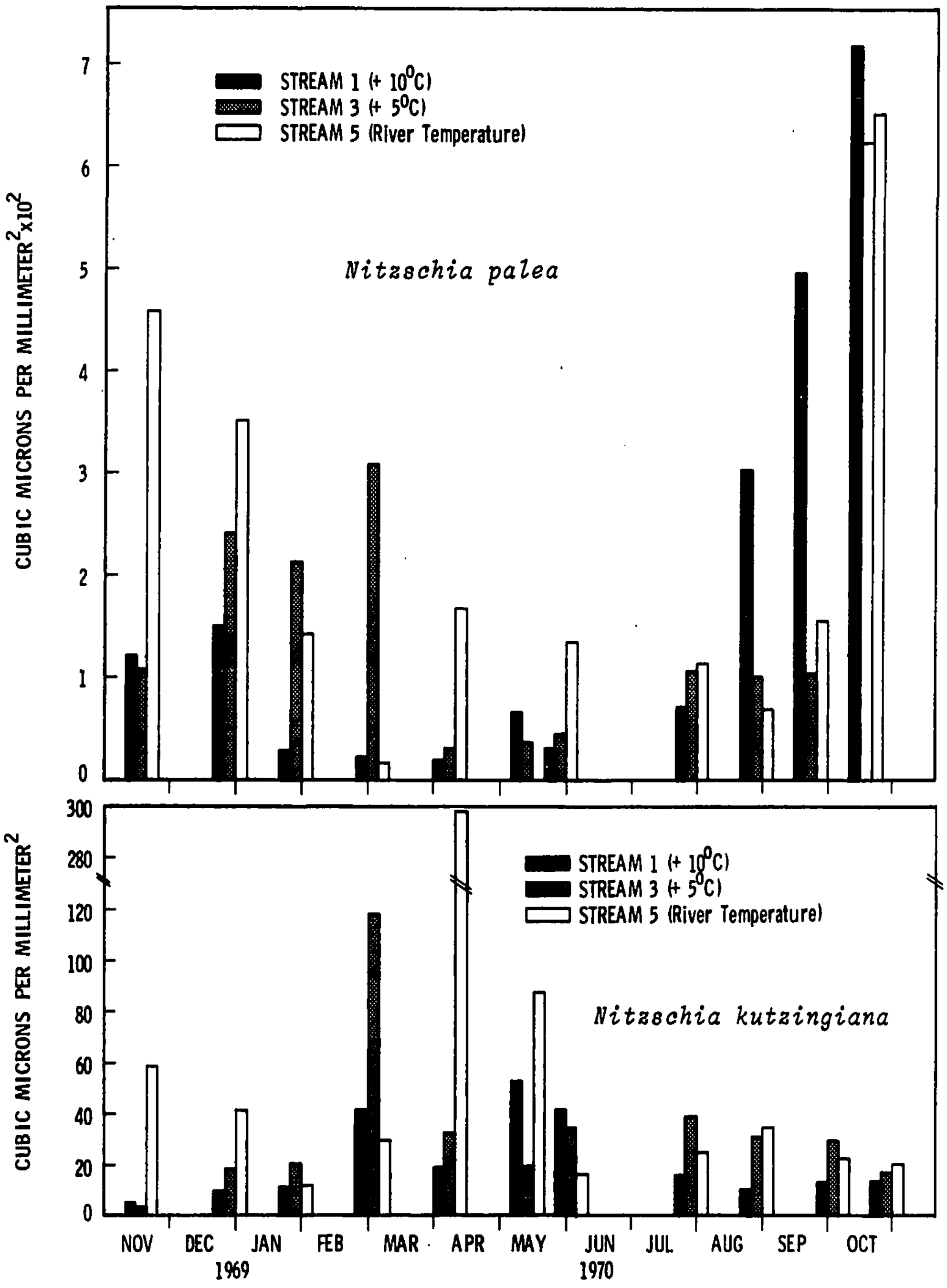

32
31
20
15
10
5
0
CUBIC MICRONS PER MILLIMETER^{2}x10^2
■ STREAM 1 (+ 10°C)
▨ STREAM 3 (+ 5°C)
□ STREAM 5 (River Temperature)
Nitzschia fonticola
14
10
8
6
4
2
0
CUBIC MICRONS PER MILLIMETER^{2}x10^2
■ STREAM 1 (+ 10°C)
▨ STREAM 3 (+ 5°C)
□ STREAM 5 (River Temperature)
Nitzschia dissipata
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
1969
1970

Figure 49. Nitzschia palea *biomass in periphyton communities of experimental streams.*

Figure 50. Nitzschia Kutzingiana *biomass in periphyton communities of experimental streams.*

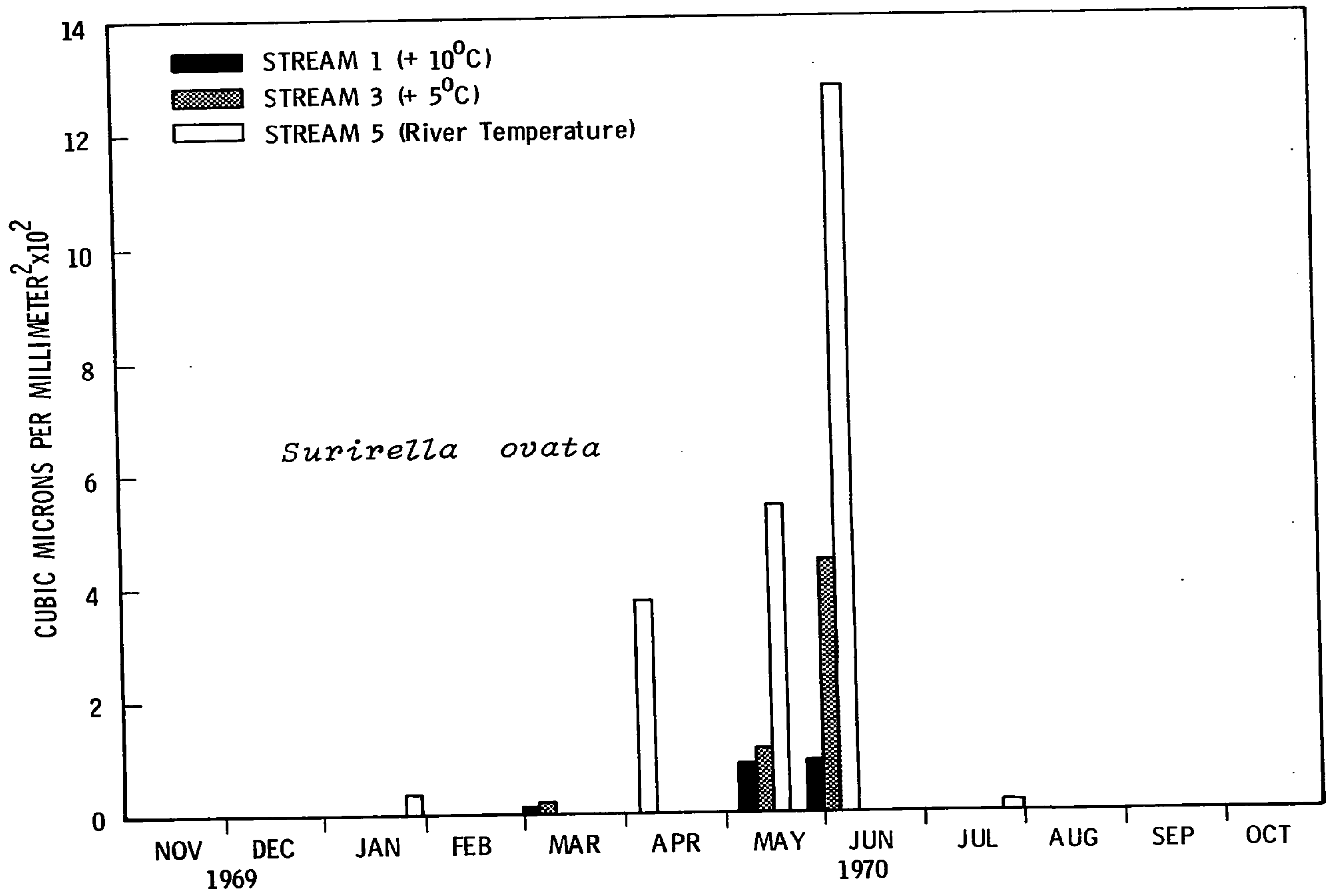

STREAM 1 (+ 10°C)
STREAM 3 (+ 5°C)
STREAM 5 (River Temperature)
Nitzschia palea
CUBIC MICRONS PER MILLIMETER²x10²
0
1
2
3
4
5
6
7
300
280
120
100
80
60
40
20
0
CUBIC MICRONS PER MILLIMETER²
STREAM 1 (+ 10°C)
STREAM 3 (+ 5°C)
STREAM 5 (River Temperature)
Nitzschia kutzingiana
NOV
DEC
1969
JAN
FEB
MAR
APR
MAY
1970
JUN
JUL
AUG
SEP
OCT

attained significance in late spring in the control stream. The heated communities, however, failed to develop large populations of this diatom. *S. ovata* apparently prefers high light intensities and moderately low temperatures.

The above discussion may add something to what we know about the autecologies of several species. These observations cannot be unique to the system, and may have application elsewhere. The ability of a species to survive or grow and reproduce under a set of abiotic environmental conditions may be secondary to how it interacts with the other members of the community. Examples of the importance of competition are provided in the "Succession" section. Consequently, each of the discussed species will almost certainly react differently in a community of species differing from those described. In any system other than the present one, flow and chemical factors would differ enough to guarantee that species compositions would not be totally comparable to those of this research.

The question of broadest ecological significance in this study is how do the described changes in community composition relate to the rest of the ecosystem? This question will remain largely unanswered until more is understood about the flux of energy from this level to the next.

Figure 51. Surirella ovata *biomass in periphyton communities of experimental streams.*


STREAM 1 (+ 10°C)
STREAM 3 (+ 5°C)
STREAM 5 (River Temperature)
Surirella ovata
CUBIC MICRONS PER MILLIMETER^{2}x10^2
0
2
4
6
8
10
12
14
NOV
DEC
1969
JAN
FEB
MAR
APR
MAY
JUN
1970
JUL
AUG
SEP
OCT

SUMMARY AND CONCLUSIONS

Experimental streams were used to study the effects of heat on periphyton communities. The streams were plexiglas, outdoor, once-through, constant-flow systems using Columbia River water at +10.0°, +7.5°, +5.0°, and +2.5°C, and ambient temperatures. Periphyton communities were allowed to develop on level, flat stream bottoms lined with glass slides. Macro-benthic grazers such as aquatic insects were excluded from the experimental streams. Organic matter generated within each stream was collected with "export" nets. Mature and immature periphyton communities were sampled at biweekly and monthly intervals for one year (November 1969-October 1970).

