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The purpose of this study was to investigate the effects of logging on the productivity, structure and biomass of a periphyton community developed in mountain streams. The three streams used in this investigation were located in the coast range of Lincoln County, Oregon. They were selected for similarity of habitat, terrestrial canopy, and benthic community, one dominated by diatoms (Bacillarophyceae).

In 1966, Deer Creek watershed was subjected to a selective pattern of logging with a buffer strip of canopy left standing along the stream. Needle Branch watershed was subjected to clearcut logging resulting in the removal of all the canopy, and the watershed of Flynn Creek was left in its natural condition and used as a control.

Clearcut logging had a profound impact on the aquatic environment of Needle Branch. As indicated by light reading taken during primary productivity runs, the stream received a mean value of seven

times more light in 1967, July-September, as compared to similar months in 1964, prior to logging. This resulted in a high of 50 langleys/hr as compared to 13 langleys/hr recorded prior to logging. Concurrently, the mean temperature of the stream, as measured during productivity runs, increased 6 C, with a high of 26 C recorded as compared to 14.8 C prior to logging.

The impact of these environmental changes resulted in a periphyton community quite different from that existing in the stream prior to logging. As indicated by the communities developed on glass artificial substrates, this stream, which supported a periphyton community of diatoms prior to logging, was changed to a habitat supporting a mixed community of filamentous algae and diatoms with the filamentous algae becoming dominant. The diatom flora of the stream changed in species composition and became more uniform throughout, after logging.

Samples of the communities taken from the natural substrate and glass artificial substrates were similar, but dissimilarities arose in the relative abundance of the species. Artificial substrates cut from native rock supported a community of greater similarity to that on the natural substrate, than existed between the communities developed on glass artificial substrates and the natural substrate.

The index of the autotrophic organisms in Needle Branch (mg chlorophyll a/m^2) was lower after logging, as compared to that found in the stream prior to logging. Mean concentrations for comparable months, of 51.3 mg chlorophyll a/m^2 were recorded before logging, compared to 9.10 mg chlorophyll a/m^2 recorded after logging. The index of the autotrophic organisms obtained from the organic matter collected on glass artificial substrates showed little relationship to that obtained from the substrate of the stream.

Respiration of the community after logging was higher than during the equivalent period prior to logging. Mean respiration for July-September, 1964,was 1.08 g O_2/m^2/day while after logging the reduced biomass had a respiration rate of 1.28 g O_2/m^2/day.

After logging, gross primary production was higher in Needle Branch than in Flynn Creek (control watershed), but slightly less than recorded for Needle Branch prior to logging. Needle Branch maintained gross primary production comparable to the prelogging period, with a smaller biomass, by increased efficiency of photosynthesis per mg chlorophyll a.

The photosynthesis-respiration ratio (P/R ratio) indicated that prior to logging, Needle Branch was autotrophic for all seasons except the fall. After logging, the stream became progressively more heterotrophic from spring to summer.

The Effects of Logging on Periphyton Communities of Coastal Streams

by

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THE EFFECTS OF LOGGING ON PERIPHYTON COMMUNITIES OF COASTAL STREAMS

INTRODUCTION

The quality of a water determines its suitability for a particular use. The study of all factors affecting the quality of water is of prime importance to the State of Oregon. The production of salmonid fish and therefore the sport and commercial fishing industry of Oregon depends to a large extent upon the condition of streams arising in the forested watersheds of the State. The salmon, steelhead, and other resident fish are dependent upon the productivity of all lower trophic levels in these streams. The primary producers of these watersheds, both terrestrial and aquatic, are the most significant group of organisms in this chain, for they are the sole converters of light energy to chemical energy as plant organic material. Plant material is consumed by the various herbivores and they in turn are consumed by carnivores of the streams.

In addition to the watersheds being important to the fishing industry, the logging industry takes from them a tremendous quantity of timber which is used for paper pulp, plywood and lumber. Logging is usually by a clear-cut operation because of some desirable biological and economic aspects, but the effects of the removal of the overstory on the aquatic environment of watersheds is poorly understood.

This study was one of several investigations taking place simultaneously to determine the impact of logging on the physical and biological characteristics of the Alsea watershed streams. Other studies of the effect of logging practices on the character of small mountain streams include: changes in stream temperatures; predictions of temperatures in small streams; changes in loads of suspended sediment; changes in the suitability of streams as habitats for populations of anadromous and resident fish. Collectively, these studies are known as the Alsea Watershed Study.

The present study was concerned with principally the effects of various logging practices upon: gross primary productivity of small woodland streams; the biomass of autotrophic benthic communities; the structure of the autotrophic benthic community.

Gross primary production is a part of the metabolism of the particular autotrophic community existing in the stream at a given time and is a function of the physical environment under which the community lives. Any variation in this environment or of the biomass or community structure will alter the community and may consequently affect the primary production of the community.

DESCRIPTION OF STUDY AREA

The three streams used in this investigation, Deer Creek, Needle Branch and Flynn Creek, are a part of the Drift Creek drainage in the Alsea Basin of the Oregon Coast Range approximately seven miles inland from the Pacific Ocean and ten miles south of Toledo, Lincoln County, Oregon.

The climate of the area is maritime with dry summers and a mean annual precipitation of 100 inches per year. The heaviest precipitation usually extends through a seven-month period, starting in October and ending the following March or April. Snowfall is uncommon and freshets occur in the streams during periods of unusually heavy precipitation. These freshets carry heavy loads of organic and inorganic material and tend to scour free all organic growth that has colonized the substrate.

Initially, the watersheds were selected because of their similarity in terrestrial vegetation and the undisturbed natural condition of the streams. The physical and chemical characteristics of the streams studied were generally similar, except for nitrates which were relatively low in Needle Branch and high in Flynn and Deer Creeks. Oxygen concentrations ranged from 9-12 ppm., and water temperatures were observed to be 7-8 in the winter months and 12-14 in the summer months (Appendix tables 18-22).

The streams were composed of a sequence of riffles and pools that were shaded moderately throughout the year by the Douglas fir overstory and more extensively during the summer months when the understory was in leaf. Depth of the water in the riffles varied with the season, ranging from one to six inches in the summer months to winter depth of six to twelve inches. The substrate in the riffles consisted of rubble and gravel, ranging from a few millimeters to 15 centimeters or more in diameter. This very soft, porous rock is derived from the Tyee Sandstone of the Coast Range.

The overstory of the terrestrial vegetation on the watersheds consisted of *Pseudotsuga menziesii* (Douglas fir), *Alnus rubra* (Red alder), and a few scattered specimens of *Thuja plicata* (Red cedar). The understory was of *Acer circinatum* (Vine maple), *Rubus spectabilis* (Salmon berry), *Polystichum munitum* (Sword fern) and *Pteridium aquilinum* (Bracken fern).

In March 1966, Needle Branch was clearcut and Deer Creek was subjected to a staggered pattern of logging (smaller spaced clear-cut) with a buffer strip of trees left standing along the stream bed. From direct observations, it appeared that the latter operation caused little change in the stream as a habitat for benthic organisms. An occasional log was felled in the stream, but was removed shortly thereafter during the yarding operation. Very little debris due to logging was observed in the stream. Soon after the logging operation was terminated, a family of beavers built a dam in the headwaters of

Deer Creek. Its construction produced silt loads in the stream and sediment deposits on the colonized rock substrate. During gross primary productivity measurements, these sediment deposits were suspended in the water of the P-R chamber. The resulting turbid water influenced subsequent production measurements by reducing the light intensity available to the organisms on the rock substrate within the chamber.

The clearcut of Needle Branch watershed removed all standing timber and most of the plants making up the understory. This operation had a pronounced affect on the aquatic habitat. The removal of the terrestrial canopy increased the quantity of light reaching the surface of the stream, and subsequently a substantial increase in the stream temperature was observed. Damming and pooling of an otherwise shallow-riffle stream by logs and slash drastically lowered the velocity of the stream. Because stream velocity is one of the many factors which influences the species composition of a community, the velocity (cm/sec) at each riffle, in which community composition was analyzed, was measured on July 6, 1967, with a Gurley Pygmy Current Meter. The location of the riffles was the distance in meters from the weir on each stream. The current velocities in Deer Creek were 22.0, 2.2, and 7.7 at riffles 15 m., 610 m. and 1158 m. respectively. In Flynn Creek, they were 37.2, 13.7 and 12.7 at riffles 15 m., 320 m., and 655 m. respectively. The velocities measured in Needle Branch were 1.8, 4.8, and < 0.01 at riffles 15 m., 168 m. and 305 m. respectively. Discharge values for the streams, taken at the weir, are shown in Appendix table 22. The influx of debris increased the load of organic material in the stream and the accompanying silt covered much of the rock substrate available for colonization.

In late April, 1966, the yarding operation of the felled logs began. The consequent dragging of the logs across and from the stream added additional silt. Although the logs were removed by the yarding operation, much of the slash remained and continued to dam and pool the stream. In September of the same year, the large debris was removed and in a short time the stream velocity increased. With the beginning of the rains in late fall, and the resulting increased stream flow, the remaining silt and debris covering the rock substrate was slowly washed from the stream, and the rock substrate was exposed to recolonization the following spring. All of the operations of logging on Deer Creek and Needle Branch were completed by December, 1966.

Flynn Creek watershed was maintained in its natural condition and used as a control throughout the investigation (Figure 1).

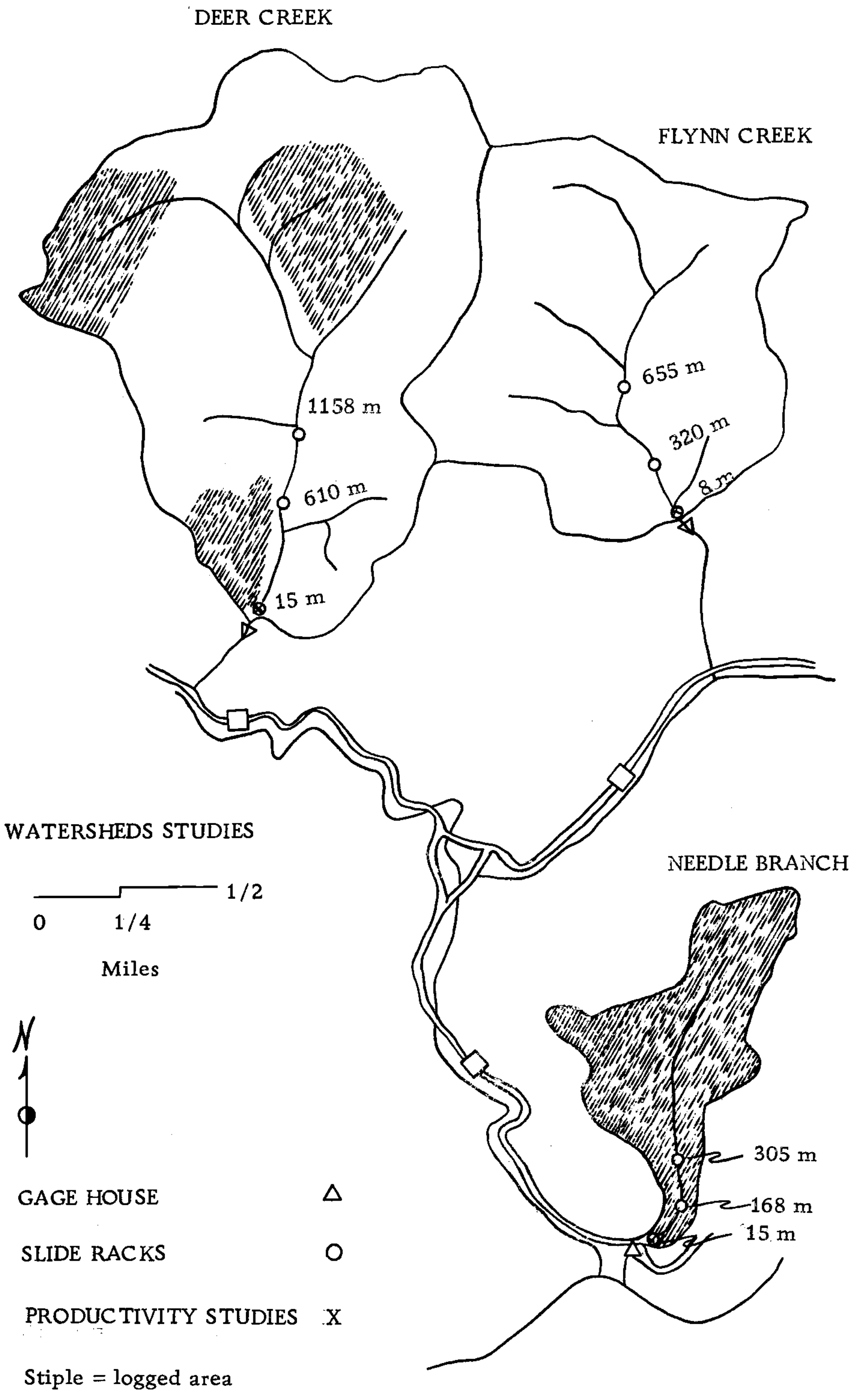

Figure 1. Diagram of study area.

METHODS

Community Metabolism

All measurements taken in 1964, prior to logging, used throughout this thesis were taken by Lane (1965). The techniques and apparatus used to obtain data on productivity and autotrophic biomass in the present study were similar to those used by Lane (1965). Analysis of the species composition, structure and periodicity of the communities inhabiting the streams began in May, 1966, although preliminary investigations indicated that the communities in these streams, prior to 1966, were dominated by diatoms.

This investigation only includes the study of the communities which inhabit the riffle areas of the streams, since this community is considered to be the most productive community in the flowing water environment.

Analysis of the productivity of communities was limited to riffles accessible by road because of the weight and volume of equipment which had to be moved to the stream. Therefore, gross primary productivity was measured at riffles located approximately 61 meters from the gauging station (0 meters) on Needle Branch, 15 meters from the guaging stations on Deer Creek and Flynn Creek (Figure 1). Attempts were made to determine rates of primary production at 4, 8, and 12 week intervals in each riffle. Because of malfunctions in the equipment, and the lack of any significant difference between the data taken at the various intervals, this procedure was abandoned and determinations were made at least once each month in each stream.

The data for productivity and autotrophic biomass presented in this thesis are to be considered valid for only those areas in which samples were taken, as the structure of the autotrophic community varied at different locations in the streams. For example, after logging on Needle Branch watershed, dense filamentous algal mats developed in some riffles of the stream, but they did not develop, to any great extent, in the riffle where the productivity studies were made.

Gross primary production and community respiration of the communities were measured in Deer Creek, Needle Branch and Flynn Creek from October 1965 to October 1967. A modification of the P-R Chamber described by McIntire, Garrison, Phinney and Warren (1964) was used to obtain an estimate of the metabolic activity of the benthic community (Lane, 1965).

When the stream velocities were low enough to allow equipment to be placed and maintained in the streams, porcelainized steel trays (45.7 X 45.7 X 2.5 cm) were positioned in selected riffle areas, and rocks and gravel from the surrounding stream bed put into the trays. Before productivity studies were made, a month was allowed for re-establishment of the benthic community. This disturbance of the community was caused by the moving of the stream gravel into the trays.

When productivity measurements were made, the tray was isolated from the stream by attaching a transparent plastic box (Figure 2) to the tray by means of C-clamps, thus producing a chamber containing a portion of the benthic community on the rock substrate. The chamber was then filled with stream water from an elevated reservoir. To simulate the current in the stream, the water in the chamber was circulated by centrifugal pumps through plastic tubing connected to the front and back of the chamber. Stream water from the reservoir flowed into the chamber at the rate of 200 ml/min or 12 liters/hr. Three small centrifugal pumps operated from a portable generator, continuously fed the reservoir with stream water and circulated the water in the system. Temperatures of the water in the stream, chamber and reservoir were monitored hourly.

Changes in concentration of dissolved oxygen produced by the metabolic activities of organisms enclosed in the chamber were measured by determining concentrations of oxygen in sample bottles attached to the influent and effluent exchange tubes of the chamber. Samples of the influent and effluent water were taken at hourly intervals. The dissolved oxygen concentration of the samples in milligrams/liter was determined by the Winkler Method (Theroux,

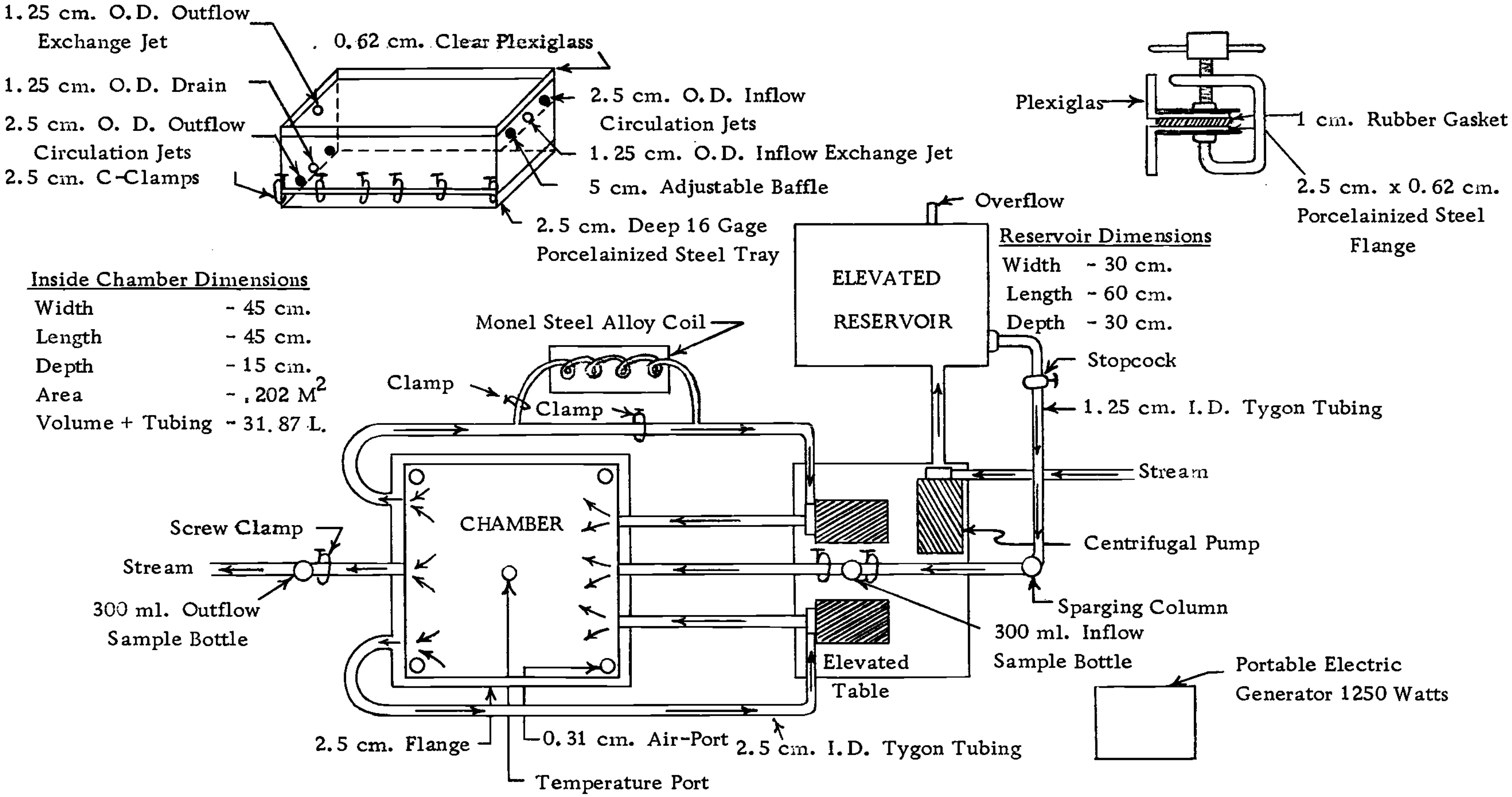

Figure 2. Diagram of the photosynthesis-respiration chamber.

Eldridge and Mallmann, 1943). Phenylarsene oxide was substituted for the sodium thiosulfate prescribed by the above method. Phenylarsene oxide has the advantage of remaining stable over a relatively longer period of time than thiosulfate. Identical results were obtained using the two reducing agents on the same sample. Metabolic activity of the enclosed community was determined hourly for a period of eight to twelve hours for each sampling period. Each sampling period was arranged in such a way that half of the hourly samples were taken in the daylight, the other half taken in the dark. This allowed computation of hourly rates of photosynthesis and respiration. The change in oxygen concentration taking place in the total volume of water in the chamber was then calculated by the following equation (McIntire, Garrison, Phinney and Warren, 1964).

$$\text{net } O_2 \text{ change} = Ft \left[\frac{(E_o + E_1)}{2} - \frac{(I_o + I_1)}{2} \right] + V(E_1 - E_o)$$

where

F = exchange rate in liters/hours,

t = time hours,

E_o = dissolved oxygen concentration in milligrams per liter of the effluent water at the beginning of the time period,

E_1 = dissolved oxygen concentration in milligrams per liter of the effluent water at the end of the time period,

I_o = dissolved oxygen concentration in milligrams per liter of the influent water at the beginning of the time period,

I_1 = dissolved oxygen concentration in milligrams per liter of the influent water at the end of the time period, and

V = volume of water in the chamber in liters.