In natural stream systems, periphyton communities are subjected to varying intensities of scouring and grazing over the year. These influences probably cause a large proportion of the periphyton community area to exist in an immature condition at any given time. Scouring and grazing stresses in the experimental streams were simulated periodically be removing mature growth from the lower sections of the channels.

Standing crops of the mature undisturbed periphyton communities (ash-free dry weight) were not significantly different among the five temperature regimes when compared on an annual basis. The heated channels had slightly larger standing crops from February through July, while the cooler channels had slightly larger standing crops from August through January. However, the rate of standing crop accrual on cleaned segments of the stream bottoms was positively correlated with increasing temperature (Figure 25). For the range of water temperatures studied (5-30° C) the increased rate of accrual for the first 18 days was approximately 1.2 $g/m^2/day/10°C$ increase.

Net community production (*sensu* Odum 1971) was computed from export and standing crop changes in mature and immature periphyton communities. Annual net community production was not significantly different among the five thermal regimes. However, thermal additions apparently altered the seasonal march of net production in the five streams (Figure 27). The heated streams outproduced the control in spring and early summer when there was moderate to high light, but river temperatures were relatively cool. In late summer and fall when water temperatures were highest and light was moderate to low, the control stream outproduced the heated ones. Increased temperatures apparently enhanced net community production only when there was sufficient light to more than compensate for the increased respiration.

Changing the seasonal pattern of production would considerably alter the ability of the periphyton community to supply food for grazers. Light would be more limiting in natural streams for periphyton growing at greater depths than those in this study. This would likely result in a prolonged period in which increased temperatures would tend to depress net community production. However, the ability of the community to regenerate standing crops may be greater than apparent from productivity data. In natural streams where perturbations likely maintain most periphyton communities in an immature state, this regenerative ability will be important. In highly disturbed situations, standing crops would likely develop more rapidly and be maintained at higher levels with thermal additions of the magnitude studied here. The rapid regeneration of standing crop could enhance the growth of benthic organisms.

Species compositions of the periphyton communities were different in the 5 thermal regimes. Late fall and early winter communities were all fairly similar, and were dominated by *Melosira varians*. Mid-winter through spring communities were different from each other; *M. varians* continued to dominate the +10°C community, while *Fragilaria* and *Nitzschia* species became more important in the cooler streams. By late spring, *Rhopalodia gibba* dominated the +10°C community, and as temperatures rose, this species gained importance in the cooler streams. However, *M. varians* reassumed and maintained dominance in the cooler streams all summer. Indices of similarity indicated that in both spring and summer, the communities of the control and the +10°C streams were occasionally less than 15% alike in species composition.

The majority of these species composition changes were confined to the diatoms. There were only slight increases on blue-green algae in the heated streams; reaching levels of less than 2% of the community biomass. On one occasion (early June) a green algae, *Spriogyra* sp., was abundant in the +10°C stream, and absent in the cooler streams. A number of species were shown to be diminished in the heated streams (*Fragilaria vaucheriae*, *Epithemia sorex*, *Nitzschia* spp. and *Surirella ovata*) while others developed larger populations in the heated streams (*Rhopalodia gibba*, *Navicula minima*, blue-green algae).

The observed shifts in diatom species may modify the food value of the periphyton to potential grazers. The impact of the presence of grazers on periphyton was not evaluated in this study. However, selective feeding of grazers is likely to encourage certain species or groups, such as blue-green algae, to develop populations in excess of those observed in this study.

Species diversities were negatively correlated with net community productivity and water temperature. The temperature regimes tested in this study did not change the seasonal pattern of maximum diversity in the spring and minimum diversity in late summer, although mean diversity was lower for each +5°C increment.

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Appendix 1. *T-tests of suspended algae in water above stream 3, versus suspended algae in water exiting stream 3 after passing through export net.*

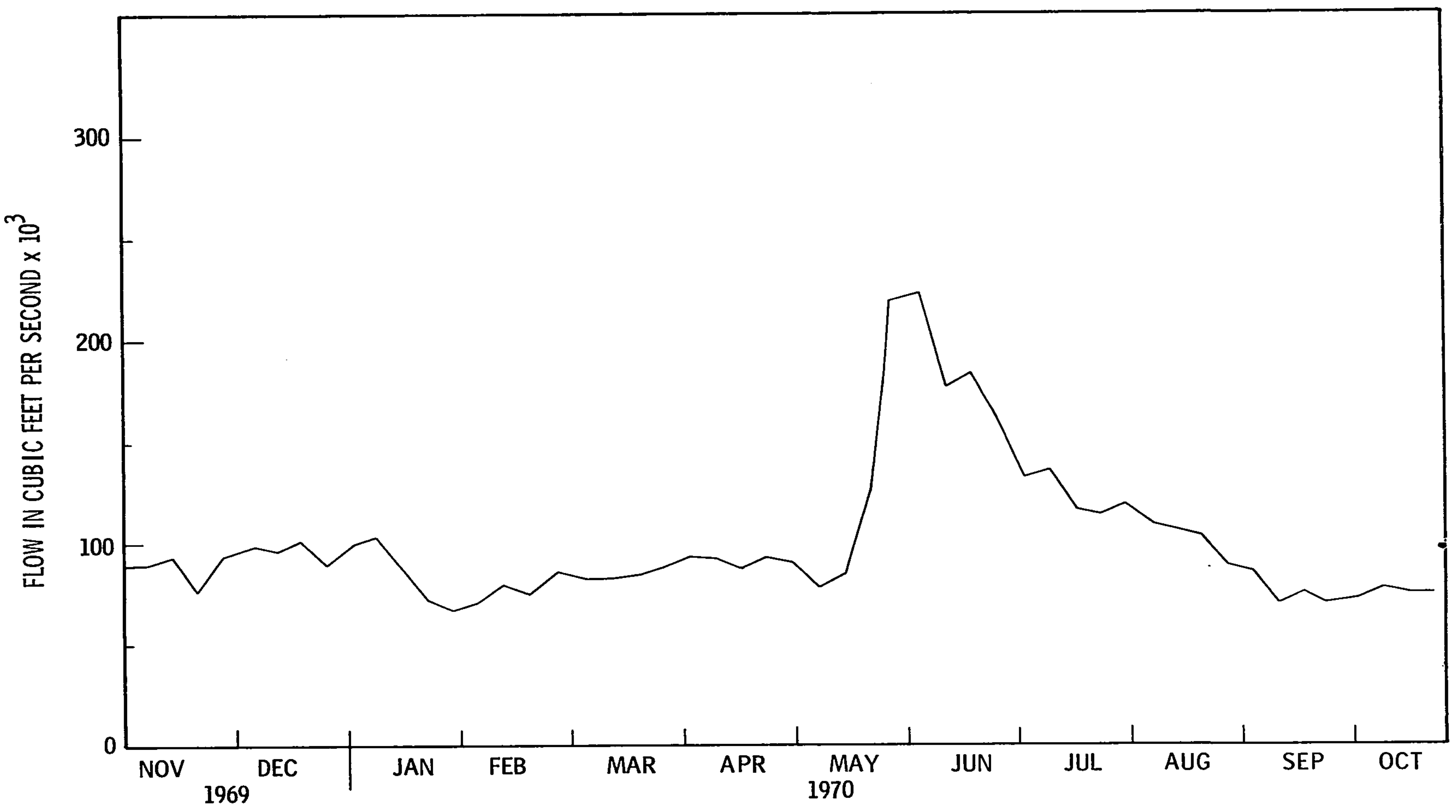
Major taxa	Mean numbers of cells/ field counted* above str. 3	below str. 3	"*t*"	Significance
Melosira italica	7.6	6.3	.93	N.S.
Stephanodiscus Hantzschii	16.4	17.1	-.26	N.S.
Asterionella formosa	1.6	1.2	.30	N.S.
Tabellaria fenestrata	1.5	1.7	-.20	N.S.
Fragilaria crotonensis	8.4	9.7	-.41	N.S.
Navicula cryptocephala	0.9	0.6	.78	N.S.
Nitzschia palea	1.1	1.4	-.64	N.S.
Nitzschia dissipata	1.1	0.7	.89	N.S.

*Number of fields counted = 10.

Appendix 2. *A comparison of physical and chemical measurements of the Columbia River near the hatchery intake, and the input water of the artificial stream system.*

SAMPLING DATE	SO_4	Mg	Fe	PO_4	Cl	Cu	O_2	Phth.Alk.	M.O. Alk.	Hardness	Ca	Solids	NO_3
	parts per million												
9/9/69 (RIVER)	12	3.0	.02	.06	.33	.001	8.48	1	54	75	21	82	.044
9/9/69 (STREAM INPUT)	13	2.5	.03	.06	.35	.000	8.32	1	54	72	25	70	.066
2/17/70 (RIVER)	19	4.9	.01	.01	.33	.004	11.20	2	68	75	22	105	.000
2/17/70 (STREAM INPUT)	19	5.6	.00	.01	.40	.003	11.68	1	69	74	20	91	.06

Appendix 3. *Discharge of the Columbia River at Priest Rapids Dam.*


FLOW IN CUBIC FEET PER SECOND x 10^3
300
200
100
0
NOV
DEC
1969
JAN
FEB
MAR
APR
MAY
1970
JUN
JUL
AUG
SEP
OCT

Appendix 4. *Comparisons of standing crops of organic matter of all streams: paired t-test.*

	10-26-70	9-21-70	8-24-70	7-30-70	6-1-70	3-4-70	1-29-70	12-29-69	11-17-69
11-17-69	☐	⧄	☐	⊠	☐	☐	☐	☐	
12-29-69	☐	⊠	☐	⊠	⧄	☐	☐		
1-29-70	☐	⧄	☐	⊠	⧄	☐			
3-4-70	☐	⊠	☐	☐	☐				
6-1-70	☐	☐	⧄	☐					
7-30-70	☐	☐	⊠						
8-24-70	☐	⊠							
9-21-70	☐								
10-26-70									

☐ not significant

⧄ significant $p \leq .05$

⊠ very significant $p \leq .01$

Appendix 5. *Mean biomass of mature periphyton communities of the experimental streams.*