Gross primary production per hour was estimated by adding mean oxygen consumption during the dark period to the oxygen evolved during photosynthesis. Gross primary production per day (24 hours) was calculated by the following formula.

Gross primary production per day = (mean gross primary production/hr) (no. of daylight hours) + (mean respiration/hr) (no. of dark hours).

These results were expressed as g $O_2/m^2/day$. This assumes that the rate of respiration in the dark is the same as that during photosynthesis.

Problems developed in the use of the equipment because of the increase in temperature of the water in the chamber above that of the stream. Differences as much as 5 C were observed. Increase in temperature in the chamber was caused by the warming of the water passing through the pumps, the poor heat exchange of the plastic dome, and absorption of heat from the sun. Increases in temperature created errors in estimating gross primary productivity. Stream water entering the chamber became supersaturated with oxygen, and the excess oxygen was given off as masses of minute bubbles on the undersurface of the top of the plastic cover. Consequently, a slight error was produced in underestimating the gross primary productivity of the stream community. Also the masses of bubbles indirectly caused an error in estimating gross primary production by reducing the amount of light reaching the community in the chamber. The amount of reduction in light intensity was not analyzed during this investigation.

Attempts to absorb the heat of the sun before it reached the chamber proved unsuccessful. In an effort to eliminate saturation of the water with oxygen, a sparging column was installed in the influent water line before the water from the reservoir entered the sample bottle, thus reducing the concentration of dissolved oxygen by bubbling nitrogen through the water entering the chamber. The degree of reduction in the concentration of oxygen was determined by the temperature expected in the chamber that day. This method proved to be satisfactory and eliminated the supersaturated condition in the chamber.

In order to control the temperature of the water in the chamber and hold it as close as possible to that of the stream, a monel alloy cooling coil was made to connect to the water circulation tubing of the chamber. Although the monel coil was not tested in the field because of lack of time, a prototype made of copper tubing performed very successfully in trials. The ends of the coil were connected to the water circulation tubing, and the coil was placed in a chest packed with ice (Figure 2). Water leaving the chamber through the circulating system was drawn through the coil and cooled before reentering the chamber. The flow of water entering the coil from the circulating tube was regulated by screw clamps. Using this procedure the temperature of the water in the chamber was controlled to within ± 0.5 C of that of the stream. Further testing of the monel coil will be performed in the future. The majority of the major mechanical problems, primarily malfunctioning of the generator, were eliminated by the end of the production runs in 1966.

At the termination of a day's study, all equipment was returned to the laboratory including the porcelainized tray holding the sample of stream substrate. One quarter of the rock substrate was removed randomly from the tray and brought to the laboratory where the sample was immersed in 90% acetone for extraction of pigments to be used in the determination of the concentration of chlorophyll. All large consumer organisms were removed from the tray and preserved in formalin for future analysis. All of the substrate, except that used for chlorophyll analysis, was returned to the stream and randomly redistributed in the riffle area. The porcelain tray was replaced in the stream in the same location from which it had been removed, and fresh rock substrate from the stream was placed in it, in preparation for the next analysis.

Glass Artificial Substrates

Those riffle areas that appeared typical of each stream, and were also available for sampling, were selected for the study of community structure and periodicity. The community was sampled from glass artificial substrates because of the problems involved in sampling from the natural substrate of the stream.

Three racks were placed in the riffles selected in each stream. The slide racks were first placed during May, 1966, but because of the logging operations at the upper stations, racks could not be placed until July. Locations of the racks was designated by the number of meters from the gauging station (0 meters) on each stream. Racks 1, 2, and 3 were located 15, 610, and 1158 meters respectively, from the gauging station on Deer Creek. Racks 4, 5, and 6 were located at 15, 168, and 305 meters from the gauging station on Needle Branch. In Flynn Creek, the racks 7, 8, and 9 were 15, 320, and 655 meters, respectively, from the gauge house.

The glass substrates were sampled after four, eight, and twelve week residence times in the stream. These intervals were selected after weekly sampling of slides indicated a definite pattern of colonization on the substrates. After one week of exposure, bacteria were essentially the only organisms found on the slides. After two to three weeks, bacteria and fungi were found and after three or four weeks, diatoms began to appear. Young (1945) found similar development of rocks and organic substrates in Douglas Lake, Michigan. This is a possible indication that colonization of substrates by diatoms is to some extent independent of the substrate, but dependent on the presence of materials deposited by the heterotrophic forms preceeding them.

Glass artificial substrates were used to sample the benthic community rather than sampling directly the organic growth of the streams. This method was used because the soft, porous nature of the natural substrate made it extremely difficult to analyze the community quantitatively. Tests showed that it was extremely difficult to remove the community because scrubbing organic material from the rock removed large quantities of inorganic material which was then incorporated into the permanent diatom slides. This inorganic material made difficult the identification of various algal species found on the natural stream substrate. Estimates of the biomass of autotrophic organisms (mg chlor $\underline{a}/m^2$) scrubbed from the rock proved unreliable, for Lane (1965) found 60% remained on the rocks after scrubbing. Because of the unreliability of the scrubbing process and the error in estimating biomass on a dry weight basis, the biomass of the autotrophic organisms were determined by the optical density of a chlorophyll extract.

Glass artificial substrates have several advantages which make them useful in studying the stream community. They have a fixed surface area, thus the biomass can be expressed in terms of surface area which is usually quite difficult to determine for most natural rock substrates. Organic material is very easily removed by scraping the glass surface with a razor blade. The amount of silt and mud that collects on the glass substrate in the vertical position is much less than collects on the natural substrate of the stream.

Although glass artificial substrates have several advantages, they also have disadvantages. The length of time a substrate must remain in the stream to accumulate organic matter representative of the stream community is very difficult to determine and seems to vary with various habitats and environmental conditions. Reese (1937) in a study of non-calcareous streams found that shade greatly reduced algal colonization on slides. Hohn and Hellerman (1963) exposed slides for two weeks in three eastern North American rivers with satisfactory results. Newcombe (1949) suggested that the time of submergence should be more than 25 days. Waters (1961) found that the time for Chlorophyll a to reach a maximum varied in Valley Creek from three to eight weeks, apparently depending on environmental conditions. Butcher (1946) found that, in highly calcareous streams, colonization of glass slides appeared to be completed in 20 days except in winter when growth was slow and colonization took 30-40 days.

In addition to the time needed for complete colonization, the position of the glass artificial substrate seems to be important. For example, Newcombe (1950) found in a study of the attachment of organisms to substrates in Sodon Lake, Michigan, that the relationship of the weight of organic matter (loss on ignition) from vertical and horizontal surfaces was in a ratio of 1 to 6. 6 and that in the littoral zone, considerable inorganic detritus settled on the slides and difficulties arose in evaluating the effects of this detritus on subsequent attachment and growth of organisms. Newcombe (1949) found, when removing slides from the water, that the loss of material was much greater from slides positioned vertically than horizontally. Sladeckova (1962), in a study of methods of collecting periphyton, found that horizontal slides collect a great amount of settling seston detritus, mud and various other debris and decaying plankton in addition to true periphyton. She also found that much heterotrophic material collected on the under surface of horizontal substrates when light could not penetrate, and the vertical glass substrates had more equal distribution of organisms than those placed horizontally.

The question always arises whether the community developed on an artificial substrate is representative of that found on the natural substrate of the stream. This will be discussed later. In taking quantitative measurements of the community on glass artificial substrates it is always a problem to differentiate between organic matter "seeded on" and that produced on the substrate.

The glass artificial substrates were held in the vertical position by use of racks developed for this investigation (Figure 3). The racks were constructed of aluminum with slotted plastic inserts mounted on the inner surfaces of the base and top. The plastic inserts had sixteen pairs of slots arranged to accommodate 32 (2.5 cm x 7.6 cm) slides. Each pair of slots held two glass slides and were designated as a "set".

In order to keep the slides immersed to a uniform depth during the entire year, a block of styrofoam was fastened to the top of each rack and the rack held in position by anchor lines attached to stakes positioned on the bank of the streams. During the high winter flows, the racks floated in approximately same general area as during the summer months and the slides were submerged to the same depth.

At each sampling time, two sets of slides with their accumulated organic matter were removed from the rack and immediately replaced by two sets of clean slides. The organic matter on one set of slides was used to obtain an extract of chlorophyll a as an index of the mass of autotrophic organisms. The second set of slides was used to analyze community structure by determining the relative abundance of species present. This set of slides was placed in a bottle of stream water and brought to the laboratory where the final alanysis was made.

Community Structure and Periodicity

The organic matter scraped from the slides was washed into a

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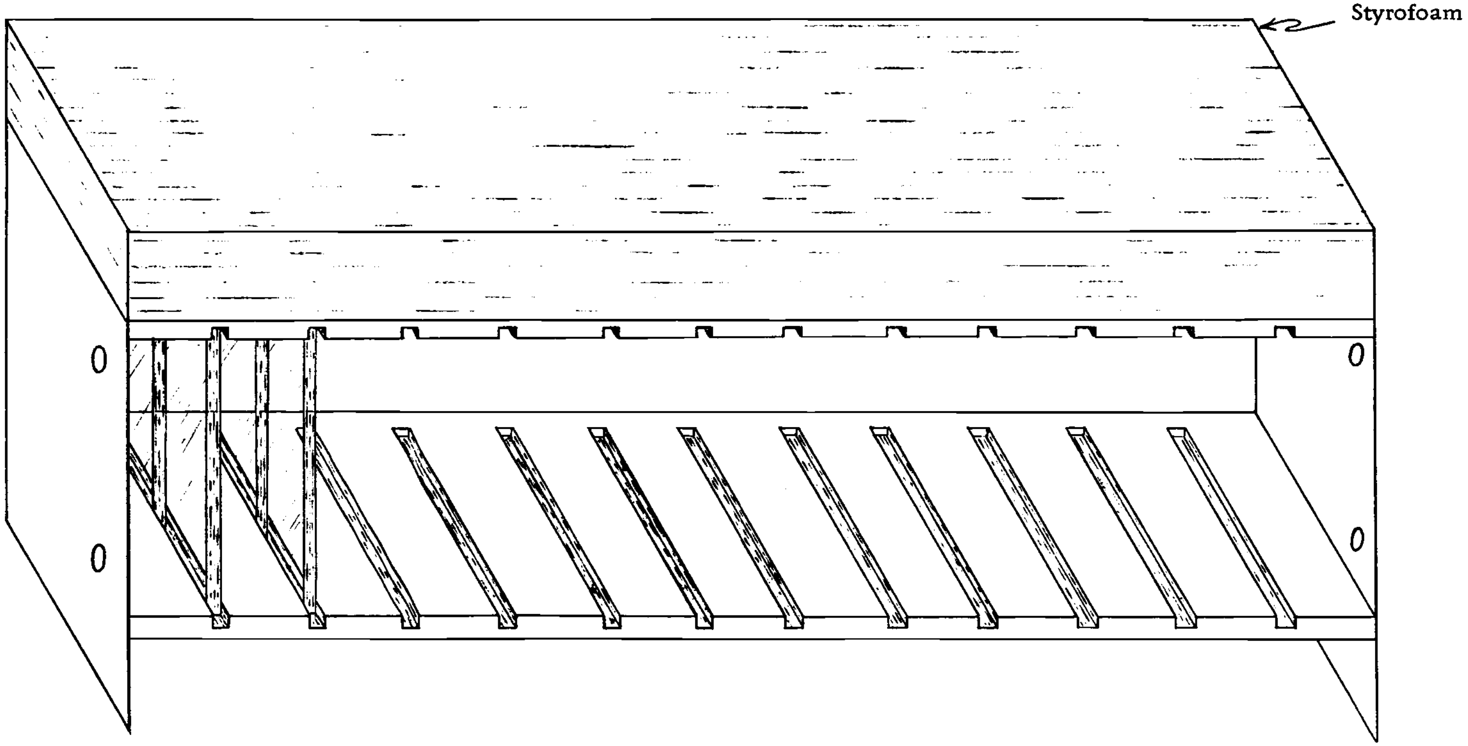


Figure 3. Diagram of the glass artificial substrate racks.

150 ml beaker with a small amount of distilled water to which was added approximately 50 cc of concentrated nitric acid. The mixture was slowly heated on a hot plate for fifteen to twenty minutes to bring about complete oxidation of the organic matter and to leave the silica frustule of the diatoms intact. The acid mixture was centrifuged to settle the frustules and the acid removed with a pipette. The frustules were washed several times with distilled water and suspended in a measured amount of distilled water. One ml of this sample was spread evenly on a 22 mm square glass cover slip and placed on a hot plate to evaporate the liquid. The glass cover slip and attached diatom frustules were permanently mounted on a 25 mm x 75 mm glass slide in hyrax mounting media. Each slide was labeled as to date of collection, location of sample and sampling interval. The diatom species were identified by microscopic examination and the use of various taxonomic manuals.

The community was characterized by determining the relative abundance of each species in the total number of individuals identified on a strip across the 22 mm cover glass. This method was used because the total number of diatoms per unit area of the slide is unrelated to the density of diatoms on the natural substrate in the stream. The width of the strip was the diameter of the field of a 4 mm. objective. The area was equivalent to 235 fields. Because the diatoms were randomly distributed at the time of preparation of the permanent slide, this method gave a good estimate of the relative abundance of the individual species making up the community. This method also eliminated possible duplication of randomly selected fields.

Permanent slides of this type were useful only for the study of those organisms possessing a silica wall. Groups of algae with organic cell walls, such as the Chlorophyta and Cyanophyta which sometimes accumulated on the glass slides together with the diatoms were quantified by suspending the scrapings from the slides in water from which a wet mount was prepared. The method of counting a strip across the mount was again used. All autotrophic forms other than diatoms were identified to genus and the cells counted. A total count was made of the diatoms present. Generic counts were then proportioned in terms of the total number of diatoms counted on the permanent hyrax slide by the following equation.

$$A = \frac{(B)\,(C)}{(D)}$$

where

A = total generic count in terms of diatoms on the hyrax permanent slide,

B = generic count per strip on wet mount,

C = total diatoms per strip on hyrax permanent slide,

D = total diatoms per strip on wet mount.

The total number of taxa per strip was tabulated for the community, and percent relative abundance for each taxon was calculated. In this study, a taxon was considered to be a dominant part of the community if it numbered 10% of the individuals counted on the slide.

After determining the relative abundance of each taxon, a comparison of the communities of the various riffle areas of a stream and of the communities of the various riffle areas of a stream and of the various streams was made. Comparisons were made by computing a "distance" index (MacIntosh, 1967)

$$Djh = \sqrt{\sum_{i=1}^{s} (Xij - Xih)^2}$$

where

Xij = the percentage abundance of the i^{th} taxon in the j^{th} community,

s = the number of taxa, and

Djh = the degree of difference or "index" between the j^{th} and the h^{th} community.

A numberical index of zero indicates that the communities are the same. As the index increases, the similarity between samples of the communities lessens. Comparisons were made of the communities developed on glass artificial substrates exposed for 4, 8, and 12 weeks (Appendix tables 10-12).

Determination of an Index of Autotrophic Biomass

All acetone extracts of chlorophylls were returned to the laboratory where analysis of chlorophyll a was performed according to the method of Parsons and Strickland (1963). Concentration was expressed as mg of chlorophyll a/m^2 of slide area.

Rock Artificial Substrates

In an attempt to create a type of artificial substrate that duplicated more closely the texture of the natural substrate of the stream, artificial substrates were made from rock similar to that found in the stream bed. Slabs of rock taken from the surrounding hillside were cut into 7.6 cm x 7.6 cm x 2.5 cm blocks with a diamond saw.

The blocks were mounted in a resin coated wooden rack (Figure 4). The rack was buried in a riffle area in Needle Branch with the rock substrates protruding and becoming part of the stream substrate. The location of this rack was approximately 68 meters from the guage house. Attempts were made to sample these substrates at 4, 8, and 12 weeks. Estimates of periphyton biomass and community structure were obtained from these blocks.

Samples for determination of the concentration of chlorophyll a were obtained by removing the rock substrates with the attached organic matter from the rack and submerging them in 100 ml of 90%

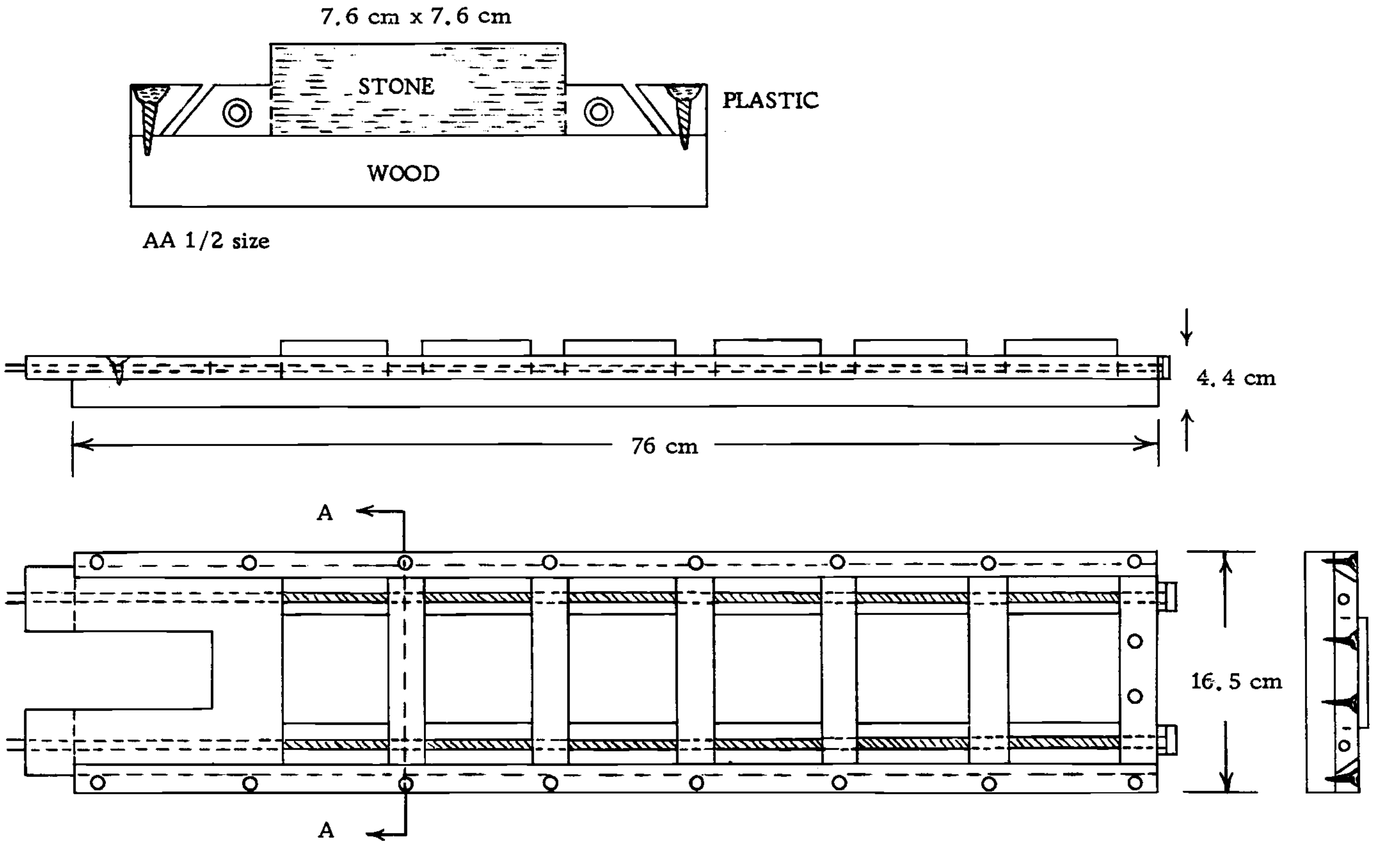


Figure 4. Rack holding rock artificial substrates.

acetone in the field. The concentration of chlorophyll a was determined in the laboratory and expressed as mg/m^2 .

The procedure for determination of the community structure was the same as that used with the glass artificial substrates.

Natural Stream Substrate

Some samples of the community colonizing the natural stream substrate were collected by randomly selecting rocks and scrubbing the organic material from them. This material was treated in the same fashion as that from the glass artificial substrates.

Solar Radiation

Solar radiation reaching the P-R Chamber was measured by a Portable Illumination Totalizer (Turkey et al., 1950). This instrument is a two-component device. One component situated at the P-R Chamber contained an RCA No. 929 photoelectric tube with a peak absorbancy at 400 mμ. The second component, placed on the shore, had a charge-discharge circuit which activated a numerical counter. Electrical energy, converted from the solar energy absorbed by the first component, activated the numerical counter through the charge-discharge circuit.

Although the Portable Illumination Totalizer had the disadvantage of absorbing only at restricted wave bands (300-600 mu), much of the benthic community inhabiting the substrate can absorb in this wavelength range because of their accessory pigments, particularly fucoxanthin. This instrument was caliberated against an Epply pyrheliometer. The linear regression of counts from the phototube and gram-calories per cm^2 from the pyrheliometer had a correlation of 0.98 for an eight hour period of variable sunny weather (Lane, 1965). Each count was equivalent to 0.023 langleys (g cal/cm^2).