Collection date		grams per square meter loss on ignition STREAM 1	2	3	4	5	6	7
11-17-69	$\bar{x}$	26.67	31.27	37.64	50.79	44.39	67.48	12.82
	SD	6.06	8.00	.85	10.33	4.00	24.99	2.55
12-29-69	$\bar{x}$	34.75	30.91	31.37	40.04	44.44	46.67	12.21
	SD	.51	5.47	8.44	.26	1.58	2.83	3.56
01-29-70	$\bar{x}$	35.41	44.42	29.13	37.60	17.54*	128.18	25.84
	SD	2.42	6.32	.38	11.21	1.47	2.85	4.65
03-04-70	$\bar{x}$	61.03	49.23	58.08	30.30	4.14*	42.38	15.59
	SD	33.68	1.92	6.38	9.03	3.66	16.26	1.07
04-07-70	$\bar{x}$	60.34	44.71	--	--	--	--	--
	SD	25.52	5.07	--	--	--	--	--
06-01-70	$\bar{x}$	80.45	76.30	52.30	50.52	46.85	51.76	--
	SD	3.82	18.70	4.48	18.39	5.67	3.33	--
07-30-70	$\bar{x}$	58.04	55.17	54.81	59.19	69.07	47.43	28.38
	SD	3.37	8.55	2.57	4.53	10.44	5.94	.36
08-24-70	$\bar{x}$	53.76	34.82	39.00	40.09	39.79	39.85	29.85
	SD	16.48	2.85	4.21	12.55	9.82	10.55	2.70
09-21-70	$\bar{x}$	79.55	78.00	71.00	48.27	64.30	83.64	33.21
	SD	32.15	20.36	18.45	8.24	21.06	32.52	19.85
10-26-70	$\bar{x}$	39.39	41.18	59.42	34.30	57.73	44.48	22.03
	SD	9.15	4.30	24.61	1.91	37.30	3.79	1.64
yearly means less 4-7-70		52.12	49.03	48.08	43.46	43.14	61.32	22.48

*heavily grazed by chironomids

Appendix 6. *Mean percentage weight loss on ignition of mature periphyton communities*

COLLECTION DATE: (NUMBER OF SAMPLES)	1	2	3	4	5	6	7
11-17-69 (4)	9.1	11.1	11.0	12.8	12.1	12.3	6.2
12-29-69 (2)	10.8	12.0	10.1	12.2	10.5	16.4	8.0
1-29-70 (2)	13.7	18.0	15.4	13.8	10.5	24.0	8.6
1-30-70*	21.5	21.1	22.1	21.2	19.0	22.9	--
3-4-70**	22.3	24.2	21.7	21.4	8.8**	24.9	5.1
4-7-70 (2)	25.8	--	--	--	--	--	--
4-24-70*	31.1	31.0	29.1	31.4	29.2	21.7	--
6-1-70 (3)	18.3	16.0	9.4	9.4	6.3	6.7	--
6-20-70*	14.0	13.0	10.8	9.0	6.9	6.3	--
7-30-70 (3)	13.9	13.7	12.2	11.1	11.8	8.5	10.8
8-24-70 (3)	8.8	7.8	12.5	16.6	21.2	17.0	10.0
9-21-70 (3)	17.3	14.7	18.4	19.9	10.6	21.0	--
10-26-70 (3)	14.6	13.8	22.7	19.4	19.5	15.3	7.7
10-27-70*	13.7	14.2	15.3	17.4	14.3	--	--
ANNUAL MEAN LESS 4-7-70	16.1	16.2	16.2	16.6	13.9	15.4	7.7

* One sample of 1/3 to 2/3 of the total stream bottom.

** Heavy chironomid grazing; very low standing crop of living periphyton organisms.

Appendix 7. *Standing crops of mature community chlorophyll a of experimental streams.*

		STREAM						
DATE		1	2	3	4	5	6	7
11-17-69	$\bar{x}$	114	253	192	--	260	357	12
	SD	--	93	62	--	24	--	--
12-29-69	$\bar{x}$	212	241	198	190	206	146	95
	SD	19	24	51	51	69	53	20
1-29-70	$\bar{x}$	349	417	352	251	159	451	240
	SD	1	9	58	32	22	176	--
3-4-70	$\bar{x}$	495	748	637	259	29	616	86
	SD	55	271	87	17	15	202	33
4-7-70	$\bar{x}$	507	710	890	746	561	833	286
	SD	118	319	24	269	19	114	25
6-1-70	$\bar{x}$	378	211	126	122	91	185	--
	SD	16	29	17	17	14	27	--
7-30-70	$\bar{x}$	242	193	260	148	159	190	136
	SD	31	24	101	32	54	24	15
8-24-70	$\bar{x}$	289	287	270	226	256	386	234
	SD	41	39	29	32	23	47	6
9-21-70	$\bar{x}$	649	459	557	557	580	565	130
	SD	65	69	120	150	107	99	12
10-26-70	$\bar{x}$	305	365	522	484	550	348	142
	SD	19	28	98	33	19	63	16
yearly $\bar{x}$ less 11-17-69		381	403	424	331	228	413	140

Appendix 8. *Standing crops of mature community carotenoids of experimental streams.*

		STREAM						
DATE		1	2	3	4	5	6	7
11-17-69	$\bar{x}$	85	212	144	--	205	269	6
	SD	--	70	55	--	14	--	--
12-29-69	$\bar{x}$	191	226	190	181	191	136	92
	SD	19	28	52	77	77	34	20
1-29-70	$\bar{x}$	263	329	300	229	145	434	215
	SD	12	11	51	31	20	183	--
3-4-70	$\bar{x}$	377	688	563	259	28	610	92
	SD	32	286	67	33	16	184	40
4-7-70	$\bar{x}$	444	603	798	705	560	687	291
	SD	102	233	34	233	15	98	38
6-1-70	$\bar{x}$	311	179	131	141	110	190	--
	SD	32	31	11	40	16	27	--
7-30-70	$\bar{x}$	176	126	162	114	126	143	92
	SD	29	12	50	22	31	24	9
8-24-70	$\bar{x}$	225	211	198	168	199	294	219
	SD	29	34	16	24	23	34	5
9-21-70	$\bar{x}$	495	367	434	443	485	254	109
	SD	63	67	96	121	107	79	8
10-26-70	$\bar{x}$	242	271	389	365	421	264	117
	SD	18	28	80	27	18	31	15
yearly $\bar{x}$ less 11-17-69		303	333	352	289	252	346	136

7

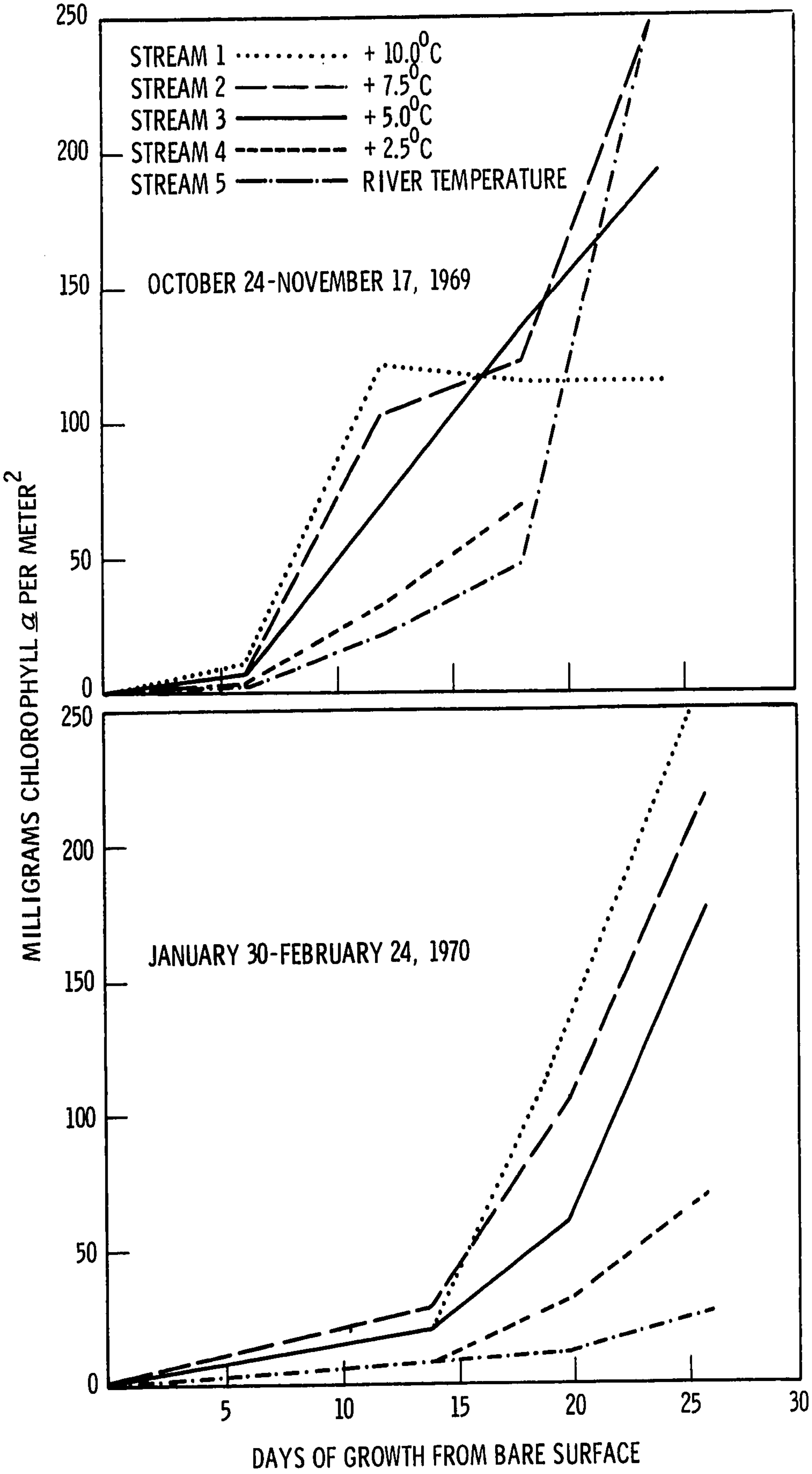
7

Appendix 9. *Biomass of immature periphyton communities of experimental streams (means of 3 samples for all dates except 4 samples for fall series).*

Date of start of growth	Days of growth	Collection date	Grams per square meter loss on ignition						
			STREAM						
			1	2	3	4	5	6	7
10-24-69	6	10-30-69	6.45	5.42	4.45	1.85	.70	5.30	3.55
		SD	.76	.58	1.61	1.15	.64	2.42	--
	12	11-5-69	24.79	20.52	17.42	8.24	5.76	27.52	7.42
		SD	6.52	3.76	1.42	1.61	2.91	4.76	1.58
	18	11-11-69	29.00	36.73	37.64	24.30	18.76	39.00	10.15
		SD	8.48	12.73	10.06	5.73	5.27	12.42	1.61
	24	11-17-69	26.67	31.27	37.64	50.79	44.39	67.48	12.82
		SD	6.06	8.00	.85	10.33	4.00	24.99	2.55
1-30-70	14	2-13-70	2.85	3.42	2.21	2.03	1.06	2.21	2.52
		SD	1.06	.42	.21	.76	.61	.30	1.06
	20	2-18-70	12.73	12.52	8.64	4.45	2.24	6.33	6.33
			2.33	4.58	1.58	1.82	1.03	2.18	2.03
	26	2-24-70	27.09	27.39	21.76	11.52	5.36	14.85	24.48
		SD	2.67	4.52	1.42	2.12	2.85	2.09	--
4-24-70	10	5-4-70	6.52	3.67	1.76	1.73	1.15	2.18	8.67
		SD	1.24	1.79	.27	1.36	.36	.67	.85
	17	5-11-70	19.55	15.27	8.82	6.18	7.30	9.09	17.03
		SD	3.82	1.79	4.18	1.36	2.33	1.15	.09
	24	5-18-70	30.18	28.76	19.27	14.39	17.61	23.21	23.91
		SD	5.18	6.85	.70	1.94	2.45	.09	.39
	38	6-1-70	80.45	76.30	52.30	50.52	46.85	51.76	--
		SD	3.82	18.70	4.48	18.39	5.67	3.33	--
7-31-70	6	8-6-70	13.58	9.61	5.36	3.36	1.36	1.64	4.45
		SD	2.52	1.03	.91	1.36	.06	.58	1.06
	12	8-12-70	37.94	29.64	34.91	23.00	19.61	24.15	18.06
		SD	2.06	3.97	11.42	6.48	3.70	6.09	2.00
	18	8-18-70	47.73	49.00	44.45	33.24	33.39	39.73	27.12
		SD	6.03	1.64	5.82	6.21	6.00	10.00	8.03
	24	8-24-70	53.76	34.82	39.00	40.09	39.79	39.85	29.85
		SD	16.48	2.85	4.21	12.55	9.82	10.55	2.70

Appendix 10. *Accumulation of chlorophyll* a *standing crops on bare substrates, October 24-November 17, 1970.*

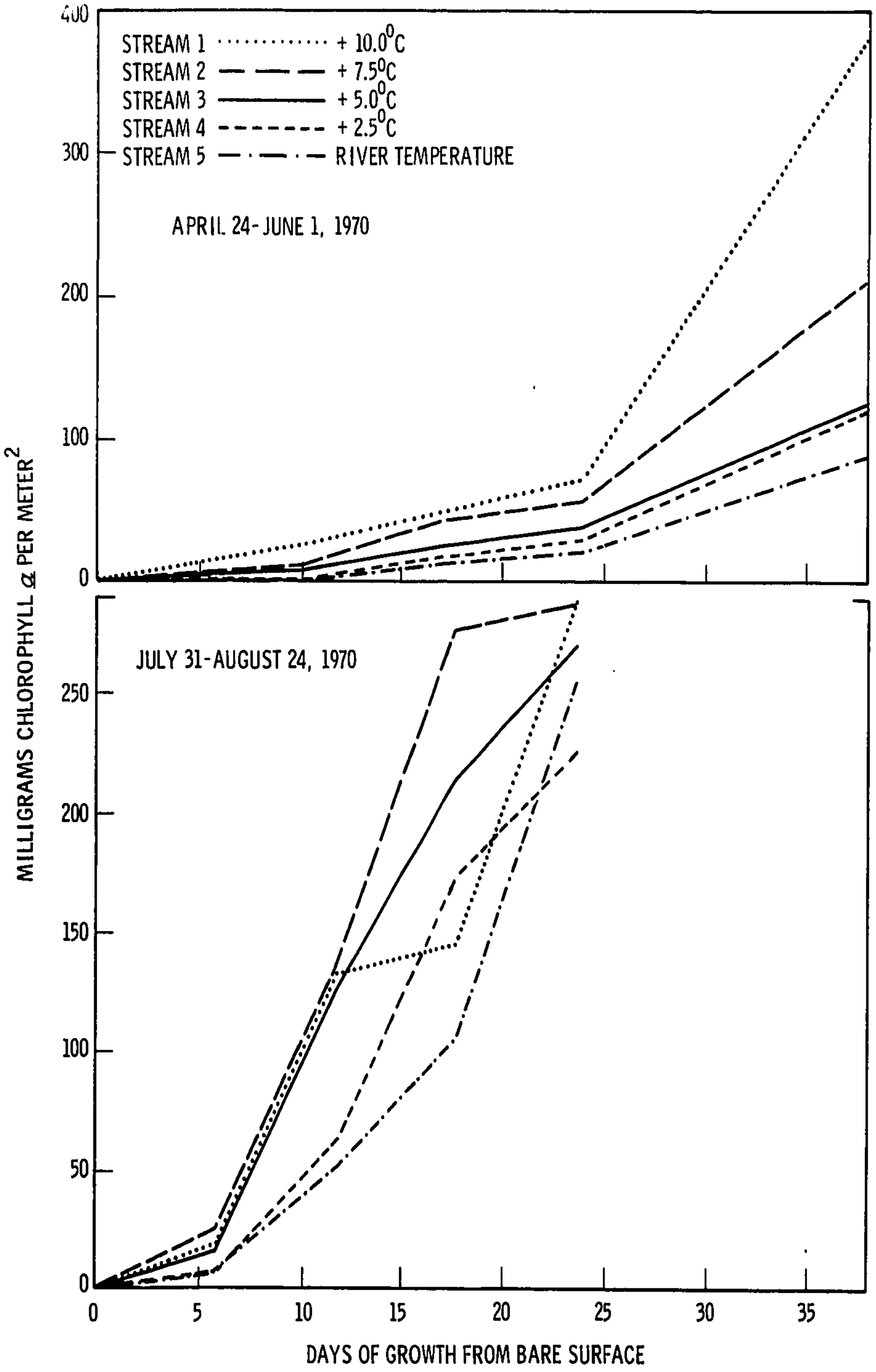
Appendix 11. *Accumulation of chlorophyll* a *standing crops on bare substrates, January 30-February 24, 1970.*



STREAM 1 ·········· + 10.0°C
STREAM 2 — — — + 7.5°C
STREAM 3 ——— + 5.0°C
STREAM 4 - - - - - + 2.5°C
STREAM 5 —·—·— RIVER TEMPERATURE
OCTOBER 24-NOVEMBER 17, 1969
JANUARY 30-FEBRUARY 24, 1970
250
200
150
100
50
0
5
10
15
20
25
30
MILLIGRAMS CHLOROPHYLL a PER METER²
DAYS OF GROWTH FROM BARE SURFACE

Appendix 12. *Accumulation of chlorophyll* a *standing crops on bare substrates, April 24-June 1, 1970.*

Appendix 13. *Accumulation of chlorophyll* a *standing crops on bare substrates, July 31 - August 24, 1970.*


STREAM 1 ············ + 10.0°C
STREAM 2 — — — + 7.5°C
STREAM 3 ——— + 5.0°C
STREAM 4 - - - - - + 2.5°C
STREAM 5 —·—·— RIVER TEMPERATURE
APRIL 24-JUNE 1, 1970
JULY 31-AUGUST 24, 1970
MILLIGRAMS CHLOROPHYLL a PER METER²
400
300
200
100
0
250
200
150
100
50
0
0
5
10
15
20
25
30
35
DAYS OF GROWTH FROM BARE SURFACE

Appendix 14. *Standing crops of immature community chloropyll a of experimental streams (mg/m^2).*

					STREAM			
DATE		1	2	3	4	5	6	7
10-30-69	$\bar{x}$	12	7	7	3	2.5	6	12
	SD	.5	1	2	.5	2	2	2
11-5-69	$\bar{x}$	122	102	70	33	22	65	32
	SD	23	12	11	5	10	19	2
11-11-69	$\bar{x}$	114	123	134	68	47	121	34
	SD	36	19	25	8	18	34	4
11-17-69	$\bar{x}$	114	253	192	--	260	357	12
	SD	--	93	62	--	24	--	--
2-13-70	$\bar{x}$	19	26	19	8	8	8	14
	SD	2.5	7	14	5	4	2	9
2-18-70	$\bar{x}$	112	102	60	30	11	59	87
	SD	15	24	10	13	4	45	40
2-24-70	$\bar{x}$	257	214	176	67	27	93	127
	SD	47	46	23	18	13	13	--
5-4-70	$\bar{x}$	23	11	6	3	1	3	1.0
	SD	4	2	2	1	.3	3	1.0
5-11-70	$\bar{x}$	49	42	25	18	14	38	53
	SD	5	8	9	4	3	9	2.8
5-18-70	$\bar{x}$	70	57	36	29	21	71	41
	SD	2	7	10	4	7	10	--
6-1-70	$\bar{x}$	378	211	126	122	91	185	--
	SD	16	29	17	32	14	27	--
8-6-70	$\bar{x}$	19	23	17	6	7	13	16
	SD	4	6	4	2	6	7	5
8-12-70	$\bar{x}$	132	133	124	63	51	152	63
	SD	7	44	38	14	13	21	9
8-18-70	$\bar{x}$	144	276	214	174	105	165	60
	SD	60	14	39	38	49	81	15
8-24-70	$\bar{x}$	289	287	270	226	256	286	234
	SD	41	29	29	32	23	47	6

Appendix 15. *Standing crops of immature community carotenoids of experimental streams* (mg/m^2).