The Portable Illumination Totalizer is vulnerable to moisture in the field which corrodes the contact points of the numerical counter. This problem produced malfunctions in the instrument and a Belfort Pyrheliograph had to be substituted in 1967.

The instruments for measurement of radiant energy were taken into the field when gross primary productivity measurements were made and brought back to the laboratory at the termination of each study.

Because of the selective absorption of the Portable Illumination Totalizer, the energy values reported in this study are only relative values and are not considered to be absolute values of incident radiation. Comparison with measurements of net radiation, made in the same general areas, (Brown, 1967) show values for net radiant energy of the same order of magnitude. He found that in 1966, before logging, the maximum net radiation was 0.525 g $cal/min/cm^2$, whereas after logging, 1967, the maximum net radiation was 1.80 g $cal/min/cm^2$.

The data concerning stream temperature and incident light energy cited in this investigation were measured hourly during the measurements of gross primary productivity. For more complete analysis of the heat budget and light regime of the watersheds involved, the reader is referred to Brown (1967).

RESULTS

Stream Environment

Effect of Logging on the Light Available at the Surface of Needle Branch

As indicated by light measurements taken during productivity measurements, the study area of Needle Branch in 1967, received seven times more light, at the stream surface, than during comparable months in 1964, whereas prior to logging, Flynn Creek received approximately 2-1/2 times more light than Needle Branch (Table 1). The measurements of 1964, are of Lane (1965). The mean intensity of available light during each run of the P-R Chamber was calculated (Appendix Table 1).

Table 1. Mean light intensity in langleys/hr recorded in 1964 and 1967.

Stream		Date	No. days sampled	Mean Light Intensity	Range
		BEFORE LOGGING (1964)			
Flynn Creek	(unlogged)	July - Oct.	5	8.10	3.90 - 17.50
Needle Branch	(unlogged)	July - Oct.	6	3.00	1.20 - 5.10
		July - Sept.	5	3.30	1.20 - 5.10
		AFTER LOGGING (1967)			
Flynn Creek	(unlogged)	July - Oct.	5	5.06	1.30 - 15.70
Deer Creek	(patch logged)	July - Oct.	4	2.52	2.10 - 3.00
Needle Branch	(clearcut)	July - Sept.	4	22.67	13.10 - 33.20

The highest intensity recorded, during productivity runs in Needle Branch, was 50.00 langleys/hr in August, 1967, whereas the highest value recorded in 1964 was 13.25 langleys/hr in June.

Effect of Logging on the Temperature of Needle Branch

When the canopy on Needle Branch was removed, the stream was subject to heating by direct solar radiation. In 1967, the mean temperature of Needle Branch, taken during productivity runs, increased approximately 7 C above the mean recorded for comparable dates in 1964 (Table 2), and 7-8 C above those recorded for Deer and Flynn Creeks in 1967. Measurements of 1964, were obtained by Lane (1965).

Table 2. Recorded mean temperature before logging (1964) and after logging (1967).

Stream		Date	No. of days	Mean Temperature	Range
		BEFORE LOGGING (1964)			
Flynn Creek	(unlogged)	July - Oct.	5	13.5 C	10.2 - 15.4
Needle Branch	(unlogged)	July - Sept.	5	14.0 C	13.4 - 14.6
		AFTER LOGGING (1967)			
Flynn Creek	(unlogged)	July - Oct.	5	12.7 C	11.2 - 14.6
Deer Creek	(patch logged)	July - Oct.	4	13.0 C	11.1 - 14.3
Needle Branch	(clearcut)	July - Sept.	3	20.7 C	19.8 - 21.8

The highest temperature recorded in 1964 was 14.8 C on July 15, whereas the highest recorded in 1967, after logging, was 26 C on July 16, 1967. Daily values of stream temperature taken during primary production runs are recorded (Appendix Table 2).

Community Structure in Streams

Description

Diatom Communities of 1966. Tow samples taken in the three streams with a No. 20 mesh plankton net indicated that the streams were devoid of rheoplankton and contained only tycoplankton, i.e., those organisms that had been dislodged from the substrate. Prior to logging activities of 1966, the undisturbed periphyton communities of the three streams were dominated by diatoms (Bacillarophyceae). During the seventeen months (May 66 - Oct. 67) of sampling, 76 species of diatoms were observed (Table 3), three of which dominated in the streams in 1966. These species were *Achnanthes lanceolata*, *Cocconeis placentula*, and *Eunotia arcus*. *Nitzschia palea* and *Meridion circulare* were also abundant in Needle Branch. Although the composition of the benthic community was similar in Flynn and Deer Creeks, there were seasonal differences in structure and periodicity of the species in the communities (Figures 5,6). Needle Branch, the logged watershed, developed a community quite

Table 3. Species list of benthic diatoms.

Chrysophyta

Bacillariophyceae

Achnanthes kryophila Pet.
Achnanthes lanceolata (Bréb.) Grun.
Achnanthes levanderi Hust.
Achnanthes linearis (W. Sm.) Grun.
Achnanthes lutheri Hust.
Achnanthes minutissima Kütz.
Achnanthes pinnata Hust.
Achnanthes saxonica Krasske
Amphora ovalis Kütz.
Asterionella formosa Hass.
Cocconeis placentula Ehr.
Cymbella lanceolata (Ehr.) V Heurck
Cymbella naviculiformis Auerswald
Cymbella perpusilla A. Cleve
Cymbella sp.
Cymbella turgidia (Gregory) Cleve
Cymbella ventricosa Kütz.
Diatoma hiemale (Roth) Heib.
Diatoma vulgare Bory
Diploneis elliptica (Kütz.) Cleve
Epithemia sp.
Eunotia arcus Ehr.
Eunotia elegans Østr.
Eunotia exiqua (Breb. ex Kütz.) Rabh.
Eunotia incisa W. Sm. ex Gregory
Eunotia lunaris (Ehr.) Grunow
Eunotia maior (W. Sm.) Rabh.
Eunotia perminuta (Grun.) Petr.
Eunotia perpusilla Grun.
Eunotia sp.
Eunotia tenella (Gren.) Cleve
Eunotia vanheurckii Patr.
Fragilaria bicapitata A. Mayer
Fragilaria brevistriata Grun.
Fragilaria capucina Desm.
Fragilaria construens (Ehr.) Grun.
Fragilaria leptostauron (Ehr.) Hust.
Fragilaria pinnata Ehr.
Fragilaria virescens Ralfs
Frustulia rhomboides (Ehr.) DeT.
Frustulia vulgaris (Thwaites) DeT.
Gomphonema angustatum (Kütz.) Rabh.
Gomphonema gracilis Ehr.
Gomphonema longiceps Ehr.
Gomphonema parvulum Kütz.
Gomphonema rombicum Fricke
Gomphonema sp.
Gomphonema ventricosum Gregory
Melosira varians Agardh
Meridion circulare (Grev.) Ag.
Navicula arvensis Hust.
Navicula capitata Ehr.
Navicula cryptocephala Kütz.
Navicula elginesis W. Sm.
Navicula minima Grun.
Navicula pelliculosa (Bréb. ex Kütz.) Hilse
Navicula pseudoarvensis Hust.
Navicula pupula Kütz.
Navicula radiosa Kütz.
Navicula recondita Hust
Navicula rhynchocephala Kütz.
Navicula ruttneri Hust.
Navicula seminulum Grun.
Navicula tantula Hust.
Navicula viridula (Kütz.) Kütz.
Neidium bisulcatum (Lagerst.) Cleve
Neidium sp.
Neidium temperei Reimer
Nitzschia palea (Kütz.) W. Smith
Nitzschia sp.
Pinnularia abaujensis (Pant.) Ross
Pinnularia biceps Gregory
Pinnularia braunii (Grun.) Cleve
Pinnularia divergentissima (Grun.) Cleve
Pinnularia mesolepta (Ehr.) W. Sm.
Pinnularia sp.
Rhoicosphenia curvata (Kütz.) Grun.
Stauroneis kriegeri Patr.
Stauroneis nobilis Schm.
Surirella angustata Kütz.
Surirella ovata Kütz.
Synedra amphicephala Kütz.
Synedra rumpens Kütz.
Synedra sp.
Synedra ulna (Nitz.) Ehr.
Tabellaria fenestrata (Lyngb.) Kütz.
Tabellaria flocculosa (Roth) Kütz.

different than either Deer or Flynn Creek (Figure 7).

Flynn Creek Community, 1966. Flynn Creek, the unlogged watershed, had three dominant species, *Achnanthes lanceolata*, *Cocconeis placentula* and *Eunotia arcus*. Very little seasonal variation was observed in Flynn Creek and *Achnanthes lanceolata* was the most abundant species throughout 1966 (Figure 5).

Deer Creek Community, 1966. Deer Creek had the same three dominant species as Flynn Creek in 1966, *Achnanthes lanceolata*, *Cocconeis placentula*, and *Eunotia arcus*. A well developed periodicity was observed, *Achnanthes lanceolata* appearing in the winter and spring months and *Cocconeis placentula* predominating in the summer months (Figure 6).

Needle Branch Community, 1966. The logging of Needle Branch watershed resulted in a community in the stream quite different from that found in the other two streams. The first visual biological effect of the change in the aquatic environment was an abundant growth of the filamentous bacterium *Sphaerotilus natans* throughout the stream in the logged area in late June and early July, 1966. This species was the only organism observed during this period, colonizing both the mud and silt that accumulated on the stream bed and all slash in the stream. Prior to the

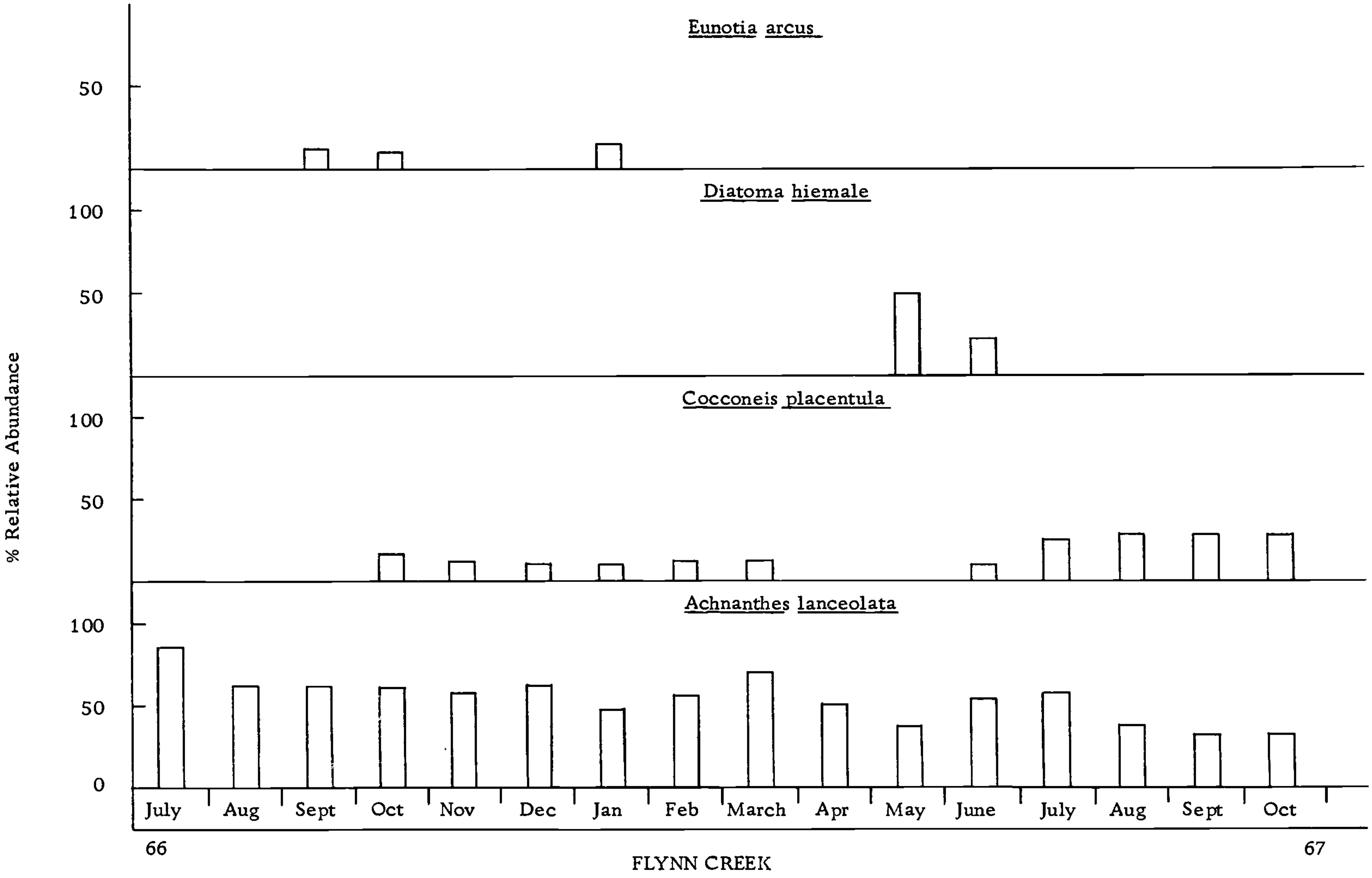


Figure 5. Relative abundance of the dominant species of benthic diatoms.

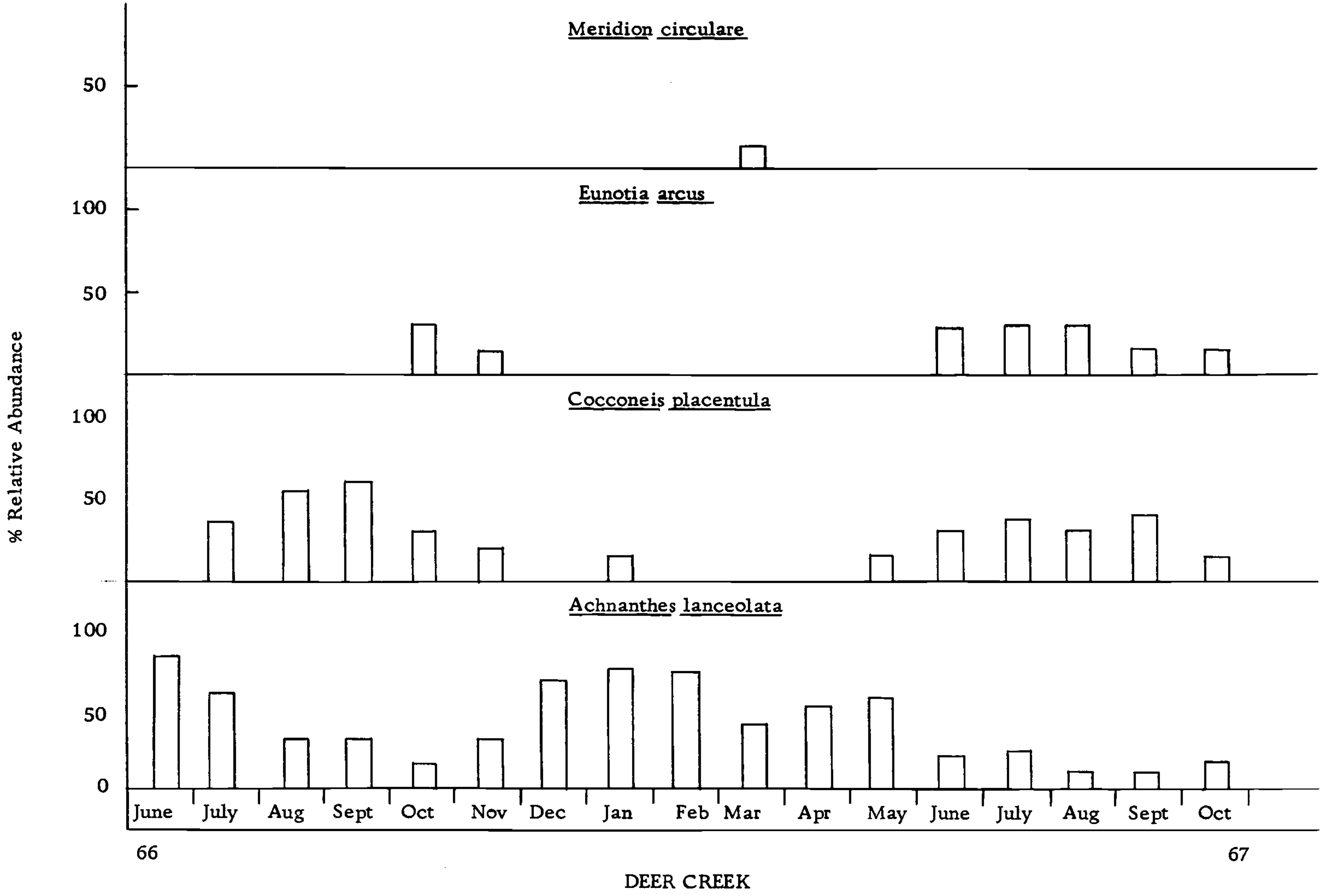


Figure 6. Relative abundance of the dominant species of benthic diatoms.

development of this organism, a putrid odor, possibly hydrogen sulfide, was detected emanating from the stream, suggesting bacterial decomposition. Studies by Ellis (1936) of the effect of erosion silt on the aquatic environment found that layers of silt mixed with organic waste possessed a much richer bacterial flora as well as a high sulfur content, as hydrogen sulfide and other sulfide derivatives, compared to adjacent bottom areas of sand and gravel. Accompanying the decline of _Sphaerotilus_ _natans_ in July, was the appearance of filamentous algae, primarily Chlorophyta, which formed a mat over most of the pool areas and slash in the stream. Species in this algal mat were,

Chlorophyta:
- _Chlamydomonas_ _sp._
- _Draparnaldia_ _glomerata_ (Vauch.)Ag.
- _Spirogyra_ _grevilleana_ (Hass) Kütz.
- _Tetraspora_ _sp._

Cyanophyta:
- _Anabaena_ _affinis_ Lemmermann
- _Oscillatoria_ _amphibia_ Gomont

This filamentous growth continued in decreasing density until the middle of September, when the velocity of the stream increased following the removal of the slash. During the latter part of this period, most algal material was located in small riffle areas where silt had not accumulated or where increased stream flow had removed the silt, while at the same time the algae attached to the slash or situated in the pools was mostly decomposed.

In the middle of October, 1966, a small freshet occurred removing the remaining mat and much of the silt and mud, thus exposing large areas of the original substrate of the riffles. In early November, a major freshet occurred removing the remaining mud and slash.

Although it was quite obvious that the changes in the environment produced a habitat capable of supporting a filamentous algal growth, the diatom populations were also quite different from those observed in the other two streams. Achnanthes lanceolata followed a periodicity similar to that in Deer Creek, decreasing in numbers in the summer and increasing in the fall and winter. Cocconeis placentula was reduced in numbers below that required to be listed as dominant in August, although it was moderately abundant in June and July. Eunotia arcus was most abundant in August through October, having replaced Cocconeis placentula, as well as Nitzschia palea in the earlier part of the summer (Figure 7). The source of Nitzschia palea was the filamentous algal mat,

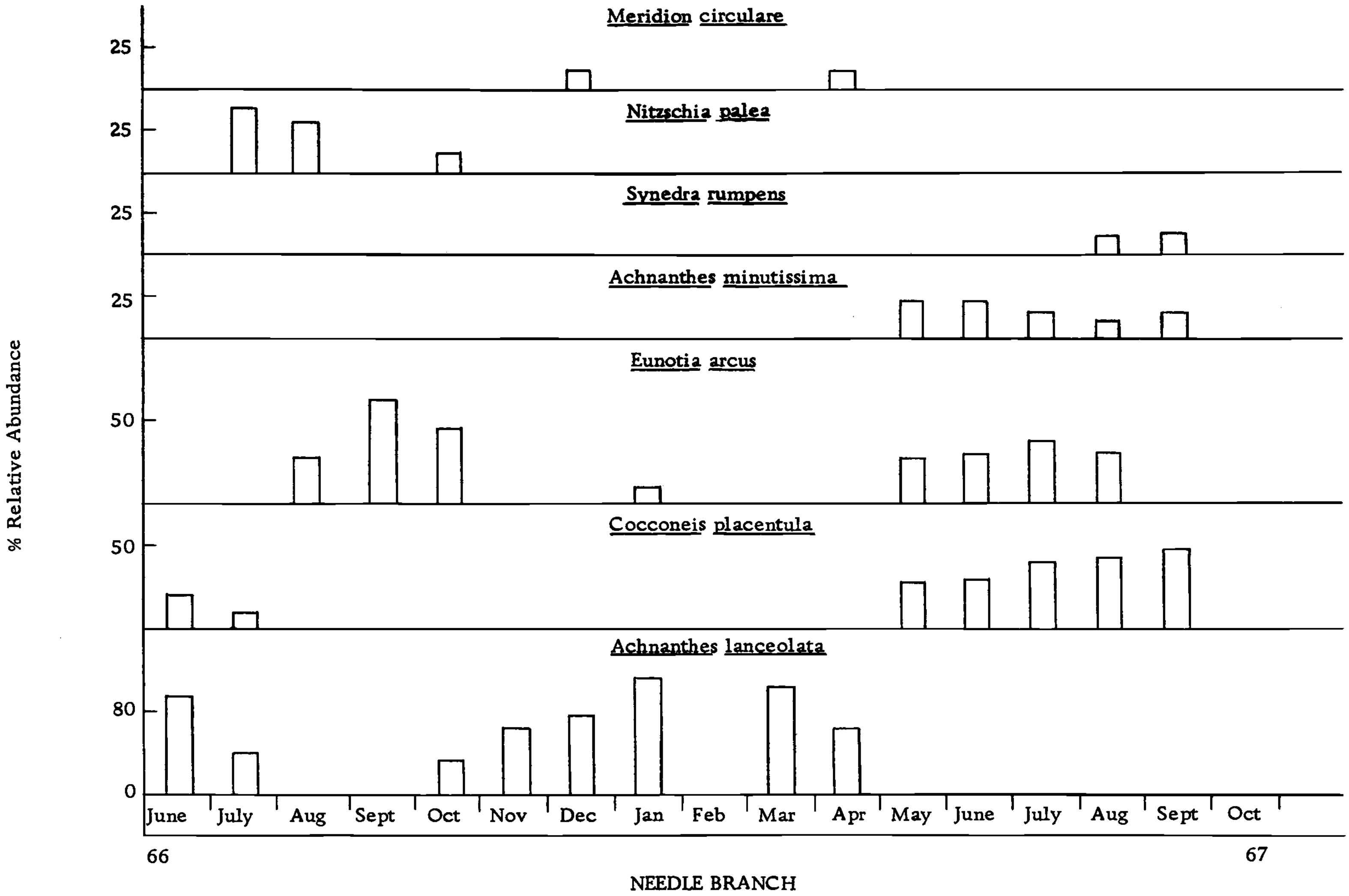


Figure 7. Relative abundance of the dominant species of benthic diatoms.

for examination of this mat showed this diatom to be attached to the filaments in large numbers.

Flynn Creek Community, 1967. The diatom community developed during 1967 varied only slightly from that in 1966. *Achnanthes lanceolata* was more abundant than in 1966. *Eunotia arcus* was abundant in January and *Diatoma hiemale* in late spring (Figure 5).

Deer Creek Community, 1967. This community was similar to that found in 1966, with *Achnanthes lanceolata* dominant in winter and spring and *Cocconeis placentula* most abundant during the summer months. *Meridion circulare* was moderately abundant in early spring, and *Eunotia arcus* was more abundant in the summer months of 1967 than in 1966 (Figure 6).

Needle Branch Community, 1967. In early spring, *Achnanthes lanceolata* was again the dominant species, as in the other two streams. As summer approached, the filamentous algae colonized many of the exposed riffle areas. Samples taken from the glass artificial substrates during 1967 showed a complete change in the structure of the community of Needle Branch. This stream, which had been a diatom habitat prior to logging, became an environment supporting a mixed community of primarily filamentous algae and diatoms, with the filamentous forms comprising the dominant part of the flora (Figure 8). Species other than diatoms in this flora included:

Ankistrodesmus sp.
Chlamdymonas sp.
Scenedesmus bijunga (Turp.) Lagerh.
Spirogyra sp.
Stigeoclonium sp.
Anabena sp.
Oscillatoria sp.
Schizothrix calciocola [Ag.] Gom.

Achnanthes lanceolata decreased in numbers in May and was not a part of the dominant flora during the remainder of the investigation. *Cocconeis placentula*, which was an infrequent member of the flora in 1966, became very abundant in the summer of 1967. *Synedra rumpens* and *Achnanthes minutissima* which were not found in large numbers in any of the streams prior to 1967, became dominant in Needle Branch during the season following logging. *Nitzschia palea* which was abundant in 1966 was observed in minimal numbers in 1967. *Meridion circulare* was abundant in early spring as was *Eunotia arcus* again abundant in the summer (Figure 7).

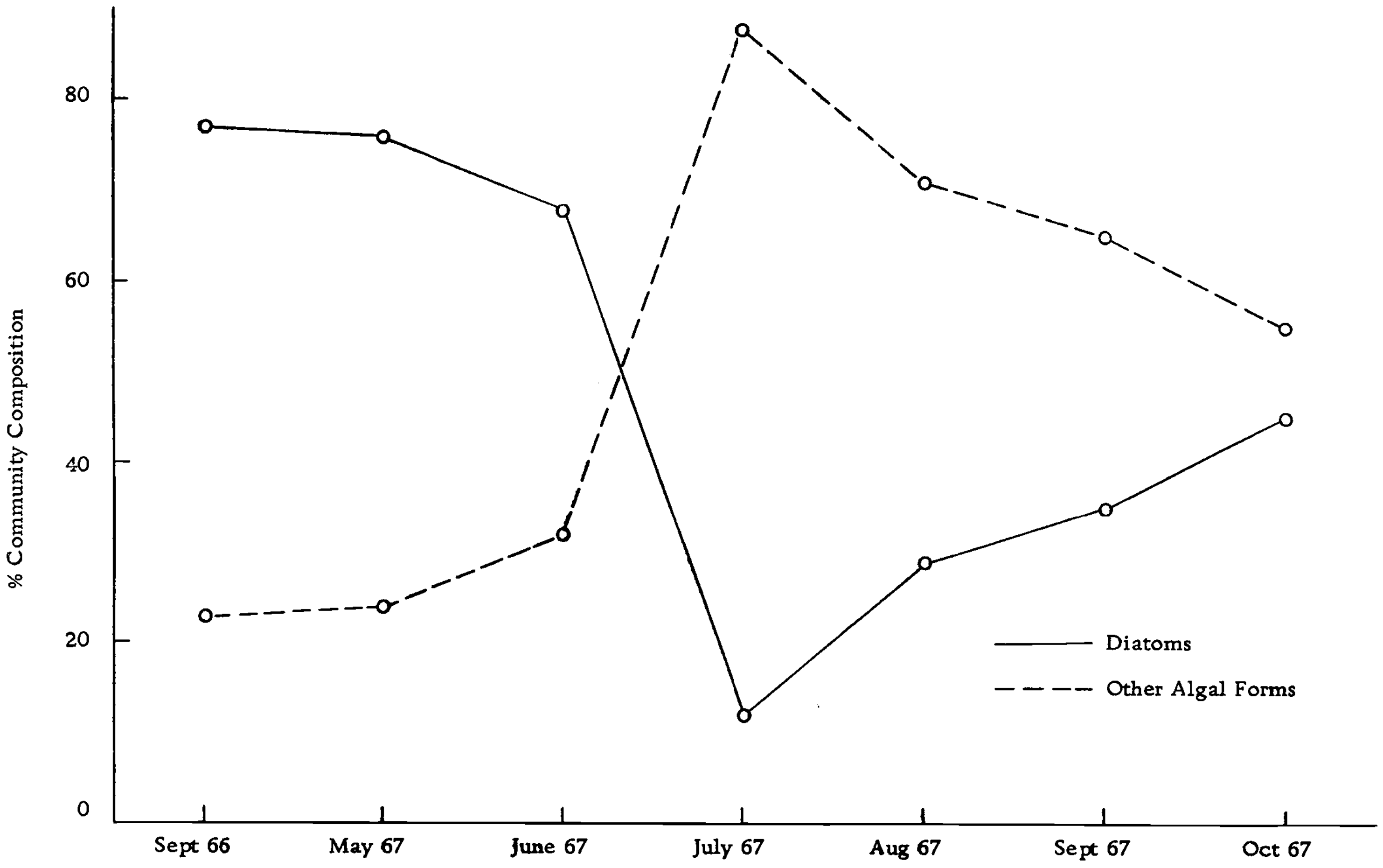


Figure 8. Composition of the community developed on glass artificial substrates in Needle Branch following logging.

Batrachospermum sp. was found in the spring, growing in isolated shaded areas of all streams, as well as in shaded areas of Needle Branch, when temperatures of the water ranged from 16-23 C.

Comparison of Benthic Diatom Communities Within Individual Streams

Although the species composition of the communities at the various sites in a given stream was generally similar, some degree of dissimilarity arose from differences in relative abundance and seasonal periodicity of the species (Appendix Tables 3-11). The length of time that the slides remained in the streams did not seem to affect the degree of similarity between the communities developed at the different sites (Appendix Tables 12-14).

The communities in Needle Branch and Deer Creek, as sampled by slides held in the stream for four weeks, indicated a greater dissimilarity during the period of April to October, when the diatom growth was most abundant, than during the winter months (Figures 9, 10). The communities in Flynn Creek do not exhibit this seasonal pattern (Figure 11).

Comparison of Benthic Diatom Communities Among the Streams

When the communities from the various streams were compared on the basis of a four week sampling interval, the pattern of

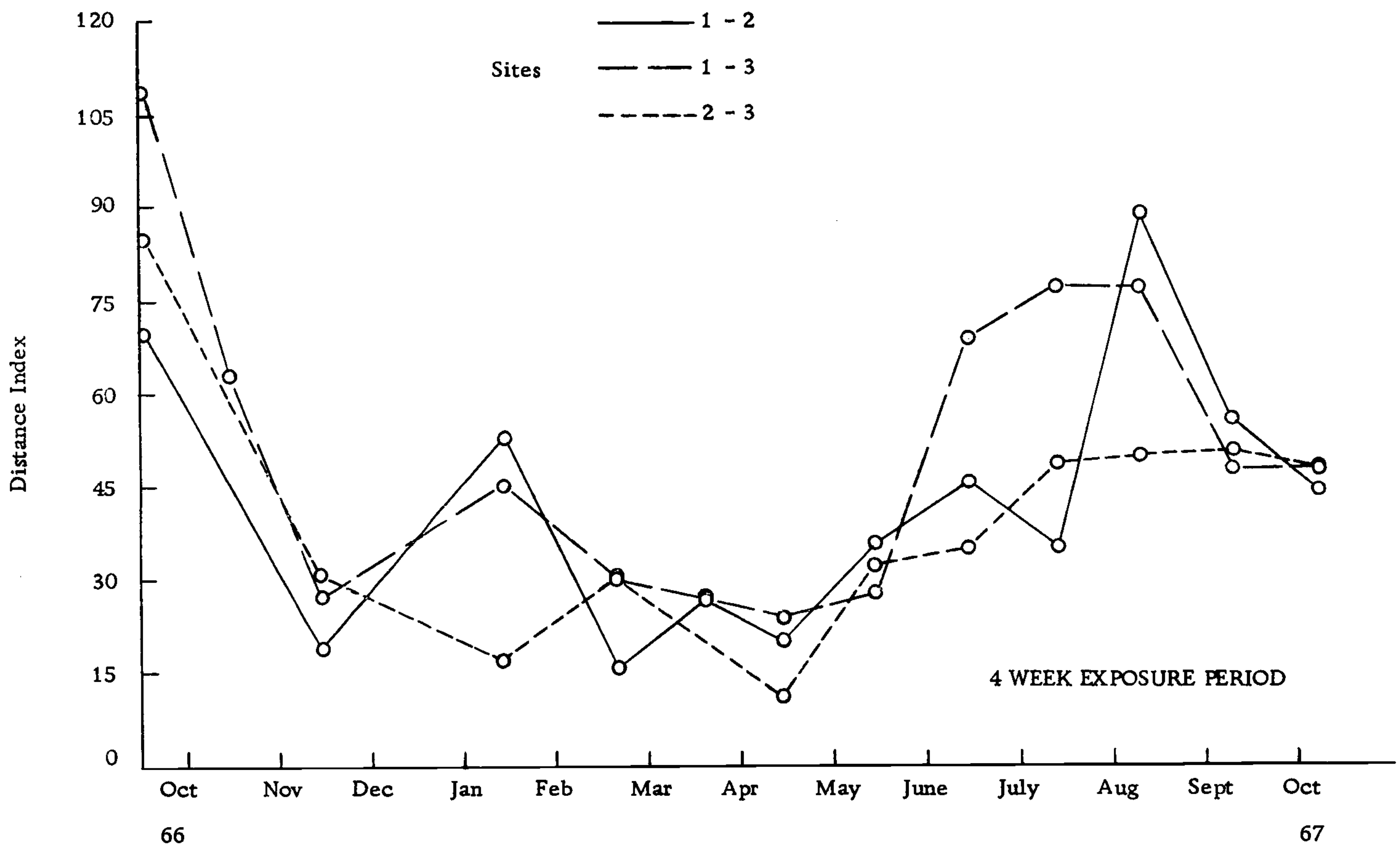


Figure 9. Comparison of the variation in the structure of diatom communities developed on glass artificial substrates between sites in Deer Creek.

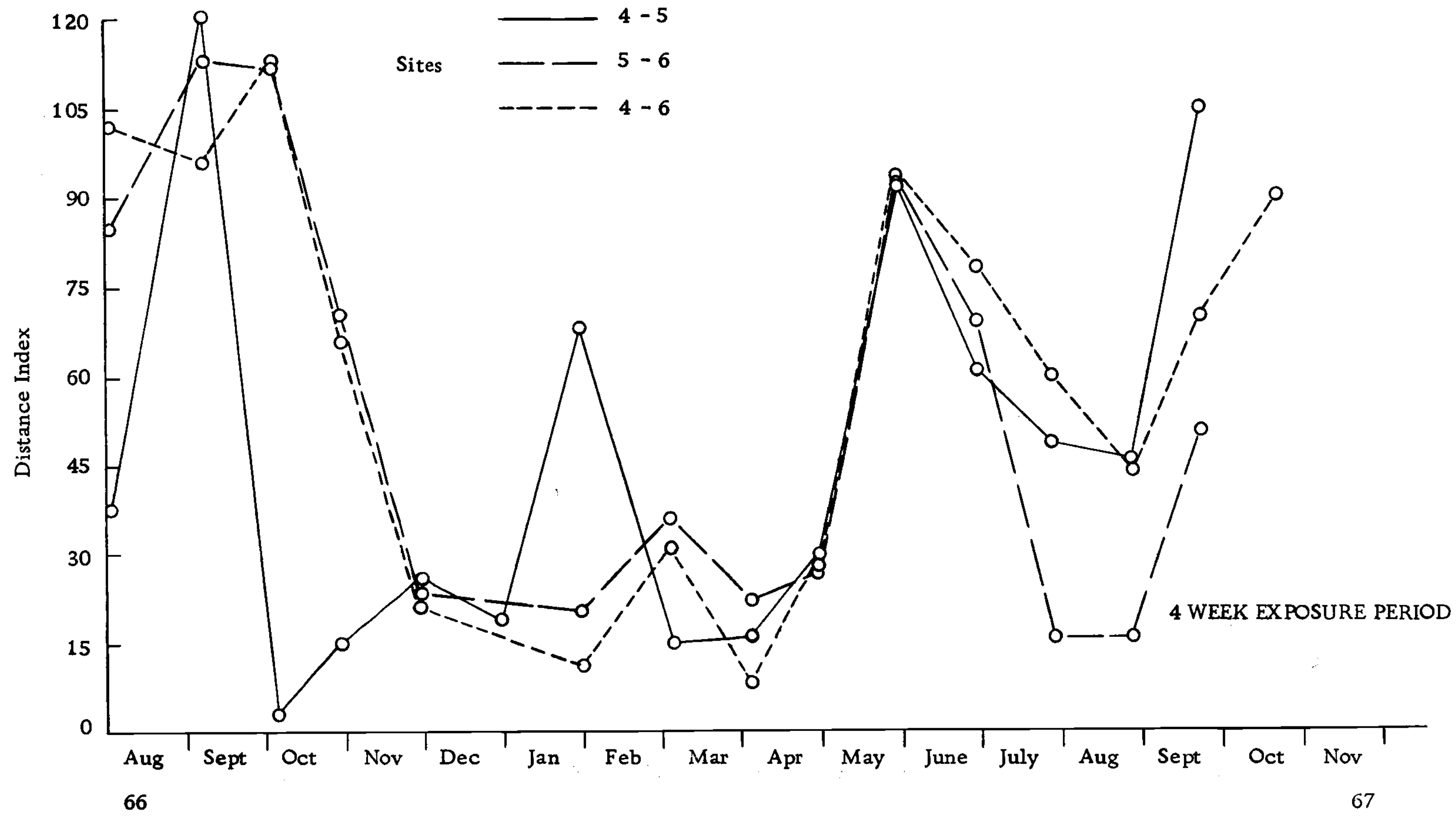


Figure 10. Comparison of the variation in structure of diatom communities developed on glass artificial substrates between sites in Needle Branch.

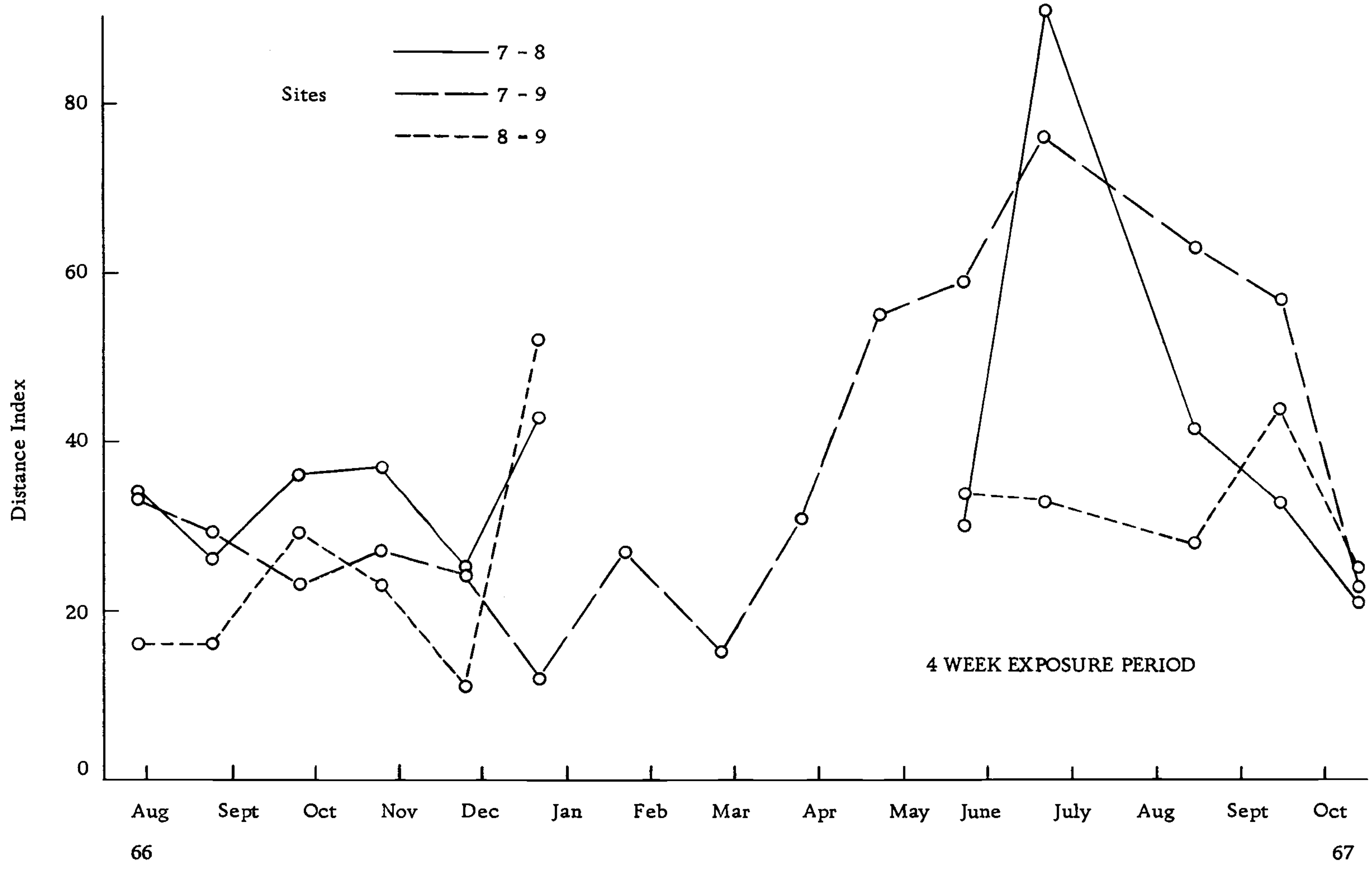


Figure 11. Comparison of the variation in structure of diatom communities developed on glass artificial substrates between sites in Flynn Creek.

community development was found to be similar to that of the communities within the streams. There was greater similarity of the communities among streams during the winter than during the spring and summer months (Figure 12).

Comparison of Logging and Post Logging Diatom Communities in Needle Branch

Comparison of the degree of similarity of the communities developed in Needle Branch at the three sites in 1966, and 1967, shows greater similarity in the communities in 1967 than in 1966 (Figure 13).

Comparison of the Structure of the Community Developed on Glass Artificial Substrates Exposed for Varying Times

A comparison was made of the variation in structure of the communities developed on substrates suspending in the same riffle for 4, 8 and 12 weeks (Figures 14, 15). The communities that developed on the slides in Deer and Flynn Creeks became more stable, showing a steady increase in similarity the longer the slides resided in the stream. Whether the community that developed by the week 12 would remain stable except for seasonal changes has not been established. A stable community was reached by week 8 in Needle Branch (Figure 16).