DATE		STREAM 1	2	3	4	5	6	7
10-30-69	$\bar{x}$	6	3	3	1	1	3	5
	SD	.3	.6	.9	.2	1.4	1.5	1
11-5-69	$\bar{x}$	55	45	29	14	11	30	14
	SD	11	10	7	.5	6	15	3
11-11-69	$\bar{x}$	59	78	80	31	23	67	14
	SD	20	16	23	6	9	21	2
11-17-69	$\bar{x}$	85.3	212	144	--	205	268.8	6
	SD	--	70	55	--	14	--	--
2-13-70	$\bar{x}$	17	24	19	9	9	9	15
	SD	3	6	13	6	5	1	10
2-18-70	$\bar{x}$	99	97	65	34	13	63	91
	SD	12	22	12	15	4	47	39
2-24-70	$\bar{x}$	231	208	287	84	35	101	148.5
	SD	32	40	19	23	17	11	--
5-4-70	$\bar{x}$	28	14	7	3	2	7	23
	SD	4	2	3	1	.5	4	1
5-11-70	$\bar{x}$	66	57	34	25	18	46	63
	SD	6	10	12	5	4	10	2
5-18-70	$\bar{x}$	87	81	55	46	33	79	48
	SD	6	7	15	7	13	9	9
6-1-70	$\bar{x}$	311	179	131	141	110	190	--
	SD	32	31	11	40	16	27	--
8-6-70	$\bar{x}$	22	24	19	7	10	10	16
	SD	4	6	5	2	6	5	.5
8-12-70	$\bar{x}$	118	118	101	55	46	136	66
	SD	7	23	29	13	9	15	7
8-18-70	$\bar{x}$	116	223	146	140	109	114	44
	SD	47	14	19	37	58	53	12
8-24-70	$\bar{x}$	225	211	198	168	199	294	219
	SD	29	34	16	24	23	34	5

Appendix 16. *Stream export (grams ash-free dry weight per stream). Each datum represents material for the total previous period in which data are not indicated.*

COLLECTION DATE	1	2	3	4	5
1969					
Oct 27	.0226	.0240	.0213	.0786	.0453
Oct 29	.0270	.1095	.0777	.1059	.1179
Oct 31	.0413	.0434	.0616	.0495	.0788
Nov 3	.1105	.1466	.2654	.2216	.1690
Nov 3	.0589	.0117	.0511	.0138	.0391
Nov 3	.0250	.0329	.0156	.0289	.0322
Nov 4	.0669	.0860	.0213	.0272	.0352
Nov 7	.2715	.1270	.0398	.0970	.2337
Nov 10	.2497	.2019	.0395	.1420	.2256
Nov 10	.0292	.0998	.0623	.0034	.0746
Nov 10	.0086	.0083	.0128	.0044	.0247
Nov 11	.0131	.0407	.0387	.0109	.0200
Nov 14	.1344	.2752	.1469	.1500*	.1662
Nov 17	.7140	.9718	.0893	.3497	.3086
Nov 19	.0888	.1776	.1481	.1352	.3536
Nov 21	.1267	.5110	.1843	.0950	.1244
Nov 24	.1082	.1440	.0710	.1271	.1127
Nov 25	.0389	.1632	.0555	.0518	.0288
Nov 28	.1498	.2254	.3237	.3147	.3720
Dec 1	.0291	.1603	.0456	.1731	.0694

Appendix 16 Continued.

COLLECTION DATE	1	2	3	4	5
1969					
Dec 5	.0515	.1604	.1240	.0953	.2782
Dec 8	.0162	.1117	.0858	.1326	.0711
Dec 9	.0519	.0825	.0429	.0185	.0282
Dec 11	.2879	.8772	.9621	.7221	.4995
Dec 15	.1098	.4833	.4801	.5618	.5426
Dec 19	.1515	.0920	.1716	.1387	.0836
Dec 22	.0818	.0529	.0845	.1247	.0557
Dec 29	.3354	.1398	.3926	.2761	.1699
1970					
Jan 2	.2096	.2913	.1729	.3358	.1453
Jan 5	.2441	.1977	.2247	.1723	.0968
Jan 9	.3667	.5835	.6415	.3033	.2047
Jan 12	.5814	.6067	.4705	.7364	.1836
Jan 16	.6713	.2678	.4221	.5127	.1869
Jan 19	.6713	.8035	.7660	1.2930	3.1982
Jan 20	1.0193	.3605	.3626	.5007	1.3853
Jan 23	1.0650	.9044	.8824	1.3496	2.5662
Jan 27	.4250	.7194	.7999	.7334	.5147
Jan 27	.1100	.0797	.1287	.0737	.0243
Jan 30	.4025	.2597	.0990	.0954	.0335
Feb 6	.4246	.5543	.4502	.2557	.1065
Feb 11	.9406	.4065	.2248	.4752	.1170
Feb 12	.1059	.1589	.0363	.0408	.0634

Appendix 16 Continued.

COLLECTION DATE	1	2	3	4	5	Control net
1970						
Feb 13	.1173	.5654	.2629	.1614	.0281	
Feb 16	1.1128	1.2554	.8005	1.3664	.4484	
Feb 22	2.2513	1.1328	.8572	1.0792	1.5878	
Feb 24	1.2162	.5472	.4752	.3618	.6124	
Feb 27	.3027	.2814	.1645	.0852	.1625	
Mar 2	2.6824	1.7664	1.3472	.3092	.5513	
Mar 6	.1875	1.1340	.7430	.2704	.2898	
Mar 10	.8705	1.4895	1.5605	.2434	.0965	
Mar 15	3.8843	2.7677	2.0302	.7776	.1768	
Mar 19	1.3728	1.8732	1.3459	.6239	.0801	
Mar 23	3.6692	2.5091	1.9834	1.3664	.2322	
Mar 27	2.2195	2.6998q	1.7558	1.5950	.2627	
Mar 31	4.1923	3.8130	2.0666	2.0904	.2989	
Apr 3	2.7423	2.9414	2.4732	1.5484	.2650	
Apr 8	2.7345	3.2744	2.5200	2.9170	.9387	
Apr 10	2.3320	1.6954	.0824	1.1344	1.5636	
Apr 13	2.0835	1.0880	.8347	1.5522	.6784	
Apr 17	3.9981	2.0093	2.0263	1.7945	1.6578	
Apr 19	2.6340	1.9592	1.5456	1.2137	1.7041	
Apr 24	1.6247	4.0291	2.7095	1.7015	5.8435	
Apr 30	1.8734	2.2264	1.9769	1.5621	1.0791	
May 6	2.1792	1.0952	1.2030	1.9810	.6297	control net installed
May 13	2.6325	1.8628	1.9102	1.5328	1.0070	

Appendix 16 Continued.

COLLECTION DATE	1	2	3	4	5	Control net
1970						
May 20	1.1763	1.1828	1.1249	.9290	.6908	
May 27	2.2563	5.1686	2.0614	1.1539	1.0385	
Jun 4	3.4760	3.6330	2.3435	2.3505	1.8027	.2328
Jun 9	8.3060	6.5090	3.9000	5.1855	4.7950	
Jun 16	2.7545	2.1097	1.2719	1.1588	.2088	
No data June 16 to July 12; streams started again July 2						
Jul 16	1.6410	2.9132	1.1563		1.5455	.8591
Jul 23	2.0445	2.0640	1.0970	1.4497	1.4778	.7643
Jul 28	2.6850	6.3830	5.7160	4.1120	3.5775	.2415
No data July 28 to August 3						
Aug 7	.8199	1.5430	3.1225	2.5415	2.8220	.2805
Aug 10	1.8590	3.1260	2.4100	2.9344	2.5973	.0995
Aug 14	2.2788	3.8664	2.6520	4.3505	4.0388	.2625
Aug 18	2.1842	3.0180	3.3218	4.4164	2.8220	.1535
Aug 24	4.8468	4.8979	3.8847	5.8655	4.6974	.2025
Aug 27	1.4633	3.0302	3.1262	3.5871	3.8483	
Aug 31	3.3705	3.7594	4.1621	4.7090	4.8143	.0402
Sep 3	2.0597	6.2130	4.9541	5.8249	3.0359	.0497
Sep 8	3.5568	2.6753	2.0510	3.1054	2.4830	
Sep 10	2.4245	1.2111	1.7491	1.1103	1.2167	
Sep 14	2.9063	2.8819	2.2214	3.6545	2.5859	
Sep 16	3.1943	2.0229	2.4443	4.4387	1.7103	

Appendix 16 Continued.

COLLECTION DATE	1	2	3	4	5	Control net
1970						
Sep 18	1.2556	2.4280	2.0418	3.2530	1.4625	.2604
Sep 21	3.2220	1.6489	4.1200	3.3937	2.7989	
Sep 23	1.5278	1.4911	1.2771	2.0428	1.9184	
Sep 25	2.2379	.6631	1.5643	.3202	.5680	.1955
Sep 28	2.7557	1.7467	3.4500	3.2683	2.0192	
Sep 30	.5793	1.2462	.5463	2.5283	3.9651	
Oct 2	1.6989	5.0528	2.4380	2.4276	1.5990	
Oct 5	2.8322	4.5565	3.2974	4.4073	3.8223	
Oct 8	1.2492	1.5415	1.7322	3.2890	1.4867	
Oct 12	1.6868	2.8325	3.0704	1.1333	3.0359	
Oct 15	.5920	2.8829	1.4416	3.1411	2.3163	
Oct 19	2.1473	2.0907	2.2816	1.4057	3.0033	
Oct 22	2.0780	.5183	.6303	1.8002	.7280	
Oct 26	.5643	1.3649	1.7355	2.0020	1.4869	

*Estimated.

Appendix 17. *Indices of similarity for the 11-17-69 communities (A and B are replicate samples).*

COLLECTION DATE		STREAM		
		1A	3A	5A
11-17-69	1A	1.000	.638	.635
	3A	.638	1.000	.963
	5A	.625	.963	1.000
12-29-70	1A	.871	.636	.633
	3A	.862	.658	.673
	5A	.781	.644	.694
1-29-70	1A	.820	.615	.613
	1B	.793	.682	.679
	3A	.710	.436	.468
	3B	.684	.427	.449
	5A	.352	.195	.214
	5B	.402	.241	.252
	6A	.310	.263	.252
3-4-70	1A	.670	.658	.671
	3A	.300	.218	.248
	5A	.248	.131	.149
4-7-70	1A	.680	.419	.425
	1B	.679	.424	.427
	3A	.322	.198	.230
	3B	.300	.180	.198
	5A	.140	.097	.133
	5B	.143	.081	.103
	6A	.117	.097	.123
5-14-70	1A	.475	.338	.355
	3A	.214	.144	.164
	5A	.137	.091	.110
6-1-70	1A	.247	.166	.173
	3A	.178	.096	.108
	5A	.096	.057	.068
7-30-70	1A	.074	.041	.040
	1B	.109	.062	.060
	3A	.729	.494	.493
	3B	.672	.515	.515
	5A	.776	.639	.637
	5B	.801	.591	.593
	6A	.848	.579	.573
	7A	.403	.230	.232

Appendix 17. Continued.