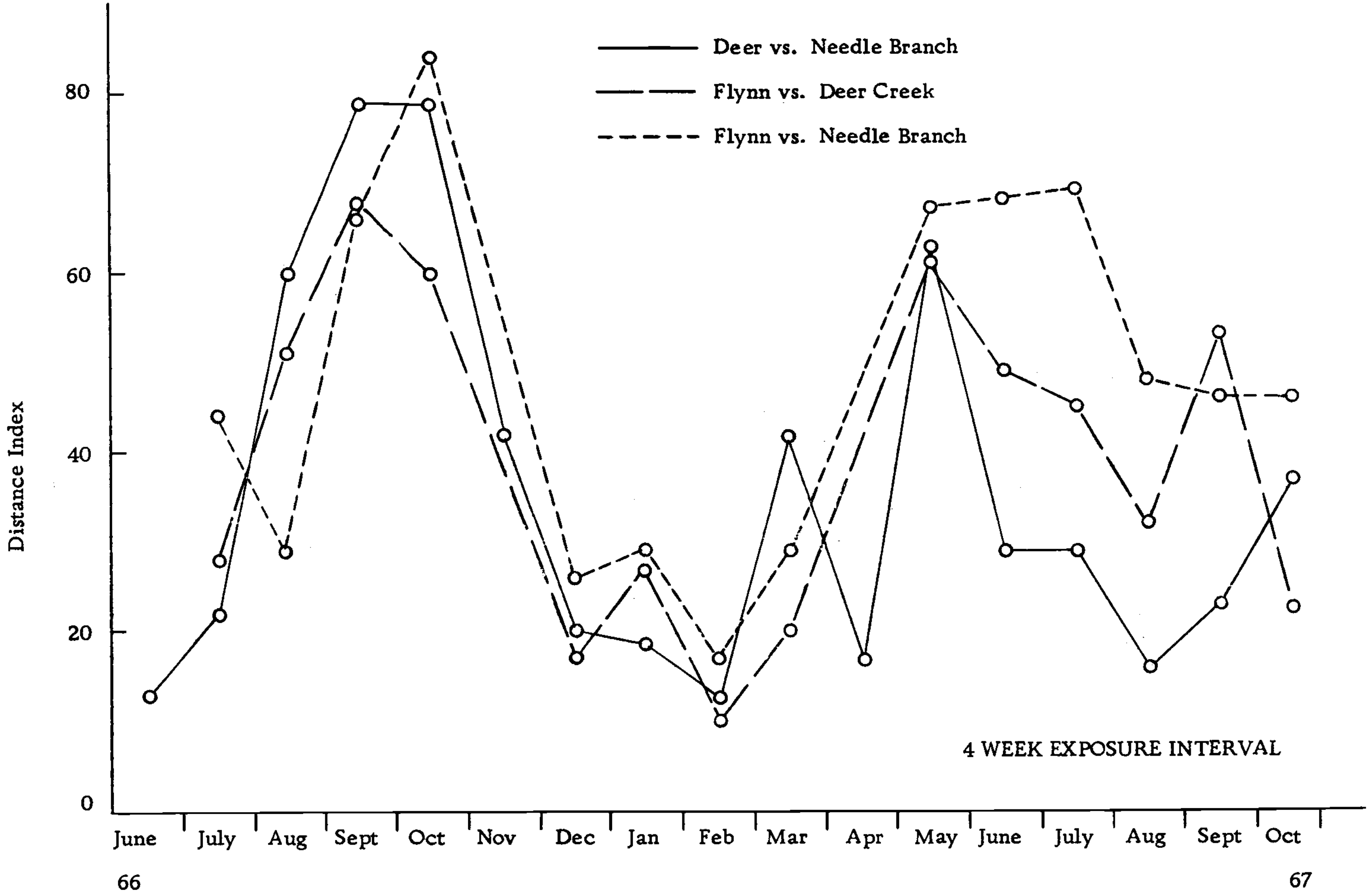


Figure 12. Comparison of variation in community structure developed on glass artificial substrates among the streams.

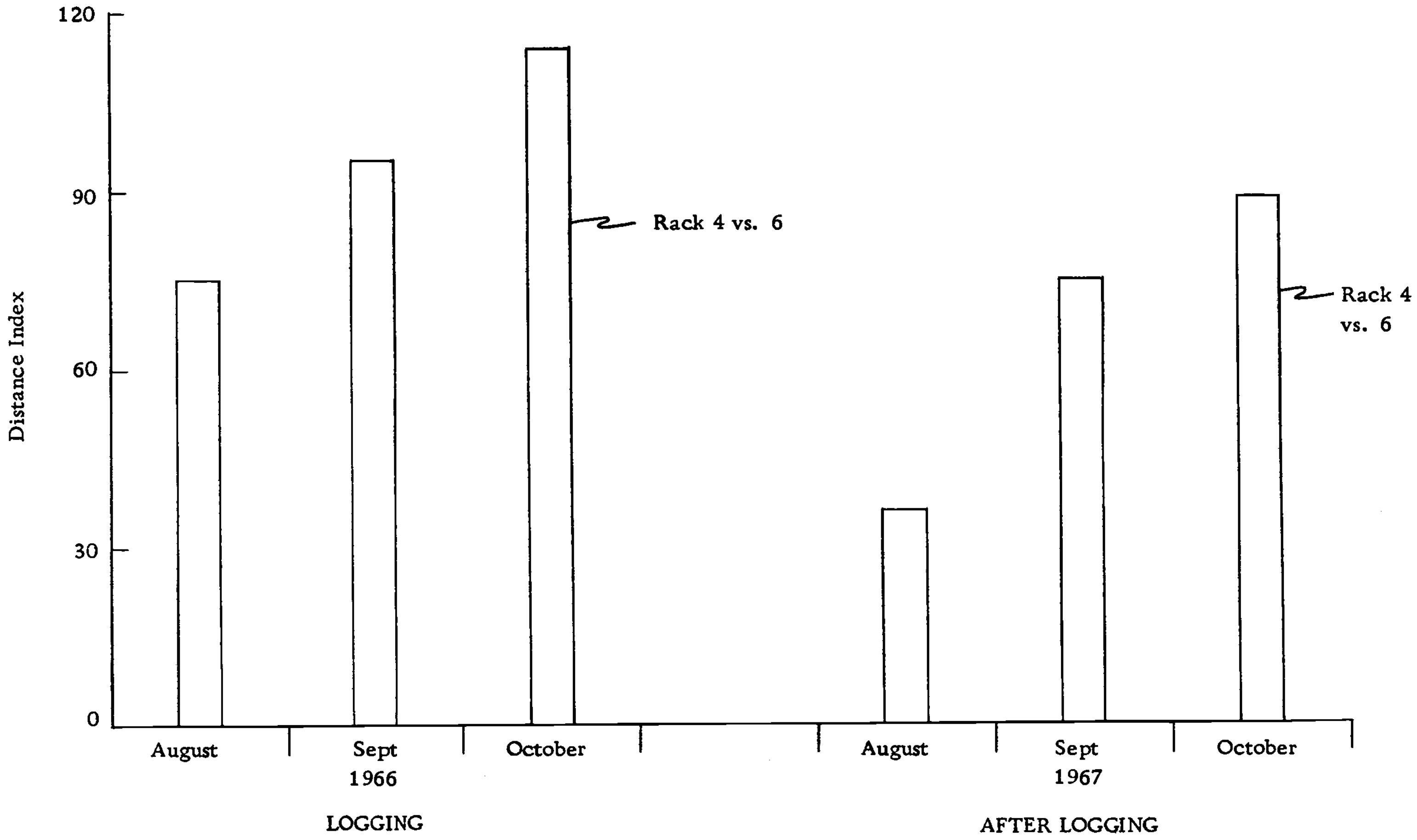


Figure 13. Mean variation in structure of the diatom community developed on glass artificial substrates in Needle Branch. October index calculated from a single observation.

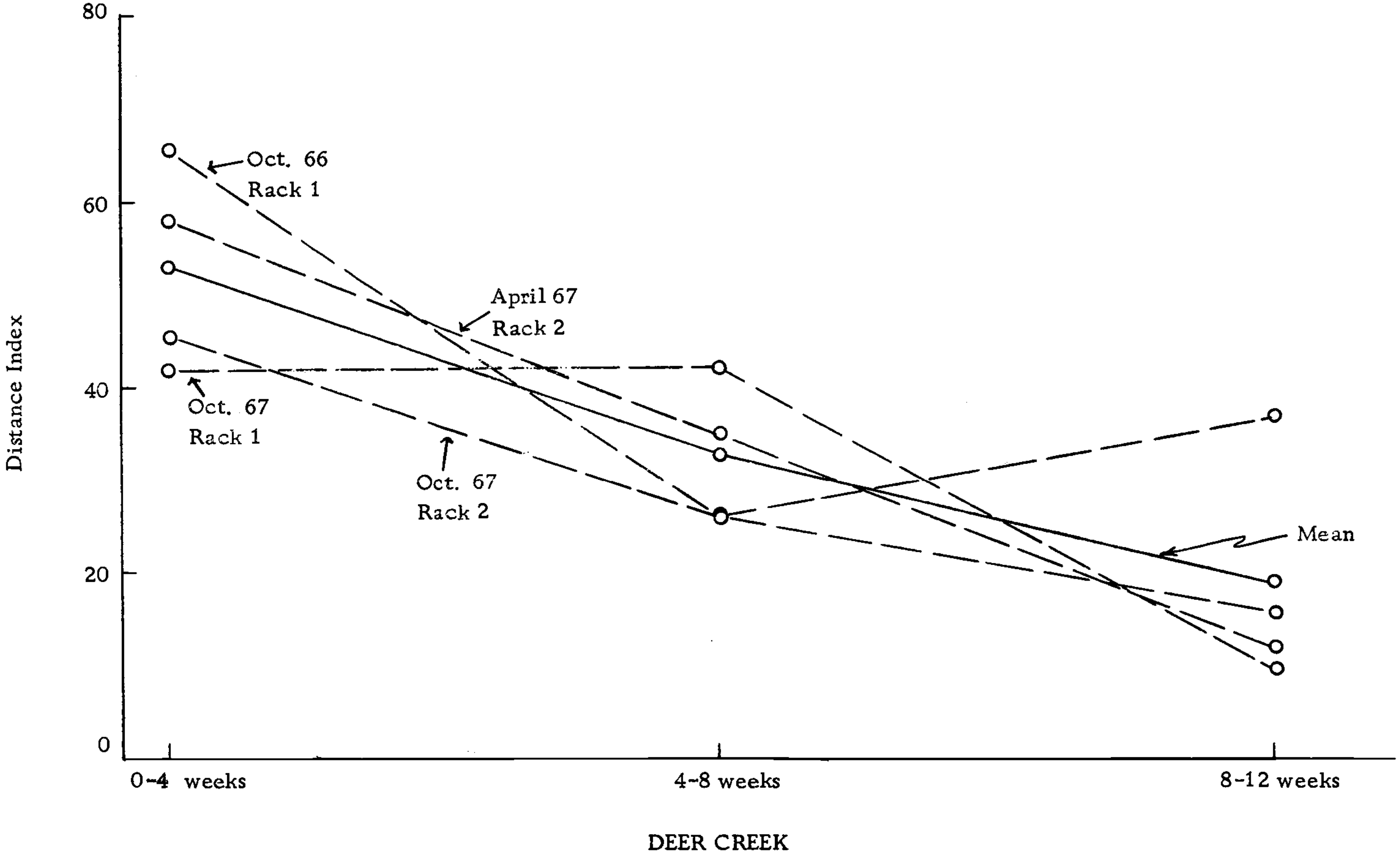


Figure 14. Comparison of the degree of similarity in the structure of the diatom community developed on glass artificial substrates following various lengths of exposure. Four, eight and twelve week slides removed from stream during month indicated. Four week community compared to bare glass substrate.

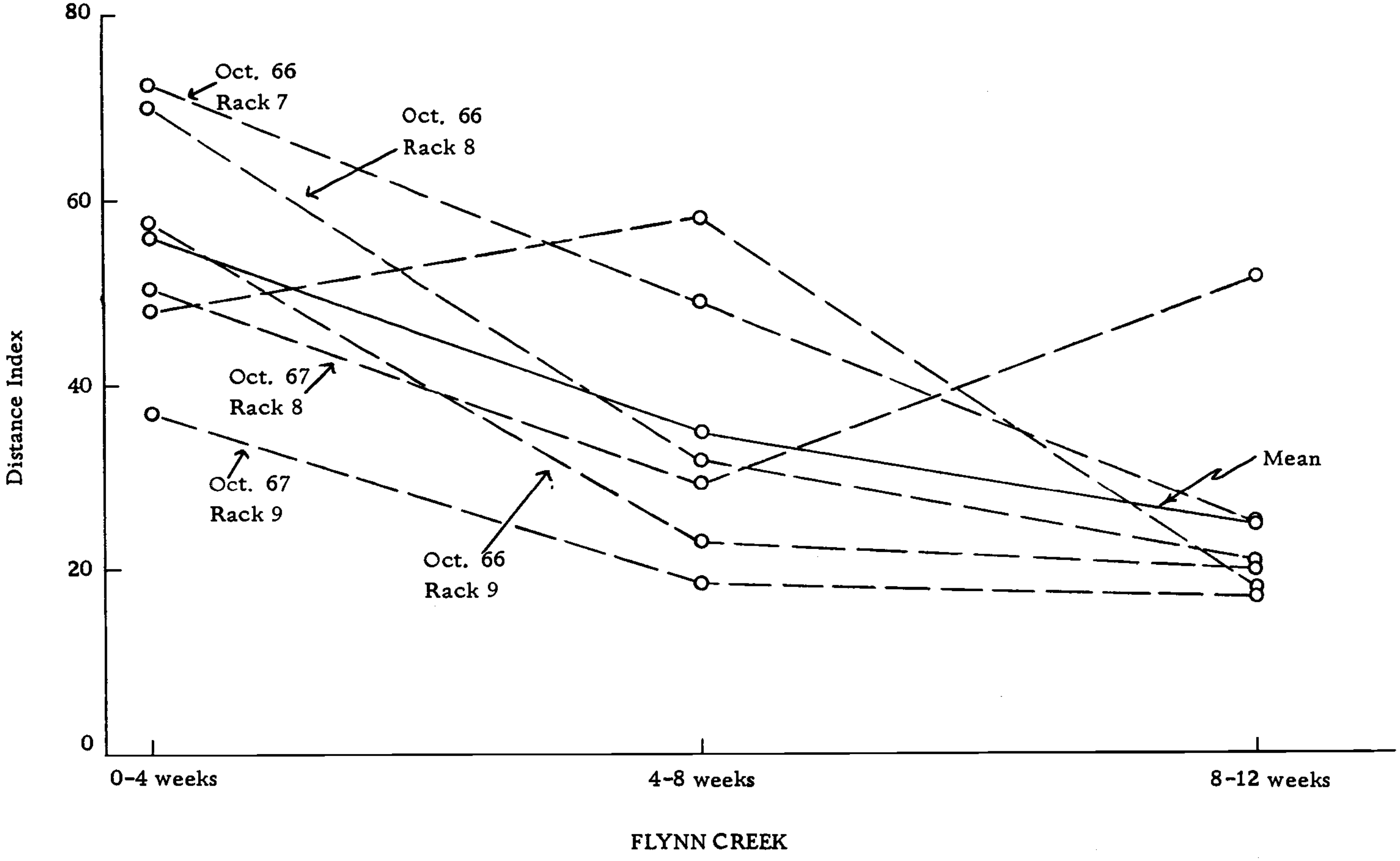


Figure 15. Comparison of the degree of similarity in the structure of the diatom community developed on glass artificial substrates following various lengths of exposure. Four, eight and twelve week slides removed from stream during month indicated. Four week community compared to bare glass substrate.

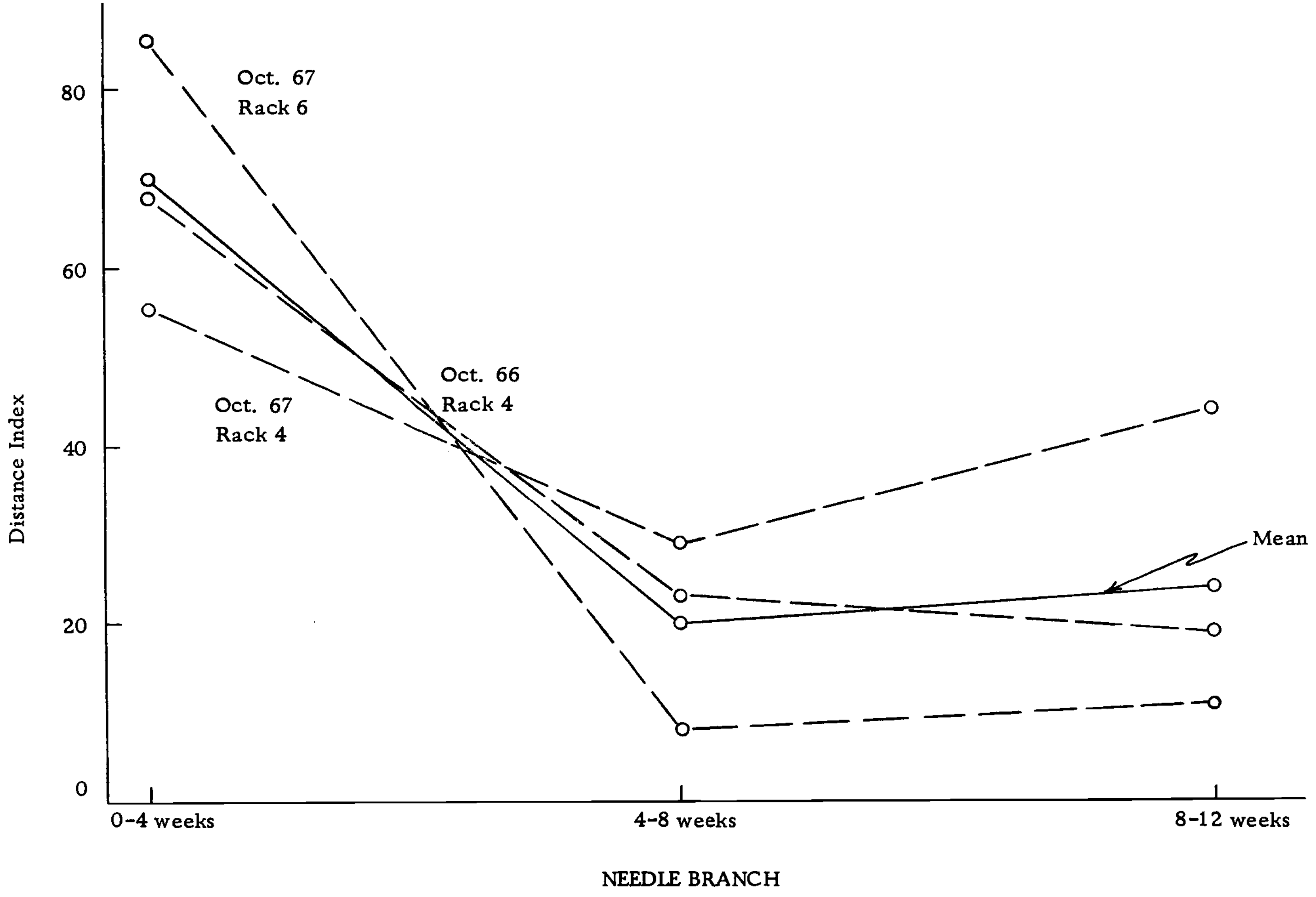


Figure 16. Comparison of the degree of similarity in the structure of the diatom community developed on glass artificial substrates following various lengths of exposure. Four, eight and twelve week slides removed from stream during month indicated. Four week community compared to bare substrate.

Comparison of Diatom Community Developed on Artificial and Natural Substrates

In an attempt to determine whether the diatom community developed on the glass artificial substrates was representative of the community of the natural substrate, random samples of rock were taken from the area of the slide rack and brought to the laboratory where the organic material was scrubbed from them. Permanent slides were made of the diatoms from this organic material and estimates made of the relative abundance of the diatom species. Species identification was made difficult by the abundant silt and sand grains present on the slides as a result of the scrubbing process. The distance equation was applied to the two communities (Table 4).

The species composition of the two communities was very similar, but the relative abundance of the species was quite varied (Figures 17, 18, 19). Longer exposure of the glass artificial substrates in the stream did not increase the similarity of the two communities (Table 5).

Comparison of Communities Developed on Rock Artificial Substrates and the Natural Substrate

Because very few samples of the community in Needle Branch were taken from the natural substrate in the same riffle in which the rock artificial substrates were placed, the diatom community of

Table 4. Comparison of the communities developed on glass artificial substrates and natural substrate of the stream. Four week exposure time for glass artificial substrates.

Stream	Rack	Date	Index
Flynn Creek	--	7-8-66	74
Needle Branch	6	8-24-67	69
Needle Branch	6	9-23-67	58
Needle Branch	5	9-23-67	87
Needle Branch	4	9-23-67	59
Deer Creek	3	9-23-67	98
Deer Creek	2	9-23-67	35
Deer Creek	1	9-23-67	80
Needle Branch	4	10-21-67	72
Needle Branch	6	10-21-67	98
Deer Creek	1	10-21-67	67

Table 5. Comparison of communities developed on glass artificial and natural substrate with various exposure times of the artificial substrates. All samples were taken in October, 1967.