		1A	3A	5A
8-24-70	1A	.555	.897	.878
	3A	.637	.414	.413
	5A	.577	.839	.839
9-21-70	1A	.554	.751	.748
	1B	.372	.641	.636
	3A	.731	.595	.596
	3B	.719	.664	.656
	5A	.480	.786	.771
	5B	.542	.776	.782
10-26-70	1A	.623	.387	.397
	3A	.687	.730	.739
	5A	.809	.604	.626
	6A	.569	.355	.362

Appendix 18. *Indices of similarity for the 12-29-69 communities (A and B are replicate samples).*

COLLECTION DATE		STREAM		
		1A	3A	5A
11-17-69	1A	.871	.862	.781
	3A	.636	.658	.664
	5A	.633	.673	.694
12-29-69	1A	1.000	.910	.781
	3A	.910	1.000	.852
	5A	.781	.852	1.000
1-29-70	1A	.929	.880	.755
	1B	.868	.869	.790
	3A	.687	.688	.618
	3B	.650	.681	.602
	5A	.309	.330	.304
	5B	.354	.379	.390
	6A	.300	.306	.341
3-4-70	1A	.751	.747	.734
	3A	.325	.338	.377
	5A	.209	.254	.241
4-7-70	1A	.696	.675	.556
	1B	.710	.682	.564
	3A	.281	.318	.376
	3B	.274	.310	.310
	5A	.118	.166	.238
	5B	.117	.162	.200
	6A	.111	.130	.188
5-14-70	1A	.518	.485	.456
	3A	.263	.240	.261
	5A	.113	.160	.191
6-1-70	1A	.246	.242	.232
	3A	.168	.177	.185
	5B	.094	.117	.117
7-30-70	1A	.076	.070	.053
	1B	.108	.103	.080
	3A	.689	.676	.612
	3B	.678	.667	.617
	5A	.788	.821	.782
	5B	.796	.689	.724
	6A	.786	.785	.718
	7A	.380	.360	.307

Appendix 18. Continued.

		1A	3A	5A
8-24-70	1A	.572	.590	.582
	3A	.597	.573	.517
	5A	.597	.614	.625
9-21-70	1A	.576	.591	.582
	1B	.396	.412	.411
	3A	.742	.770	.735
	3B	.719	.747	.725
	5A	.506	.529	.523
	5B	.564	.598	.600
10-26-70	1A	.592	.597	.533
	3A	.693	.723	.745
	5A	.805	.809	.796
	6A	.554	.563	.496

Appendix 19. *Indices of similarity for the 1-29-70 communities (A and B are replicate samples).*

COLLECTION DATE		STREAM 1A	1B	3A	3B	5A	5B	6A
11-17-69	1A	.820	.793	.710	.684	.352	.402	.310
	3A	.615	.682	.463	.427	.195	.241	.263
	5A	.613	.679	.468	.449	.214	.274	.282
12-29-69	1A	.929	.868	.687	.650	.309	.354	.300
	3A	.880	.869	.688	.681	.330	.379	.306
	5A	.755	.790	.618	.602	.304	.390	.341
1-29-70	1A	1.000	.911	.655	.636	.273	.323	.288
	1B	.911	1.000	.640	.617	.271	.312	.283
	3A	.655	.640	1.000	.854	.447	.541	.290
	3B	.636	.617	.854	1.000	.513	.601	.283
	5A	.273	.271	.447	.513	1.000	.790	.123
	5B	.323	.312	.541	.601	.790	1.000	.167
	6A	.288	.283	.290	.283	.123	.167	1.000
3-4-70	1A	.776	.818	.556	.537	.248	.298	.294
	3A	.321	.306	.421	.423	.266	.343	.212
	5A	.194	.194	.381	.397	.585	.570	.088
4-7-70	1A	.681	.658	.855	.857	.453	.499	.265
	1B	.694	.661	.857	.824	.435	.475	.270
	3A	.255	.254	.548	.475	.597	.637	.179
	3B	.262	.258	.417	.476	.595	.606	.175
	5A	.108	.107	.262	.280	.295	.353	.144
	5B	.107	.105	.236	.287	.313	.380	.126
	6A	.104	.103	.162	.175	.157	.188	.713
5-14-70	1A	.529	.495	.600	.587	.258	.336	.252
	3A	.275	.252	.331	.336	.286	.324	.171
	5A	.108	.109	.233	.243	.244	.302	.138

Appendix 19. Continued

		1A	1B	3A	3B	5A	5B	6A
6-1-70	1A	.239	.237	.299	.331	.261	.326	.129
	3A	.159	.161	.253	.306	.366	.369	.098
	5A	.091	.086	.147	.187	.216	.212	.083
7-30-70	1A	.066	.066	.078	.085	.114	.091	.025
	1B	.095	.092	.120	.130	.184	.150	.037
	3A	.663	.638	.589	.589	.265	.316	.291
	3B	.655	.637	.472	.467	.209	.249	.266
	5A	.776	.809	.553	.557	.258	.304	.291
	5B	.757	.735	.582	.276	.274	.333	.300
	6A	.756	.720	.676	.669	.338	.409	.323
	7A	.351	.338	.464	.493	.494	.547	.133
8-24-70	1A	.561	.624	.375	.370	.149	.177	.235
	3A	.563	.545	.656	.647	.298	.349	.259
	5A	.585	.652	.409	.404	.168	.215	.256
9-21-70	1A	.581	.644	.380	.369	.143	.174	.231
	1B	.401	.448	.253	.250	.094	.117	.190
	3A	.726	.739	.534	.522	.238	.289	.283
	3B	.702	.778	.518	.492	.219	.258	.266
	5A	.495	.553	.344	.339	.142	.168	.222
	5B	.550	.613	.400	.403	.180	.218	.250
10-26-70	1A	.588	.569	.712	.791	.379	.432	.251
	3A	.669	.741	.516	.503	.221	.289	.293
	5A	.757	.736	.620	.616	.293	.376	.327
	6A	.569	.543	.679	.758	.429	.488	.223

Appendix 20. *Indices of similarity for the 3-4-70 communities (A and B are replicate samples)*

COLLECTION DATE		STREAM 1A	3A	5A
11-17-69	1A	.670	.300	.248
	3A	.658	.218	.131
	5A	.671	.248	.149
12-29-70	1A	.751	.325	.209
	3A	.747	.338	.254
	5A	.734	.377	.241
1-29-70	1A	.776	.321	.194
	1B	.818	.306	.194
	3A	.556	.421	.381
	3B	.537	.423	.397
	5A	.248	.266	.585
	5B	.298	.242	.570
	6A	.294	.212	.088
3-4-70	1A	.000	.367	.176
	3A	.367	1.000	.255
	5A	.176	.255	1.000
4-7-70	1A	.551	.396	.346
	1B	.573	.413	.351
	3A	.296	.418	.558
	3B	.283	.366	.491
	5A	.178	.351	.360
	5B	.149	.297	.371
	6A	.174	.269	.144
5-14-70	1A	.594	.395	.215
	3A	.336	.396	.235
	5A	.182	.333	.311
6-1-70	1A	.232	.243	.186
	3A	.186	.214	.379
	5A	.121	.131	.188
7-30-70	1A	.063	.063	.095
	1B	.079	.083	.166
	3A	.563	.277	.142
	3B	.567	.235	.122
	5A	.714	.276	.152
	5B	.667	.298	.179
	6A	.645	.316	.234
	7A	.262	.272	.317

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Appendix 20. Continued

		1A	3A	5A
8-24-70	1A	.590	.179	.083
	3A	.447	.261	.164
	5A	.629	.225	.103
9-21-70	1A	.610	.190	.080
	1B	.445	.142	.059
	3A	.646	.269	.151
	3B	.704	.244	.137
	5A	.547	.190	.090
	5B	.609	.225	.113
10-26-70	1A	.489	.350	.236
	3A	.729	.280	.155
	5A	.694	.337	.200
	6A	.464	.365	.286

Appendix 21. *Indices of similarity for the 4-7-70 communities (A and B are replicate samples).*

COLLECTION DATE		STREAM 1A	1B	3A	3B	5A	5B	6A
11-17-69	1A	.680	.679	.322	.300	.140	.143	.117
	3A	.419	.424	.198	.180	.097	.081	.097
	5A	.425	.427	.230	.198	.133	.103	.123
12-29-69	1A	.696	.710	.281	.274	.118	.117	.111
	3A	.675	.682	.318	.310	.166	.162	.130
	5A	.556	.564	.376	.310	.238	.200	.188
1-29-70	1A	.681	.694	.255	.262	.108	.107	.104
	1B	.658	.661	.254	.258	.107	.105	.103
	3A	.855	.857	.468	.417	.262	.236	.162
	3B	.857	.824	.475	.476	.280	.287	.175
	5A	.453	.435	.597	.595	.295	.313	.157
	5B	.499	.475	.637	.606	.353	.380	.188
	6A	.265	.270	.179	.175	.144	.126	.713
3-4-70	1A	.551	.573	.296	.283	.178	.149	.174
	3A	.396	.413	.148	.366	.351	.297	.269
	5A	.346	.351	.558	.491	.360	.371	.144
4-7-70	1A	1.000	.947	.440	.458	.226	.239	.145
	1B	.947	1.000	.445	.448	.232	.240	.149
	3A	.440	.445	1.000	.729	.492	.450	.269
	3B	.458	.448	.729	1.000	.555	.601	.281
	5A	.226	.232	.492	.555	1.000	.825	.335
	5B	.239	.240	.450	.601	.825	1.000	.285
	6A	.145	.149	.269	.281	.335	.285	1.000
5-14-70	1A	.616	.639	.349	.344	.251	.220	.223
	3A	.336	.351	.436	.480	.407	.382	.321
	5A	.213	.230	.416	.520	.584	.559	.307

Appendix 21. Continued

		1A	1B	3A	3B	5A	5B	6A
6-1-70	1A	.348	.344	.295	.323	.191	.174	.158
	3A	.312	.313	.448	.479	.423	.445	.205
	5A	.178	.184	.257	.281	.337	.302	.168
7-30-70	1A	.117	.119	.117	.114	.079	.080	.041
	1B	.156	.155	.172	.163	.087	.088	.055
	3A	.623	.627	.301	.311	.122	.121	.117
	3B	.494	.500	.234	.234	.103	.102	.103
	5A	.586	.593	.301	.312	.163	.145	.146
	5B	.595	.605	.331	.333	.172	.164	.146
	6A	.689	.691	.384	.384	.218	.185	.176
	7A	.518	.495	.444	.448	.156	.167	.112
8-24-70	1A	.388	.393	.144	.146	.057	.054	.073
	3A	.688	.684	.281	.280	.097	.101	.093
	5A	.416	.419	.204	.217	.106	.108	.106
9-21-70	1A	.396	.404	.149	.159	.075	.069	.083
	1B	.266	.273	.102	.114	.065	.055	.086
	3A	.550	.547	.260	.286	.160	.145	.128
	3B	.523	.526	.223	.241	.124	.111	.110
	5A	.357	.362	.149	.164	.099	.087	.104
	5B	.400	.404	.190	.196	.125	.120	.116
10-26-70	1A	.773	.747	.365	.377	.229	.223	.162
	3A	.492	.495	.271	.248	.196	.164	.161
	5A	.596	.596	.356	.323	.248	.207	.194
	6A	.736	.705	.392	.435	.248	.231	.187

Appendix 22. *Indices of similarity for the 5-14-70 communities (A and B are replicate samples).*

COLLECTION DATE		STREAM		
		1A	3A	5A
11-17-69	1A	.475	.214	.137
	3A	.338	.144	.091
	5A	.355	.164	.110
12-29-69	1A	.518	.263	.113
	3A	.485	.240	.160
	5A	.456	.261	.191
1-29-70	1A	.529	.275	.108
	1B	.495	.252	.109
	3A	.600	.331	.233
	3B	.587	.336	.243
	5A	.258	.286	.244
	5B	.336	.324	.302
	6A	.252	.171	.138
3-4-70	1A	.594	.336	.182
	3A	.395	.396	.333
	5A	.215	.235	.311
4-7-70	1A	.616	.336	.213
	1B	.639	.351	.230
	3A	.349	.436	.416
	3B	.344	.480	.520
	5A	.251	.407	.584
	5B	.220	.382	.559
	6A	.223	.321	.307
5-14-70	1A	1.000	.687	.509
	3A	.687	1.000	.673
	5A	.509	.673	1.000
6-1-70	1A	.371	.299	.232
	3A	.417	.422	.489
	5A	.221	.258	.331
7-30-70	1A	.118	.087	.082
	1B	.141	.108	.085
	3A	.508	.233	.136
	3B	.428	.199	.111
	5A	.505	.278	.174
	5B	.512	.305	.180
	6A	.536	.292	.252
	7A	.331	.299	.137

Appendix 22. Continued

		1A	3A	5A
8-24-70	1A	.329	.119	.055
	3A	.505	.204	.094
	5A	.379	.217	.113
9-21-70	1A	.351	.136	.068
	1B	.272	.118	.069
	3A	.469	.255	.147
	3B	.447	.230	.119
	5A	.331	.209	.099
	5B	.352	.228	.104
10-26-70	1A	.577	.321	.170
	3A	.467	.283	.147
	5A	.520	.349	.186
	6A	.552	.355	.257

Appendix 23. *Indices of similarity for the 6-1-70 communities (A and B are replicate samples).*

COLLECTION DATE		STREAM		
		1A	3A	5A
11-17-69	1A	.247	.178	.096
	3A	.166	.096	.057
	5A	.173	.108	.068
12-29-69	1A	.246	.168	.094
	3A	.242	.177	.117
	5A	.232	.185	.117
1-29-70	1A	.239	.159	.091
	1B	.237	.161	.086
	3A	.299	.253	.147
	3B	.331	.306	.187
	5A	.261	.366	.216
	5B	.326	.369	.212
	6A	.129	.098	.083
3-4-70	1A	.232	.186	.121
	3A	.243	.214	.131
	5A	.186	.379	.188
4-7-70	1A	.348	.312	.178
	1B	.344	.313	.184
	3A	.295	.448	.256
	3B	.323	.479	.281
	5A	.191	.423	.337
	5B	.174	.445	.302
	6A	.158	.205	.168
5-14-70	1A	.371	.417	.221
	3A	.299	.422	.258
	5A	.232	.489	.331
6-1-70	1A	1.000	.395	.226
	3A	.395	1.000	.477
	5A	.226	.477	1.000
7-30-70	1A	.569	.219	.086
	1B	.588	.278	.094
	3A	.474	.296	.130
	3B	.561	.229	.097
	5A	.356	.337	.185
	5B	.368	.304	.149
	6A	.322	.321	.223
	7A	.391	.358	.143

Appendix 23. Continued.

		1A	3A	5A
8-24-70	1A	.290	.136	.058
	3A	.490	.273	.105
	5A	.287	.193	.083
9-21-70	1A	.368	.160	.074
	1B	.342	.127	.068
	3A	.472	.280	.127
	3B	.419	.242	.111
	5A	.207	.150	.095
	5B	.216	.162	.101
10-26-70	1A	.372	.365	.202
	3A	.320	.252	.133
	5A	.298	.273	.175
	6A	.284	.402	.294

Appendix 24. *Indices of similarity for the 7-30-70 communities (A and B are replicate samples).*

COLLECTION DATE		STREAM							
		1A	1B	3A	3B	5A	5B	6A	7A
11-17-69	1A	.074	.109	.729	.672	.776	.801	.848	.403
	3A	.041	.062	.494	.515	.639	.591	.579	.230
	5A	.040	.060	.493	.515	.637	.593	.573	.232
12-29-69	1A	.076	.108	.689	.678	.788	.796	.786	.380
	3A	.070	.103	.676	.667	.821	.789	.785	.360
	5A	.053	.080	.612	.617	.782	.724	.718	.307
1-29-70	1A	.066	.095	.663	.655	.776	.757	.756	.351
	1B	.066	.092	.638	.637	.809	.735	.720	.338
	3A	.078	.120	.589	.472	.553	.582	.676	.464
	3B	.085	.130	.589	.467	.557	.576	.669	.493
	5A	.114	.184	.265	.209	.258	.274	.338	.494
	5B	.091	.150	.316	.249	.304	.333	.409	.547
	6A	.025	.037	.291	.266	.291	.300	.323	.133
3-4-70	1A	.063	.079	.563	.567	.714	.667	.645	.262
	3A	.063	.083	.277	.235	.276	.298	.316	.272
	5A	.095	.166	.142	.122	.152	.179	.234	.317
4-7-70	1A	.117	.156	.623	.494	.586	.595	.689	.518
	1B	.119	.155	.627	.500	.593	.605	.691	.495
	3A	.117	.172	.301	.234	.301	.331	.384	.444
	3B	.114	.163	.311	.234	.312	.333	.384	.448
	5A	.079	.087	.122	.103	.163	.172	.218	.156
	5B	.080	.088	.121	.102	.145	.164	.185	.167
	6A	.041	.055	.117	.103	.146	.146	.176	.112
5-14-70	1A	.118	.141	.508	.428	.505	.512	.536	.331
	3A	.087	.108	.233	.199	.278	.305	.292	.299
	5A	.082	.085	.136	.111	.174	.180	.252	.137

Appendix 24. Continued.

		1A	1B	3A	3B	5A	5B	6A	7A
6-1-70	1A	.569	.588	.474	.561	.356	.368	.322	.391
	3A	.219	.278	.296	.229	.337	.304	.321	.358
	5A	.086	.094	.130	.097	.185	.149	.223	.143
7-30-70	1A	1.000	.838	.347	.571	.161	.203	.083	.181
	1B	.838	1.000	.403	.503	.191	.236	.113	.244
	3A	.347	.403	1.000	.785	.761	.811	.768	.442
	3B	.571	.503	.785	1.000	.736	.773	.646	.343
	5A	.161	.191	.761	.736	1.000	.892	.795	.443
	5B	.203	.236	.811	.773	.892	1.000	.800	.457
	6A	.083	.113	.768	.646	.795	.800	1.000	.414
	7A	.181	.244	.442	.343	.443	.457	.414	1.000
8-24-70	1A	.202	.230	.606	.604	.644	.611	.508	.232
	3A	.376	.443	.868	.689	.654	.699	.638	.519
	5A	.149	.174	.606	.609	.718	.712	.550	.306
9-21-70	1A	.270	.297	.617	.655	.647	.615	.510	.241
	1B	.302	.259	.418	.578	.464	.429	.359	.152
	3A	.313	.354	.817	.808	.858	.837	.702	.400
	3B	.273	.310	.781	.762	.843	.806	.672	.373
	5A	.057	.069	.428	.459	.582	.547	.472	.233
	5B	.059	.074	.481	.507	.631	.605	.515	.262
10-26-70	1A	.166	.208	.635	.507	.592	.597	.619	.520
	3A	.148	.177	.664	.665	.805	.789	.651	.355
	5A	.099	.127	.717	.700	.816	.868	.774	.443
	6A	.100	.144	.526	.412	.539	.517	.659	.529

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Appendix 25. *Indices of similarity for the 8-24-70 communities (A and B are replicate samples).*

COLLECTION DATE		STREAM 1A	3A	5A
11-17-69	1A	.555	.637	.577
	3A	.897	.414	.839
	5A	.878	.413	.839
12-29-69	1A	.572	.597	.597
	3A	.590	.573	.614
	5A	.582	.517	.625
1-29-70	1A	.561	.563	.585
	1B	.624	.545	.652
	3A	.375	.656	.409
	3B	.370	.647	.404
	5A	.149	.298	.168
	5B	.177	.349	.215
	6A	.235	.259	.256
3-4-70	1A	.590	.447	.629
	3A	.179	.261	.225
	5A	.083	.164	.103
4-7-70	1A	.388	.688	.416
	1B	.393	.684	.419
	3A	.144	.281	.204
	3B	.146	.280	.217
	5A	.057	.097	.106
	5B	.054	.101	.108
	6A	.073	.093	.106
5-14-70	1A	.329	.505	.379
	3A	.119	.204	.217
	5A	.055	.094	.113
6-1-70	1A	.290	.490	.287
	3A	.136	.273	.193
	5A	.058	.105	.083
7-30-70	1A	.202	.376	.149
	1B	.230	.443	.174
	3A	.606	.686	.606
	3B	.604	.689	.609
	5A	.644	.654	.718
	5B	.611	.699	.712
	6A	.508	.638	.550
	7A	.232	.519	.306

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Appendix 25. Continued.