Stream	Rack	Exposure Time	Index
Deer Creek	1	8 weeks	93
Needle Branch	4	12 weeks	73
Needle Branch	6	12 weeks	95
Deer Creek	1	12 weeks	100

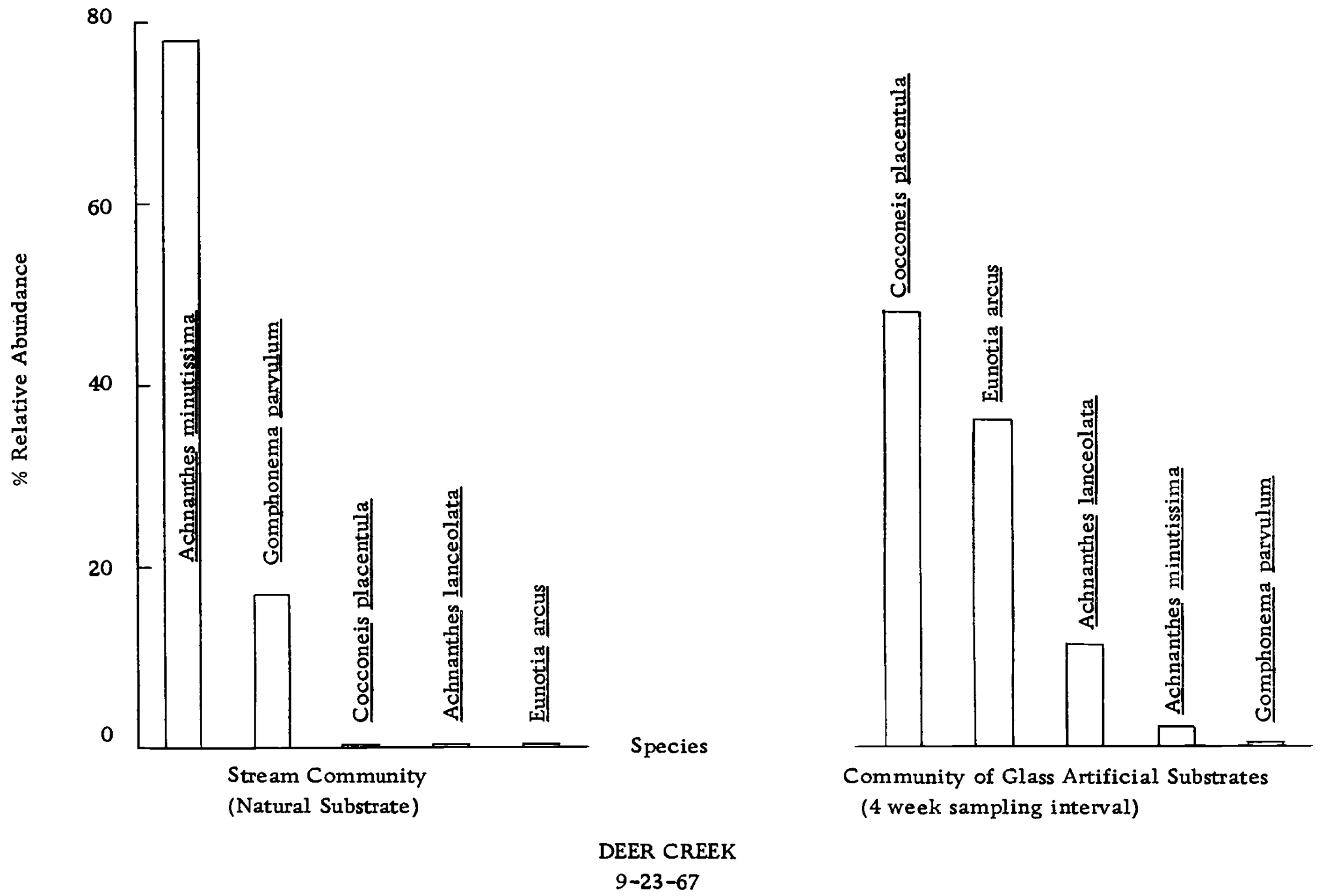
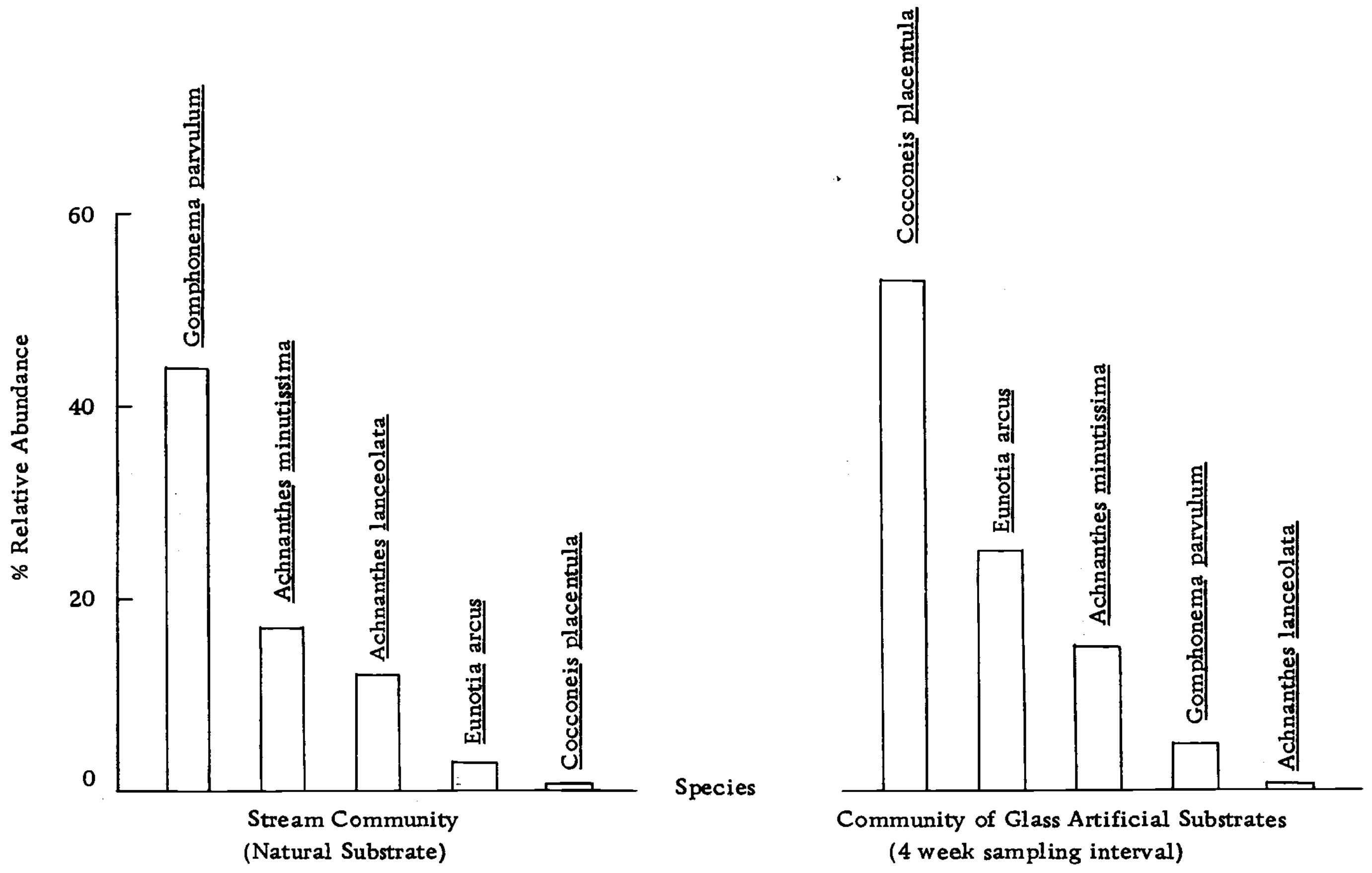


Figure 17. Dominant species of the community found on two substrates taken from the same site.



NEEDLE BRANCH
8-24-67

Figure 18. Dominant species of the community found on two substrates taken from the same site.

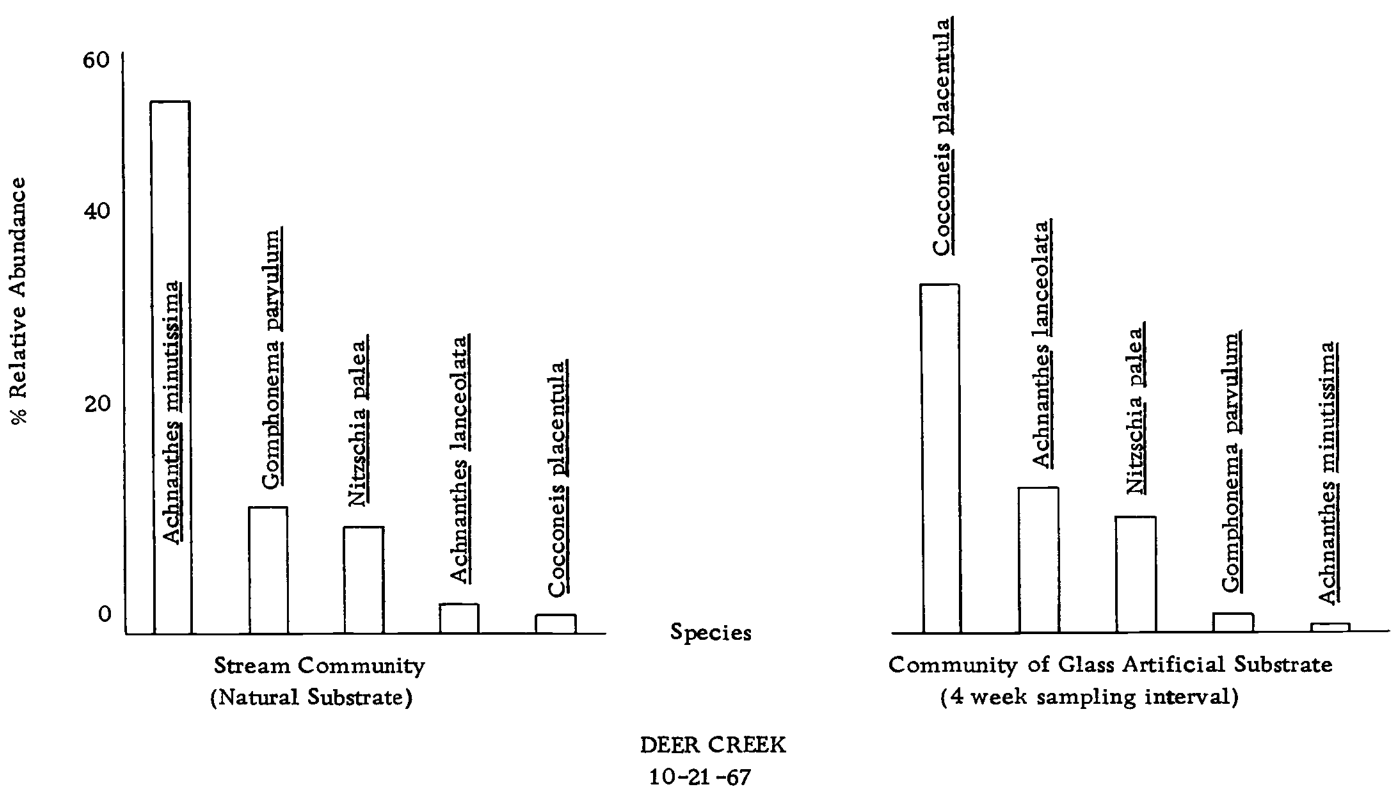


Figure 19. Dominant species of the community found on two substrates taken from the same site.

the nearest riffle containing a slide rack was used for comparison. This riffle was the site of rack 5. For the dates indicated, there was more similarity between the communities of the natural substrate and rock artificial substrate than there was between the communities on the natural substrate and glass artificial substrate (Tables 4 and 6). For example, on September 23, 1967, the index of similarity between the natural substrate and rock artificial substrate was 39, whereas for the same date, the glass artificial substrate and the natural substrate had an index of similarity of 87.

Similar results were obtained from the mixed community of diatoms and filamentous algae. The community of the rock artificial substrate and natural stream community had a similarity index of 10, while the community of the glass substrate and natural substrate had an index of 66.

Table 6. Comparison of communities developed on rock artificial substrate and natural substrate. Samples taken no more than eight days apart. Sample date of rock artificial substrate given.

Date	Stream	Index
8-2-67	Needle Branch	36
9-23-67	Needle Branch	39
10-21-67	Needle Branch	18

Effects of Logging on the Biomass of Autotrophic Organisms

The biomass of autotrophic organisms colonizing the natural substrate was estimated by determining the concentration of chlorophyll a in mg/m^2 (Appendix Table 15). Because of a malfunction of the spectrophotometer used, all data prior to early July, 1967, had to be discarded. This error was not found until a new instrument was used and the optical densities of the same sample were determined on both instruments and compared.

The concentration of chlorophyll a extracted from the community on the natural substrate in the trays used in the P-R Chamber studies in Needle Branch, was lower after than before logging. In 1964, estimates of mean concentration of chlorophyll a were slightly less from Needle Branch than from Flynn Creek. However, in 1967, the chlorophyll a concentration in Needle Branch was estimated to be one-fifth of that in 1964, although the value for Flynn Creek was approximately the same in 1967 as in 1964 (Table 7). All 1964 measurements were taken by Lane (1965).

The lowest chlorophyll a value recorded for Needle Branch in 1967 was 2.59 mg/m^2 on August 8, 1967. This value is approximately 1/25 of that recorded for the other streams during the same period (Figure 20).

From microscopic examination of the organic material taken

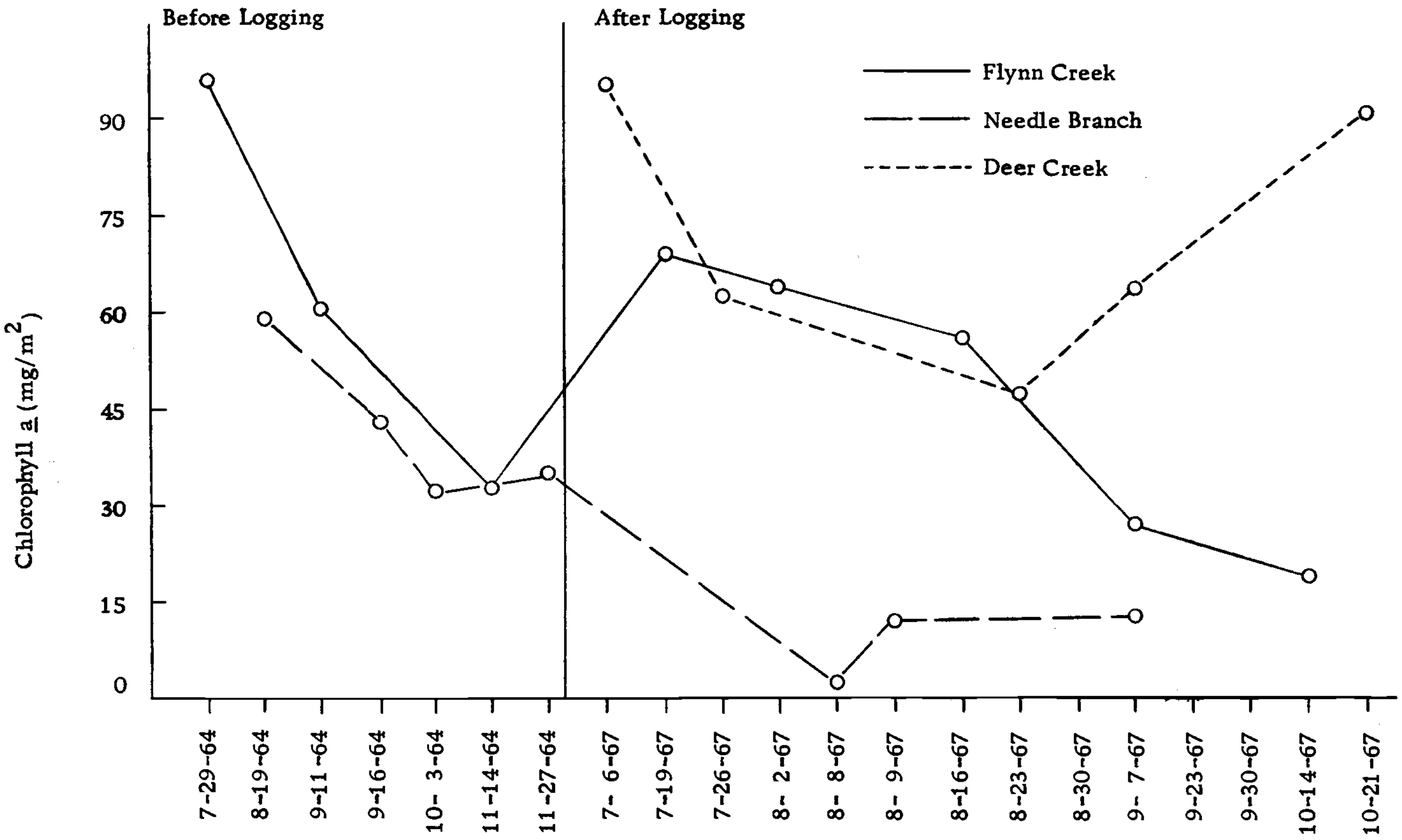


Figure 20. Chlorophyll a content of the communities developed on the substrates in the trays used in P-R Chamber studies.

from glass artificial substrates prior to 1967, the majority of the attached diatoms were living and contained plastids. During 1967, samples from the glass artificial substrates on September 23, showed that 70% of the diatoms were living, and 30% were dead. On October 21, samples showed that 62% of the diatoms were living and 38% were dead. Scrapings taken from the natural substrate, at six different locations in the logged area of Needle Branch indicated that 34% of the diatom flora was living, while 66% of it was empty frustules.

Table 7. Mean estimate of the biomass of autotrophic organisms (chlor. a mg/m^2) recorded in 1964 and 1967.

Stream		Date	Mean Biomass	Range
		BEFORE LOGGING 1964		
Flynn Creek	(unlogged)	Aug. - Nov.	58.50	33.00 - 82.00
Needle Branch	(unlogged)	Aug. - Nov.	40.40	31.90 - 59.10
Needle Branch	(unlogged)	Aug. - Sept.	51.30	43.50 - 59.10
		AFTER LOGGING 1967		
Flynn Creek	(unlogged)	July - Oct.	46.74	19.00 - 68.80
Needle Branch	(clearcut)	Aug. - Sept.	9.10	2.60 - 12.70

Comparison shows little relationship between the mg chlorophyll a/m^2 developed on glass artificial substrates and that found on the natural substrate of Deer Creek (Figure 21). While the biomass

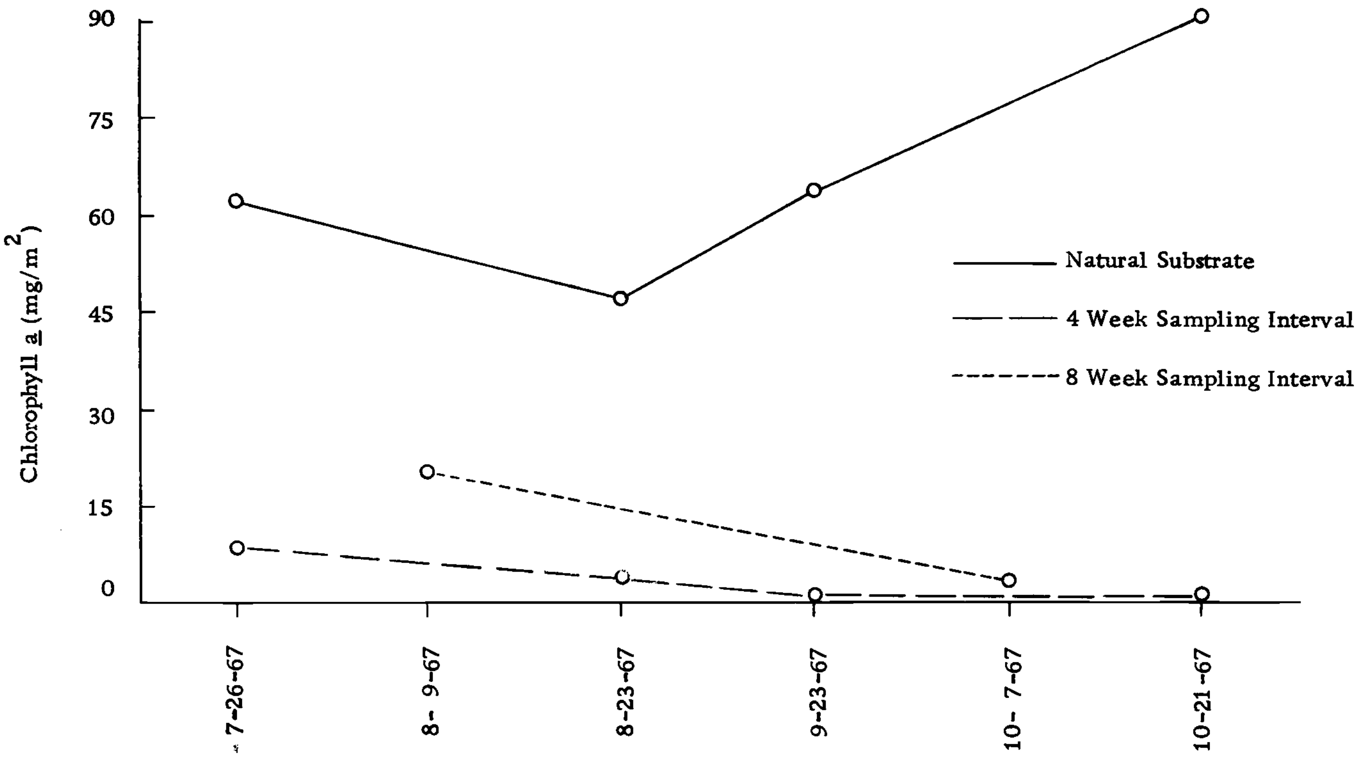


Figure 21. Comparison of chlorophyll a content of the communities developed on natural and artificial substrates in Deer Creek.

on the natural substrate of the stream shows a decrease through July and August, 1967 and then a steady monthly increase until the end of the investigation in October, the development on the glass artificial substrates exposed to the stream for four and eight week periods showed a steady decrease during the same period.

Community Metabolism

Respiration

The hourly mean estimates of respiration (mg O_2/m^2 hr) obtained during the determinations of gross primary productivity were used to calculate daily values for respiration (Appendix Table 16). The assumption was made that respiration was constant over a 24 hour period. Prior to logging (1964), the mean value of respiration of the community in Needle Branch was lower than that of Flynn Creek, the unlogged watershed (Lane, 1965). After logging in 1967, the mean respiration of the community in Needle Branch exceeded that of both Flynn and Deer Creeks and was slightly greater than that observed in Needle Branch for comparable months in 1964 (Table 8). Although mean respiration in Needle Branch was higher than that observed in the other two streams during 1967, respiration of the community in August was lower than that observed in August, 1964 (Figure 22). This reduced respiration was observed at a time when the concentration of chlorophyll a was very small.

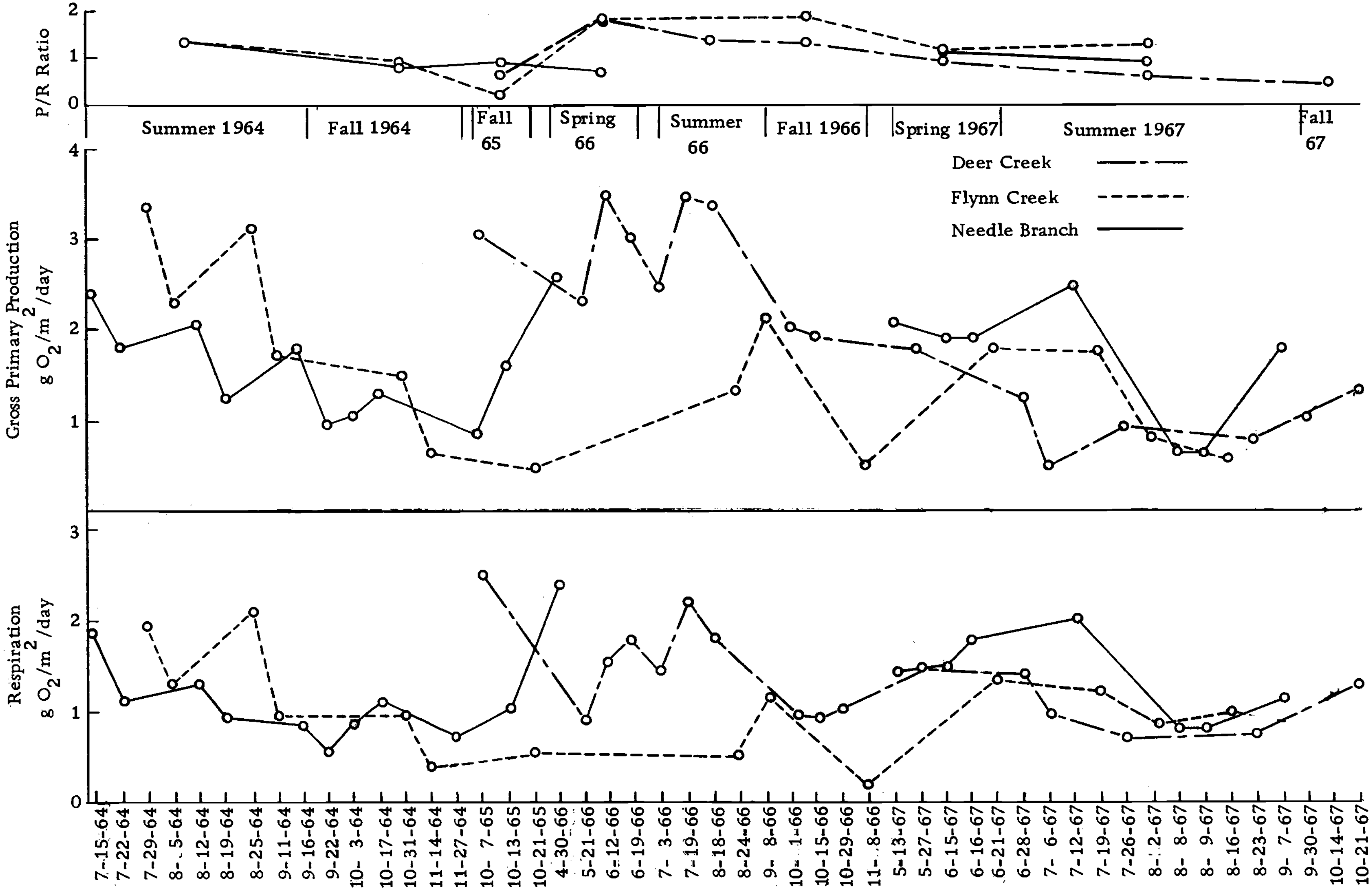


Figure 22. Gross primary production, respiration and P/R ratio of Flynn, Deer and Needle Branch Creeks.

Table 8. Mean community respiration (g O_2/m^2 day) before logging (1964) and after logging (1967).

Stream		Date	No. of days	Mean Respiration	Range
		BEFORE LOGGING (1964)			
Flynn Creek	(unlogged)	July - Aug.	3	1.77	1.25 - 2.08
Needle Branch	(unlogged)	July - Aug.	3	1.40	1.12 - 1.82
Needle Branch	(unlogged)	July - Sept.	6	1.08	0.52 - 1.82
		AFTER LOGGING (1967)			
Flynn Creek	(unlogged)	July - Aug.	3	0.98	0.79 - 1.15
Deer Creek	(patch logged)	July - Sept.	3	0.81	0.68 - 0.96
Needle Branch	(clearcut)	July - Sept.	4	1.28	0.73 - 2.02

Gross Primary Production

Gross primary production measurements were made in all streams (Appendix Table 17). Comparing gross primary production in Needle Branch and Flynn Creek during 1964 and 1967, the mean productivity for both streams decreased in 1967 as compared to 1964. Mean gross production, for comparable months (July - August) was 2.91 g O_2/m^2 day for Flynn Creek and 1.88 g O_2/m^2 day for Needle Branch. In 1967, the mean production rates, for comparable months (June-August) was 1.05 g O_2/m^2 day in Flynn Creek and 1.32 g O_2/m^2 day in Needle Branch. The reduction in gross primary productivity in Flynn Creek during 1967, as compared to the production in Flynn Creek in 1964, was probably associated with the reduction in light intensity during productivity runs in 1967.

The effect of light of poor quality and of low intensity for photosynthesis, transmitted through the canopy of Flynn Creek watershed is evident. In 1967, Flynn Creek had a mean biomass of autotrophic organisms (mg chlorophyll a/m^2) five times that observed in Needle Branch, but productivity in Flynn Creek (canopy present) was less than that observed in Needle Branch (canopy removed).

The efficiency of the photosynthetic process in terms of chlorophyll a (gross production/hr/mg chlorophyll a) increased in Needle Branch in 1967, over that observed in 1964, and that observed in Flynn Creek the same year, 1967 (Figure 23). The efficiency of carbon fixation per mg of chlorphyll a in each stream is shown in Table 9.

Table 9. Photosynthetic efficiency (mg O_2/mg of chlorophyll a/m^2/hr) before logging and after logging.

Stream	Date	Mean Photosynthetic Efficiency	Range
	BEFORE LOGGING (1964)		
Flynn Creek	Aug. - Nov.	1.50	1.25 - 1.77
Needle Branch	Aug. - Nov.	1.60	1.07 - 2.42
	AFTER LOGGING (1967)		
Flynn Creek	July - Aug.	0.70	0.28 - 1.22
Needle Branch	Aug. - Sept.	7.00	2.30 - 11.60

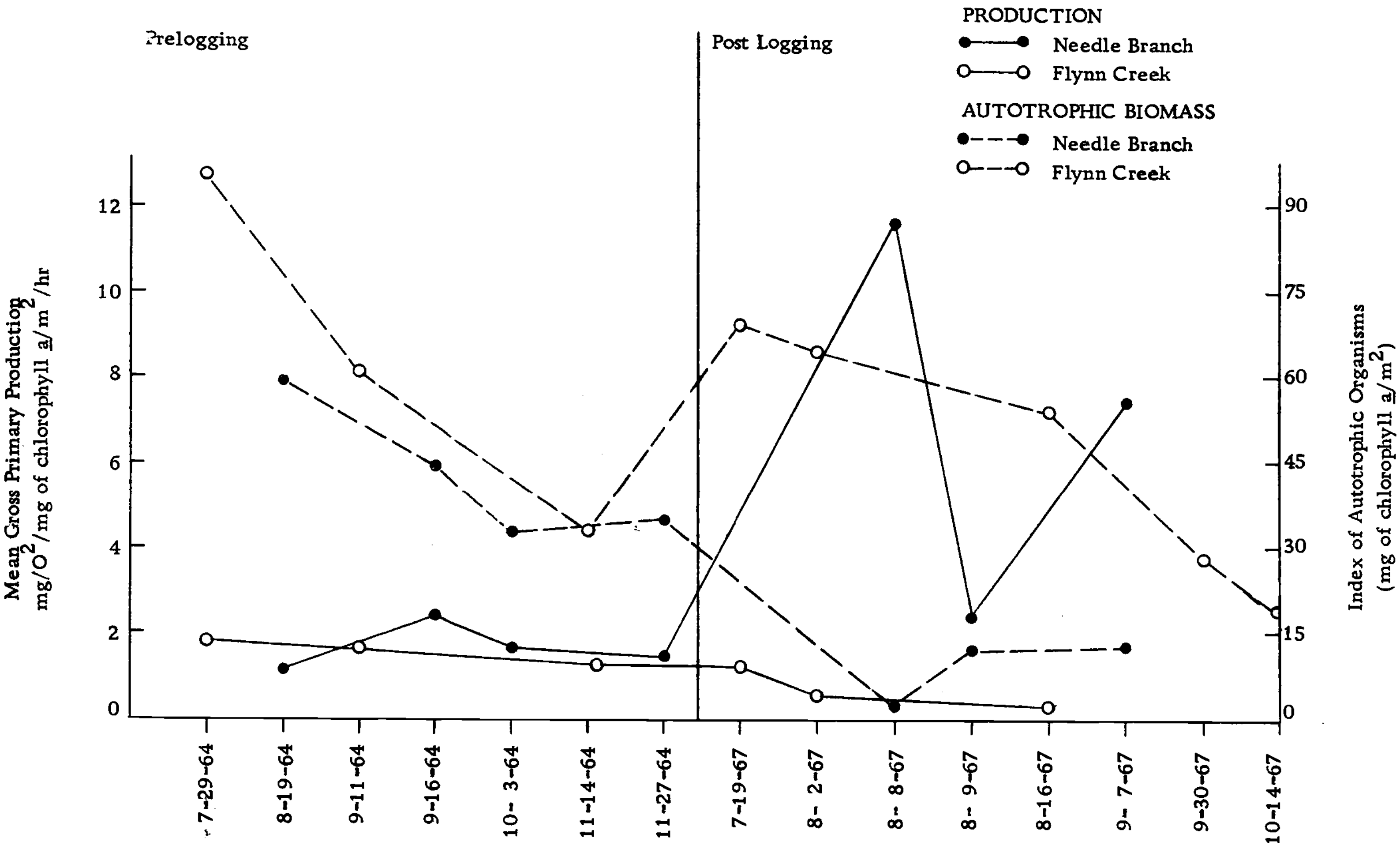


Figure 23. Comparison of the index of autotrophic organisms to gross primary production in a logged (Needle Branch) and unlogged stream (Flynn Creek).

Photosynthesis-Respiration Ratio

The ratio of gross primary production to community respiration (P/R ratio) was calculated by dividing the gross photosynthesis per day by the respiration per day. Seasonal P/R ratios of Flynn Creek in 1964, indicated that this stream was autotrophic except during the fall months. The same results were obtained for Needle Branch in 1964 and 1965. In 1967, following logging, Needle Branch was autotrophic in the spring, but became heterotrophic in the summer months. At the same time, Flynn Creek remained autotrophic (Figure 22).

DISCUSSION

Community Structure

Community Structure and Seasonal Periodicity

The composition of the communities in the three streams was typical of most mountain streams, and a community of similar composition has been noted in the streams of Spain by Margalef (1960) and by other authors in streams of Belgium, Germany, France, Denmark, Czechoslovakia and Japan (Margalef, 1960). Although the streams presented quite similar physical and chemical environments, prior to logging (Appendix Tables 18-21), each stream had its own distinct diatom community. The community of Flynn Creek was dominated by Achnanthes lanceolata throughout the investigation. This seemed somewhat unusual considering the numbers of habitats involved within the test area, the various degrees of light intensity reaching the pools and riffles, and the seasonal fluctuations in temperature and total light energy reaching the surface of the stream.

The community of Deer Creek had a rather distinct seasonal periodicity with two species most dominant throughout the investigation. Achnanthes lanceolata was most abundant in the fall and winter months and appeared to be better adapted to conditions during this time of the year, whereas Cocconeis placentula was more tolerant of the shaded conditions of the summer months and was the most abundant species at that time. However, it is not certain whether or not this periodicity was a function of light intensity. Douglas (1958) found that the abundance of Achnanthes sp. had no correlation with light or temperature, but that the flow of water was most important. Low flows seemed to have a repressing effect on the species and the grazing of a caddis fly affected the numbers. She suggested that there was no regular periodicity, such as is found with certain planktonic species, but that the periodicity depended mainly on the flow of water. Whitford (1956) also found Cocconeis sp. most abundant in the shaded area of spring streams of Florida, and Butcher (1932) found the genus abundant during the summer. Pearsall (1923) concluded that the real causes of diatom periodicity have no connection with temperature, though the factors that regulate periodicity are probably operative during cold weather. Butcher (1946) in studying the algal growth in highly calcareous streams found the following five dominant species: Cocconeis placentula, Achnanthes lanceolata, Gomphonema parvulum, Gomphonema olivaceum, Nitzschia palea and Cymbella ventricosa. These dominants were present throughout the year and though the numbers fluctuated among themselves, neither a seasonal cycle nor smaller regular variations were detected in the large numbers of streams examined. Patrick, Cairnes, and Roback (1966) conducted studies of the Savannah River and found Achnanthes lanceolata abundant in the summer with Eunotia pectinalis and *Gomphonema parvulum* plentiful in the spring. To add to the various observations and conclusions, I suggest that possibly *Achnanthes lanceolata* was dominant during the winter months, the time of high flows, because of its smaller surface area and concave shape which would make it more adaptable for clinging to the spherical substrate of the streams and less affected by the high flows.

Needle Branch, a habitat similar to Deer Creek and Flynn Creek prior to logging, was changed in 1966 to a habitat capable of supporting a mixed community of filamentous algae and diatoms, with the filamentous algae dominant. The polysaprobic condition of the stream was very evident immediately after logging. This condition was made apparent by the presence of *Sphaerotilus natans*, an organism tolerant of low dissolved oxygen concentrations. A concentration of 0.6 mg O_2/liter was recorded during this time (Dr. James Hall, personal communication). Reese (1966) found in laboratory streams, that growth of *Sphaerotilus natans* was closely related to the amount of carbon and nitrogen enrichment. He showed that *Sphaerotilus natans* decreased as the carbon source was reduced even though adequate nitrogen was present. During the present investigation organic nutrients were not analyzed. The emanation of a putrid odor, possibly hydrogen sulfide, indicating bacterial oxidation of the slash also indicated the substantial heterotrophic condition of the stream immediately after logging. The increase of the filamentous algal mat as the density of Sphaerotilus decreased suggested that the algae could not compete earlier, when the Sphaerotilus was abundant in the stream. Dever (1962) also found smaller algal population in areas of dense Sphaerotilus growth and attributed low productivity in such areas to the inability of the algae to compete.

The persistence of the algal growth in the riffle areas later in the season, while it was decomposing in the pools, indicates the importance of flowing water in the exchange of nutrients and decomposition products. Whitford (1960) observed that lotic species of Stigeoclonium, Draparnaldia, Chaetophora and Tetraspora were found in pools in late winter and spring, but as pools got warm, these species disappeared.

The individual factor or the combination of factors essential to the development of the filamentous growth has not been established. Various environmental conditions are reported to stimulate the growth of filamentous algae in streams. Whitford (1963) in studies of the stream flora of North Carolina reported that 15 C seemed to be the critical temperature for most fresh water algae, but the Chlorophyceae grew best at 15 to 20 C. He concluded that the Chlorophyceae grew best at moderate temperatures and high light intensity. Butcher (1946) in studies of highly calcareous streams, found stream enrichment a factor in the growth of various species of

Chlorophyta and Chanophyta. McIntire (1966b) studying the effects of variation in current velocity on periphyton communities in laboratory streams found that at low velocities (9 cm/sec) the community was dominated by species of chlorophyta and some Cyanophyta, whereas at higher velocities (38 cm/sec) the community was dominated by diatoms. Butcher (1946), Dever (1962), and McIntire and Phinney (1965) suggested that additional light appeared to induce growth of Chlorophyta. Blum (1957) suggested that the volume of flow has some effect upon the *Phormidium-Schizothrix* community for it was never found well developed in the headwater portion of the stream. All of these various conditions which are suggested as increasing the growth of filamentous algae existed in Needle Branch after logging. The low occurrence of *Cocconeis placentula* in the late summer of 1966, when it had been a dominant in June and July of the same year was probably caused by the organic enrichment that existed in the stream. Butcher (1947) also found this to be true, for *Cocconeis placentula* occurred in the headwaters of the streams being studied. Downstream in the polluted zone, this species was eliminated and then reappeared still further downstream, in the oligosaprobic zone. Buthcer (1940) also attributed the reduction of *Achnanthes sp.* to organic pollution. Whether the reduction of the populations of *Achnanthes* and *Cocconeis* in Needle Branch was the direct result of the organic enrichment or of the covering of the colonizable substrate by silt and mud has not been established in this investigation. *Eunotia arcus* was very abundant in late summer and early fall of 1966. This genus has been reported from various habitats and seasons by several authors.

In 1967, *Achnanthes lanceolata* was eliminated as part of the dominant flora of Needle Branch. This indicated that this species in addition to being intolerant of low flows (Douglas, 1958) and organic pollution (Butcher, 1940) was most likely intolerant of the high temperatures that existed in the stream in 1967. *Cocconeis placentula* reappeared as a dominant part of the flora in the summer of 1967. This species seems to have a wide tolerance to variations in temperature and light conditions, for it was found in the warm waters of Needle Branch and the cooler waters of the other streams as well as under high and low light intensities. *Achnanthes minutissima* and *Synedra rumpens* became dominant in 1967, whereas they previously were observed only in small numbers. Undoubtedly, the opening of the canopy created conditions nearer their optimum than existed prior to logging.

It has become clear that although much information is available on factors affecting the metabolism of various stream communities, the factors that affect the population dynamics of these communities are beyond our knowledge at this time. Blum (1956) says that several reports on European streams make it clear that, in any given season, streams expected to have similar characteristic vegetation sometimes produce quite diverse floras. The extent of the effect of physical, chemical and environmental factors on seasonal changes has not been established.

Comparison Between the Diatom Communities Within a Stream

The communities developed on the glass artificial substrates show less similarity in the summer months than in the winter months. I suggest two possible explanations for this phenomenon. First, during the summer months, each community colonizing a particular riffle area tends to be a distinct entity, separated ecologically and floristically from those of other riffle areas. During the winter months, high stream flows scour the flora from the rocks and randomly distribute it, thus creating a homogenous stream community. Second, species diversity (ratio of the number of species to the number of individuals) is lower in the summer months than in the winter months. In terms of the distance equation, this reduction in diversity would increase the dissimilarity in summer. The species composition at the sites investigated was generally similar, but dissimilarity arose from differences in the relative abundance and periodicity of the species involved.

An increase in the similarity of the communities was observed in Needle Branch in 1967, as compared to those observed in 1966. This would be expected because the opening of the canopy produced greater uniformity of habitat over the length of the stream. Although more uniform, it was also a more extreme habitat, thus several species were eliminated while others became more abundant and common throughout the extent of this new environment. In addition, the filamentous algae probably competed effectively with some species of diatoms. Whitford (1963) found that at water temperatures above 15 C Meridion and Fragilaria disappeared. Blum (1956) found that temperature was the limiting factor in the establishment of Diatoma hiemale which was common in cool waters of upland streams. He also stated that H. Budde found, in studies of streams in Germany, that several diatoms grew best at temperatures between 3-10 C and disappeared in July and August, apparently being unable to survive above 19 C.