		1A	3A	5A
8-24-70	1A	1.000	.541	.869
	3A	.541	1.000	.527
	5A	.869	.527	1.000
9-21-70	1A	.817	.537	.797
	1B	.713	.355	.630
	3A	.675	.735	.706
	3B	.729	.701	.739
	5A	.773	.354	.772
	5B	.737	.395	.831
10-26-70	1A	.391	.673	.416
	3A	.725	.567	.802
	5A	.552	.600	.652
	6A	.315	.578	.347

Appendix 26. *Indices of similarity for the 9-21-70 communities (A and B are replicate samples).*

COLLECTION DATE		STREAM 1A	1B	3A	3B	5A	5B
11-17-69	1A	.554	.372	.731	.719	.480	.542
	3A	.751	.641	.595	.664	.786	.776
	5A	.748	.636	.596	.656	.771	.782
12-29-70	1A	.576	.396	.742	.719	.506	.564
	3A	.591	.412	.770	.747	.529	.598
	5A	.582	.411	.735	.725	.523	.600
1-29-70	1A	.581	.401	.726	.702	.495	.550
	1B	.644	.448	.739	.778	.553	.613
	3A	.380	.253	.534	.518	.344	.400
	3B	.369	.250	.522	.492	.339	.403
	5A	.143	.094	.238	.219	.142	.180
	5B	.174	.117	.289	.258	.168	.218
	6A	.231	.190	.283	.266	.222	.250
3-4-70	1A	.610	.445	.646	.704	.547	.609
	3A	.190	.142	.269	.244	.190	.225
	5A	.080	.059	.151	.137	.090	.113
4-7-70	1A	.396	.266	.550	.523	.357	.400
	1B	.404	.273	.547	.526	.362	.404
	3A	.149	.102	.260	.223	.149	.190
	3B	.159	.114	.286	.241	.164	.196
	5A	.075	.065	.160	.124	.099	.125
	5B	.069	.055	.145	.111	.087	.120
	6A	.083	.086	.128	.110	.104	.116
5-14-70	1A	.351	.272	.469	.447	.331	.352
	3A	.136	.118	.255	.230	.209	.228
	5A	.069	.147	.147	.119	.099	.104

Appendix 26. Continued

		1A	1B	3A	3B	5A	5B
6-1-70	1A	.368	.342	.472	.419	.207	.216
	3A	.160	.127	.280	.242	.150	.162
	5A	.074	.068	.127	.111	.095	.101
7-30-70	1A	.270	.302	.313	.273	.057	.059
	1B	.297	.259	.354	.310	.069	.074
	3A	.617	.418	.817	.781	.428	.481
	3B	.655	.578	.808	.762	.459	.507
	5A	.647	.464	.858	.843	.582	.631
	5B	.615	.429	.837	.806	.547	.605
	6A	.510	.359	.702	.672	.472	.515
	7A	.241	.152	.400	.373	.233	.262
8-24-70	1A	.817	.713	.675	.729	.773	.737
	3A	.537	.355	.735	.701	.354	.395
	5A	.797	.630	.706	.739	.772	.831
9-21-70	1A	1.000	.720	.715	.757	.648	.702
	1B	.720	1.000	.517	.543	.664	.563
	3A	.715	.517	1.000	.910	.552	.605
	3B	.757	.543	.910	1.000	.602	.652
	5A	.648	.664	.552	.602	1.000	.890
	5B	.702	.563	.605	.652	.890	1.000
10-26-70	1A	.422	.300	.570	.549	.358	.407
	3A	.733	.540	.795	.839	.652	.730
	5A	.561	.402	.778	.736	.544	.626
	6A	.335	.241	.483	.460	.328	.348

Appendix 27. *Indices of similarity for the 10-26-70 communities (A and B are replicate samples).*

COLLECTION DATE		STREAM			
		1A	3A	5A	6A
11-17-69	1A	.623	.687	.809	.569
	3A	.387	.730	.604	.355
	5A	.397	.739	.626	.362
12-29-69	1A	.592	.693	.805	.554
	3A	.597	.723	.809	.563
	5A	.533	.745	.796	.496
1-29-70	1A	.588	.669	.757	.569
	1B	.569	.741	.736	.543
	3A	.712	.516	.620	.679
	3B	.791	.503	.616	.758
	5A	.397	.221	.293	.429
	5B	.432	.289	.376	.488
	6A	.251	.293	.327	.223
3-4-70	1A	.489	.729	.694	.464
	3A	.350	.280	.337	.365
	5A	.236	.155	.200	.286
4-7-70	1A	.773	.492	.596	.736
	1B	.747	.495	.596	.705
	3A	.365	.271	.356	.392
	3B	.377	.248	.323	.435
	5A	.229	.196	.248	.248
	5B	.223	.164	.207	.231
	6A	.162	.161	.194	.187
5-14-70	1A	.577	.467	.520	.552
	3A	.321	.283	.349	.355
	5A	.170	.147	.186	.257
6-1-70	1A	.372	.320	.298	.384
	3A	.365	.252	.273	.402
	5A	.202	.133	.175	.294
7-30-70	1A	.166	.148	.099	.100
	1B	.208	.177	.127	.144
	3A	.635	.644	.717	.526
	3B	.507	.665	.700	.412
	5A	.592	.805	.816	.539
	5B	.597	.789	.868	.517
	6A	.619	.651	.774	.659
	7A	.520	.355	.443	.529
8-24-70	1A	.391	.725	.552	.315
	3A	.673	.567	.600	.578
	5A	.416	.802	.652	.347

Appendix 27. Continued.

		1A	3A	5A	6A
9-21-70	1A	.422	.733	.561	.335
	1B	.300	.540	.402	.241
	3A	.570	.795	.778	.483
	3B	.549	.839	.736	.460
	5A	.358	.652	.544	.328
	5B	.407	.730	.626	.348
10-26-70	1A	1.000	.577	.645	.754
	3A	.577	1.000	.813	.435
	5A	.645	.813	1.000	.535
	6A	.754	.435	.535	1.000

Appendix 28. *Periphyton species diversity indices from experimental streams. Indices based on:*

DATE;	Stream	Mean # sp.	TOTAL COMMUNITY BIOMASS Mean H'	Range H'*	Mean J'	DIATOM BIOMASS Mean H'	DIATOM COUNT Mean H'	DIATOM COUNT LIVE + DEAD Mean H'
11-17-69	1	26	1.35		.29	1.25	2.81	3.28
	3	21	.60		.14	.60	2.25	3.09
	5	23	.87		.19	.86	2.80	3.31
12-29-69	1	26	1.47		.32	1.35	1.59	1.78
	3	26	1.47		.32	1.46	2.51	2.74
	5	27	1.94		.41	1.93	3.05	3.60
1-29-70	1	24	1.47	±.14	.34	1.27	1.79	2.01
	3	30	2.45	±.00	.50	2.44	2.42	3.07
	5	27	3.08	±.05	.64	3.07	3.23	3.37
3-4-70	1	36	2.29		.44	2.16	1.82	1.99
	3	33	2.69		.53	2.67	2.00	2.35
	5	27	3.36		.71	3.36	3.05	3.44
4-7-70	1	27	2.30	±.14	.47	2.15	2.20	2.57
	3	28	3.26	±.01	.68	3.17	2.84	3.31
	5	30	3.68	±.05	.74	3.60	2.84	3.08
5-14-70	1	25	3.16		.68	3.04	2.42	2.77
	3	26	3.41		.73	3.35	2.76	2.96
	5	25	2.90		.63	2.90	2.79	3.01
6-1-70	1	29	2.85		.59	2.33	3.53	3.01
	3	26	3.57		.76	3.50	3.45	3.49
	5	25	2.78		.60	3.23	3.36	3.21
7-30-70	1	17	1.26	±.05	.32	.81	2.44	2.92
	3	22	1.74	±.07	.40	1.61	2.97	3.39
	5	27	1.85	±.20	.36	1.77	3.07	3.44
8-24-70	1	25	.84		.18	.81	2.46	3.23
	3	18	1.63		.39	1.53	3.01	3.62
	5	22	1.34		.30	1.32	2.88	3.52
9-21-70	1	24	1.79	±.13	.37	1.40	2.78	3.55
	3	24	1.88	±.19	.43	1.77	2.84	3.51
	5	25	1.60	±.19	.33	1.50	2.98	3.43
10-26-70	1	26	2.59		.55	2.41	3.41	3.84
	3	26	1.90		.40	1.79	2.96	3.46
	5	27	2.20		.46	2.11	3.26	3.63

* 2 duplicates H' = Shannon diversity index J' = Evenness

Appendix 29. *Correlation analyses of periphyton diversity versus temperature, diversity versus temperature, and productivity versus temperature.*

I. Diversity versus temperature

Stream	n	r	A	B	Significance of r*
1	11	-.33	27.06	-2.42	--
3	11	-.47	23.85	-2.69	--
5	11	-.78	23.73	-4.61	v.s.
All	33	-.53	26.82	-4.11	v.s.

II. Diversity versus productivity.

Stream	n	r	A	B	Significance of r
1	11	-.11	2.35	-.17	--
3	11	-.24	2.68	-.35	--
5	11	-.62	4.12	-.96	s.
All	33	-.35	3.07	-.52	v.s.

III. Temperature versus productivity

Stream	n	r	A	B	Significance of r
1 1	11	.58	-.84	.12	--
3	11	.82	-1.82	.21	v.s.
5	11	.91	-1.22	.24	v.s.
All	33	.64	-.26	.12	v.s.

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* -- = not significant
s. = p between .05 and .01
v.s. = p less than .01

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Appendix 19. *Indices of similarity for the 1-29-70 communities (A and B are replicate samples).*

COLLECTION DATE		STREAM						
		1A	1B	3A	3B	5A	5B	6A
11-17-69	1A	.820	.793	.710	.684	.352	.402	.310
	3A	.615	.682	.463	.427	.195	.241	.263
	5A	.613	.679	.468	.449	.214	.274	.282
12-29-69	1A	.929	.868	.687	.650	.309	.354	.300
	3A	.880	.869	.688	.681	.330	.379	.306
	5A	.755	.790	.618	.602	.304	.390	.341
1-29-70	1A	1.000	.911	.655	.636	.273	.323	.288
	1B	.911	1.000	.640	.617	.271	.312	.283
	3A	.655	.640	1.000	.854	.447	.541	.290
	3B	.636	.617	.854	1.000	.513	.601	.283
	5A	.273	.271	.447	.513	1.000	.790	.123
	5B	.323	.312	.541	.601	.790	1.000	.167
	6A	.288	.283	.290	.283	.123	.167	1.000
3-4-70	1A	.776	.818	.556	.537	.248	.298	.294
	3A	.321	.306	.421	.423	.266	.343	.212
	5A	.194	.194	.381	.397	.585	.570	.088
4-7-70	1A	.681	.658	.855	.857	.453	.499	.265
	1B	.694	.661	.857	.824	.435	.475	.270
	3A	.255	.254	.548	.475	.597	.637	.179
	3B	.262	.258	.417	.476	.595	.606	.175
	5A	.108	.107	.262	.280	.295	.353	.144
	5B	.107	.105	.236	.287	.313	.380	.126
	6A	.104	.103	.162	.175	.157	.188	.713
5-14-70	1A	.529	.495	.600	.587	.258	.336	.252
	3A	.275	.252	.331	.336	.286	.324	.171
	5A	.108	.109	.233	.243	.244	.302	.138