Margalef (1960) suggested that differences in the size of rocks may result in differences in the communities colonizing them. Smaller rocks are scoured clean by frequent movement and colonization is forced to begin anew. He also suggested that the presence of various aquatic flowering plants adds to the complexity of the community.

Comparison of Diatom Communities Between Streams

The communities that developed on the glass artificial substrates in the various streams exhibited a pattern of development similar to that observed of the communities within each stream, with less similarity in the summer than in the winter. This appears to be related to the effect of high stream flows in winter months, distributing the flora of the streams. High flows were common in all streams during the winter months. Butcher (1946) found that the greatest numbers of free floating micro-organisms are present immediately after a flood, the source being the periphyton scoured free and washed into the water. Those species which remain attached to the substrate in some protected position, such as rock fissures or superficial sediment, can repopulate the stream during favorable periods (Blum, 1956). The species composition that developed in Needle Branch after logging was much more stable than that which developed under the shaded conditions of Flynn Creek and Deer Creek. This was probably associated with the more uniform environment over the length of the stream, which produced a more similar community throughout the logged area.

Comparison of Communities Developed on Artificial Substrates and on the Natural Substrate

Although the species composition of the communities developed on the glass artificial substrates and the community of the natural substrate was similar, differences arose in the relative abundance of the species. This seems to indicate that the community developed on the glass artificial substrates was not representative of the community found on the natural substrate of the stream. The quantitative analysis made of the community developed on the glass artificial substrates is indicative only of that community and not the natural community of the stream. Other authors have reported similar observations. Blum (1956) reported that Reese (1935) in studying the effects of lead mine pollution, found evidence that counts made from slides immersed in the stream were not comparable to those of samples of the river bottom, but the species composition was generally similar. In a study of the ecology of attached diatoms and other algae in small stony streams, Douglas (1958) found that Cocconeis placentula and Eunotia pectinalis occurred more exclusively in the moss rather than on stones and in apparently higher numbers on submerged slides than on stones. Hohn and Hellerman (1963), using three sampling methods in a study of diatom populations, stated that preliminary studies indicate that an increased rate of flow drastically reduces the number of diatoms on glass slides at temperatures up to 7 C. The explanation for the differences in the communities can only be hypothetical. Whitford (1956) in a study of algae in spring streams used glass, wood and plastic substrates. He found that the pioneer colonizer of bare surfaces such as plants and stones was *Cocconeis* followed by *Synedra*, *Achnanthes* and *Gomphonema*. These intial communities which develop on bare surfaces may be quite different from communities developed on natural substrates which have gone through aging processes and have a community already established. Margalef (1960) states that heterogeneity is often a consequence of the diversity of the first occupants when there has not been sufficient time for regulating distribution. Obviously, the communities on the natural substrate of the stream have been subject to the regulating effect of the stream for longer periods than have the communities on slides exposed in the stream. Glass artificial substrates have a much different surface texture than that of the natural substrate, being more smooth and less porous, and sloughing of the organic material occurs more readily from the glass artificial substrate. It is my contention, that chance is largely involved in the colonization of artificial substrates since colonization depends on the material sloughing from the natural substrate. Once a bare substrate has been colonized by a particular species, this species under favorable environmental conditions can reproduce relatively unimpeded by compeition from other species. The microclimate associated with the artificial substrate also may be completely different from that around the natural substrates in the stream, thus permitting a different community to develop over a period of time. The high concentration of Nitzschia palea found attached to the filamentous mat in Needle Branch in 1966, suggest that selectivity of substrates for attachment may exist in some species of algae. This species was never found in abundance on the natural substrates of the stream.

Although dissimilarities existed between the communities on glass artificial substrates and the natural substrate of the stream, the samples taken of the community on the natural substrate, by this author, may not have been large enough to give an adequate picture of the natural stream community. Hohn and Hellerman (1963) suggested that at least 8000 individuals must be identified and counted before a true picture of the natural community develops.

Communities of the Rock Artificial Substrate and Stream Substrate

The index of similarity between the communities of the rock artificial substrate and the natural substrate, was less than between the glass artificial substrate and natural substrate. A reduction in the similarity index as much as 1/2 or more was observed. It also indicated that a high degree of similarity existed between the mixed community of filamentous algae and diatoms found on the rock artificial substrate and stream substrate, and that filamentous algae attached more readily to the rock artificial substrate than to the glass artificial substrate. The orientation of the rock artificial substrate in the stream most likely added to the greater similarity which existed between its community and that of the natural substrate of the stream. Since the rock artificial substrate was positioned in such a way that it became part of the natural substrate, rather than suspended above the natural substrate, attachment by the surrounding community was more natural and more easily accomplished.

Effect of Logging on the Biomass of Autotrophic Organisms in Needle Branch

Logging had a profound effect on the biomass of autotrophs in the stream. The opening of the canopy and the subsequent increase in stream temperature reduced the biomass below that found in the stream prior to logging. The hypothesis that this response to the opening of the canopy was probably caused by increased temperatures of the water was supported by Dr. Ruth Patrick (personal communication), for she found similar effects in streams of eastern United States. During 1967, it was observed that pieces of rock forming the substrate of Needle Branch were smaller and less abundant than prior to logging. McConnell and Sigler (1959) found, in studies of the Logan River, that most of the chlorophyll was supported on rock with a diameter of 12 cm or more, and less than 6% was supported by rocks having a maximum diameter less than 2.5 cm.

Community Metabolism

Respiration of the Biomass of Needle Branch After Logging

Various investigations into the effects of variations in oxygen concentrations, stream velocity and water temperatures upon the metabolism of the community have been performed by Whitford (1960), Owens and Maris (1964), Verduin (1956) and McIntire (1966a). Studies have shown that these parameters play an important role in regulating respiration of the community in flowing waters.

The total living biomass, flora and fauna, of the stream decreased after logging. Various authors (Odum, 1959, and Ruttner, 1963) refer to situations in which increases in terrestrial and aquatic temperatures either reduced the growth rate of various animal populations or completely eliminated them. I observed a reduction in the number of animals collected in Needle Branch compared to Deer Creek and Flynn Creek in 1967. Those organisms remaining in the stream and the new species that became established exhibited a higher rate of respiration per unit of biomass than the community present prior to logging.

Various investigators have analyzed the relationship of temperature and rates of respiration. Phinney and McIntire (1965) indicate a Q_{10} value of approximately 2 for a temperature range of 6-20 C.

McIntire (1966) found that temperature had the greatest influence on respiratory activity in communities between 8 and 13 C. He found that community developed in a slow current (9 cm/sec) had a Q_{10} of 4.37, while that developed in the faster current (38 cm/sec) had a Q_{10} value of 2.37. Owens and Maris (1964) showed Q_{10} values of 1.32-3.48 in a temperature range of 10-20 C. Verduin (1956) estimated that in diatom populations from Lake Erie, the mean ratio of respiration to maximum photosynthesis was 0.125. Verduin also reported that Ryther (1954) found that algal respiration usually represented about 10% of maximum photosynthesis in vigorous laboratory cultures of algae.

Effects of Logging on the Gross Primary Production in Needle Branch

Several approaches have been used in estimating productivity of flowing water. Odum (1956) described an upstream downstream method for the estimating of productivity. Several authors have used the accumulation of organic matter and chlorophyll on artificial substrates as an indrect index (Waters, 1961; Grzenda and Brehmer, 1960). Odum (1959) discusses various other methods including the light and dark bottle method, carbon dioxide and isotope methods. The P-R Chamber method of McIntire *et al.* (1964) measures directly the production rates in streams, thus eliminating the necessity of estimating other parameters, such as oxygen diffusion rates, which influence the oxygen concentration. This method was especially applicable to this study because of the scant amounts of periphyton found on the stream substrate.

Although the biomass of autotrophic organisms in Needle Branch decreased in 1967, productivity was greater than that observed in Flynn Creek, the unlogged watershed, but was slightly less than that observed in Needle Branch in 1964. The ability of the reduced biomass of the autotrophic organisms to maintain production at a rate higher than that observed in Flynn Creek resulted from higher rates of carbon fixation per unit of biomass under an open canopy as compared to the closed canopy. Others (McIntire and Phinney, 1965) found that by increasing illumination intensity from 65 yo 2030 foot candles, the gross production of laboratory stream communities increased from 24 to 480 mg $O_2/m^2/hr$ with a constant concentration of carbon dioxide.

By opening the canopy, two characteristics of the available light reaching the surface of the stream were altered, the intensity and the quality. Prior to logging, the intensity of the light reaching the surface of the stream was low, and the quality, of the major portion of the light, was within a wavelength band (440-500 mμ) that is least absorbed by chlorophyll a. Thus production per unit of the existing biomass of autotrophic organisms was lower than under the open canopy of 1967. In 1967, (open canopy), the intensity and quality of light reaching the stream favored higher production rates per mg of biomass of the autotrophic organisms. Thus, mean production/day was maintained at a level comparable to that of 1964.

Probably two environmental factors worked together on separate reactions of photosynthesis and increased the carbon fixation of the existing biomass. The higher light intensity in the more favorable wavelength of light increased the rate of the light reaction of photosynthesis thus increasing the supply of chemical energy (ATP) and reducing agent (NADPH) used in the fixation of carbon dioxide by the accompanying dark enzymatic reaction. Since the rate of the enzymatic reaction is increased by increase in temperature, the rate of reduction of carbon dioxide was increased. A study of the effects of variations in temperature and productivity of laboratory stream communities by Phinney and McIntire (1965) indicated that temperature did not affect rates of net oxygen evolution until the light intensity reached approximately 11,100 lux. Below this illumination intensity, the rate of gross production was not affected by temperature.

In the present study, the sizable increases in productivity, which one would expect to result from opening the stream canopy, did not materialize. Although production/mg of biomass was greater in the logged watershed than in the unlogged watershed, the limiting factors in the new environment, such as increased stream temperature and possibly light saturation, reduced the biomass and changed the structure of the community. The sum of these factors created an environment in which gross primary production was only just comparable to that observed in the same stream prior to logging.

The heterotrophic condition of Needle Branch in the summer of 1967, following logging, placed a great stress on the autotrophic community, since it was being consumed at a rate faster than it was produced. This condition was undoubtedly caused by the high temperatures of the stream and higher rates of respiration of the existing organisms.

The heterotrophic condition of both Needle Branch and Flynn Creek in the fall, prior to logging, was most likely associated with high rates of oxidation of the leaf litter which accumulates in the pools and riffles of the stream during the fall season of the year.

CONCLUSION

1. Prior to logging, all three streams investigated were dominated by diatom floras.
2. The clearcut logging operations of Needle Branch watershed in 1966 altered the ecology and produced a habitat capable of supporting a mixed community of filamentous algae and diatoms.
3. The algal community that developed in Needle Branch, after the clear-cut logging operation, was the result of the accumulation of slash in the stream, the increase in stream temperature, and the increase in available energy reaching the surface of the water.
4. The more uniform distribution of the diatom community in Needle Branch after logging, 1967, as compared to the community that was present in the stream during logging, 1966, was the result of a more uniform environment produced by the removal of the terrestrial canopy. This new environment was not acceptable for the continued growth of several species, thus these species were reduced in numbers, while other species found it much more favorable than the environment exicting prior to logging, and these species increased their growth rates

and became a dominant part of the diatom flora.

5. Prior to logging, the community existing in Needle Branch was autotrophic for all seasons except fall, with rates of primary production higher than the rates of community respiration. After logging, the reduced biomass of autotrophic organisms maintained a rate of production comparable to that found in the stream, prior to logging, but with the increase stream temperature, the rate of respiration of the community exceeded the rate of production and thus the community exhibited various degrees of heterotrophism.

6. The stresses placed on the autotrophic organisms by the heterotrophic community will most likely continue to varying degrees, until the terrestrial vegetation produces a shaded environment in the stream, in which respiration of the community will decrease or until gross primary production can be maintained at a rate higher than the rate of consumption.

7. The heterotrophic community during the fall season, prior to logging, was probably associated with leaf fall and the accumulation and breakdown of this leaf litter in riffles and pools of the streams.

8. As the terrestrial vegetation grows, and the stream

again becomes shaded by the terrestrial canopy, most likely the flora of the stream will become dominated by diatoms, and exhibit a pattern of community production similar to that of Flynn Creek, the unlogged watershed. Autotrophism during the spring and summer months and heterotrophism during the fall months, when the leaf litter accumulates in the streams.

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APPENDICES

Appendix Table 1. Mean Light Energy (g cal/cm^2/hr) at Stream Surface Recorded During Studies of Primary Production.

Date	Needle Branch	Flynn Creek	Deer Creek
7-15-64	4.2		
7-22-64	5.1		
7-29-64		17.5	
8- 5-64		3.9	
8-12-64	2.6		
8-19-64	1.2		
8-25-64		9.5	
9-11-64		5.4	
9-16-64	3.4		
10- 3-64	1.5		
10-31-64		4.2	
11-14-64		3.1	
11-27-64	1.3		
12-18-64	0.9		
10- 7-65			5.5
10-13-65	10.1		
10-21-65		0.6	
4-30-66	31.4		
5-21-66			6.0
6-12-66			31.4
6-19-66			30.0
7- 3-66			9.2
7-19-66			36.7
10-15-66			13.0
10-29-66			5.6
11- 8-66		6.5	
5-27-67			5.2
6-15-67	14.8		
6-16-67	21.2		
6-21-67		7.2	
6-28-67			3.1
7- 6-67			2.5
7-12-67	13.1		
7-19-67		4.4	
7-26-67			2.1
8- 2-67		15.7	
8- 8-67	33.2		
8- 9-67	26.1		

Appendix Table 1 Continued.

Date	Needle Branch	Flynn Creek	Deer Creek
8-16-67		1.3	
8-23-67			3.0
9- 7-67	18.3		
9-30-67		2.2	
10-14-67		1.7	
10-21-67			2.5

Appendix Table 2. Mean Temperatures (Centigrade) of Stream Water/Day Recorded During Studies of Primary Production.

Date	Needle Branch	Flynn Creek	Deer Creek
7-15-64	14.6		
7-22-64	13.7		
7-29-64		15.4	
8- 5-64		13.6	
8-12-64	14.4		
8-19-64	13.8		
8-25-64		15.0	
9-11-64		12.2	
9-16-64	13.4		
10-17-64	9.3		
10-31-64		10.2	
11-14-64		6.2	
11-27-64	8.9		
12-18-64	6.2		
10- 7-65			12.9
10-13-65	11.8		
10-21-65		10.0	
4-30-66	8.8		
5-21-66			10.5
6-12-66			11.6
6-19-66			12.6
7- 3-66			12.3
7-19-66			14.2
8-18-66			13.9
8-24-66		12.2	
8-31-66			12.2
9- 8-66		13.1	
10- 1-66			12.4
10-15-66			9.2
10-29-66			10.5
11- 8-66		7.1	
5-13-67	15.6		
5-20-67		11.5	
5-27-67			11.3
6-15-67	21.4		
6-16-67	22.5		
6-21-67		11.9	
6-28-67			13.8

Appendix Table 2 Continued.

Date	Needle Branch	Flynn Creek	Deer Creek
7- 6-67			13.3
7-12-67	19.8		
7-19-67		12.8	
7-26-67			13.2
8- 2-67		13.2	
8- 8-67	21.8		
8-16-67		14.6	
8-23-67			14.3
9- 7-67	20.5		
9-30-67		12.1	
9-23-67			13.3
10-14-67		11.2	
10-21-67			11.1

Appendix Table 3. Deer Creek. Rack 1. Percent Relative Abundance of Dominant Species Found on Glass Artificial Substrates, Based on Four Week Exposure Time of Substrate.

Date	*Achnanthes lanceolata*	*Cocconeis placentula*	*Nitzschia sp.*
6- 4-66	83		
7- 3-66	58	36	
8- 3-66	42	54	
9- 2-66	35	63	
10- 1-66	19	78	
10-29-66	24	61	
11-29-66	47	18	
1-28-67	55	43	
3- 5-67	62	14	
4- 2-67	41		
4-29-67	41	12	
5-28-67	53	31	
6-28-67	20	73	
7-26-67	42	54	
8-24-67		80	
9-23-67		70	
10-21-67	15	36	12

Appendix Table 4. Deer Creek. Rack 2. Percent Relative Abundance of Dominant Species Found on Glass Artificial Substrates, Based on Four Week Exposure Time of Substrates.

Date	*Achnanthes lanceolata*	*Achnanthes minutissima*	*Cocconeis placentula*	*Diatoma hiemale*	*Eunotia arcus*	*Meridion circulare*	*Navicula pelliculosa*
6- 4-66							
7- 3-66							
8- 3-66							
9- 2-66							
10- 1-66	17		11				
10-29-66							
11-29-66	37	16					
1-28-67	86						
3- 5-67	60						
4- 2-67	37			12		18	19
4-29-67	57						
5-28-67	72						
6-28-67	23		14		54		
7-26-67	24		42		27		
8-24-67	18				28		
9-23-67	16	12	17				
10-21-67	13	10					

Appendix Table 5. Deer Creek. Rack 3. Percent Relative Abundance of Dominant Species Found on Glass Artificial Substrates, Based on Four Week Exposure Time of Substrates.

Date	Achnanthes lanceolata	Achnanthes minutissima	Cocconeis placentula	Diatoma hiemale	Eunotia arcus	Meridion circulare
6- 4-66						
7- 3-66						
8- 3-66						
9- 2-66						
10- 1-66	10		6		80	
10-29-66	38	15			23	
11-29-66	65					
1-28-67	74					10
3- 5-67	88					
4- 2-67						
4-29-67		57		13		
5-28-67	44	12		11		
6-28-67	35				24	
7-26-67	13		19		63	
8-24-67		13	26		57	
9-23-67	11		48		36	
10-21-67	19	11	19		38	

Appendix Table 6. Needle Branch. Rack 4. Percent Relative Abundance of Dominant Species Found on Glass Artificial Substrates, Based on Four Week Exposure Time of Substrates.

Date	Achnanthes lanceolata	Achnanthes minutissima	Cocconeis placentula	Eunotia arcus	Eunotia perpusilla	Gomphonema parvulum	Nitzschia palea	Synedra rumpens
6- 4-66	77							
7- 3-66	63		22					
8- 3-66	52		20					
9- 2-66	9						77	
10- 1-66				94				
10-29-66	18			65				
11-29-66	47					13		
12-29-66	51					12		
1-28-67	77							
3- 5-67	54			11				
4- 2-67	80							
4-29-67	45			14				
5-28-67				78				
6-28-67		12	14	70				
7-26-67		17	12	60				
8-24-67		14	22	25				29
9-23-67		20			21			43
10-21-67				52	16			

Appendix Table 7. Needle Branch. Rack 5. Percent Relative Abundance of Dominant Species Found on Glass Artificial Substrates, Based on Four Week Exposure Time of Substrates.

	Achnanthes lanceolata	Achnanthes minutissima	Cocconeis placentula	Diatoma hiemale	Eunotia arcus	Gomphonema angustatum	Gomphonema parvulum	Meridion circulare	Nitzschia palea
6- 4-66									
7- 3-66									
8- 3-66	24		12						15
9- 2-66					84				
10- 1-66					93				
10-29-66	30				66				
11-29-66	31					14			15
12-29-66	46				10		12	14	
1-28-67	66				18				
3- 5-67	50			11					
4- 2-67	65								
4-29-67	30			19			22		
5-28-67			74		17				
6-28-67			60		31				
7-26-67		11	52		34				
8-24-67			50		40				
9-23-67			92						
10-21-67									

Appendix Table 8. Needle Branch. Rack 6. Percent Relative Abundance of Dominant Species Found on Glass Artificial Substrates, Based on Four Week Exposure Time of Substrates.

	Achnanthes lanceolata	Achnanthes minutissima	Cocconeis placentula	Diatoma hiemale	Eunotia arcus	Gomphonema angustatum	Gomphonema sp.	Navicula cryptocephala	Navicula pelliculosa	Nitzschia palea	Gomphonema parvulum
6- 4-66											
7- 3-66											
8- 3-66										94	
9- 2-66							75			18	
10- 1-66						17				63	
10-29-66	12					16				22	14
11-29-66	43					15			11		
12-29-66											
1-28-67	73										
3- 5-67	82										
4- 2-67	86										
4-29-67	47			17				11			
5-28-67		58									
6-28-67											
7-26-67											
8-24-67											
9-23-67											
10-21-67											

Appendix Table 9. Flynn Creek. Rack 7. Percent Relative Abundance of Dominant Species Found on Glass Artificial Substrates, Based on Four Week Exposure Time of Substrates.

	Achnanthes lanceolata	Achnanthes minutissima	Cocconeis placentula	Diatoma hiemale	Eunotia arcus	Eunotia perpusilla	Nitzschia sp.	Rhicosphenia curvata
7- 8-66	85							
8-12-66	70				28			
9- 8-66	73				25			
10- 9-66	68				24			
11- 9-66	75					14		
12- 8-66	70							
1- 6-67	56		18					
2- 5-67	60		15					
3-11-67	75		13					
4- 8-67	62		15					
5- 7-67		18		69				
6- 7-67	33		23	38				
7- 6-67	26		70					
8- 2-67								
8-30-67	24		59					
9-30-67	35			13			13	16
10-28-67	28		37					

Appendix Table 10. Flynn Creek. Rack 8. Percent Relative Abundance of Dominant Species Found on Glass Artificial Substrates, Based on Four Week Exposure Time of Substrates.

Date	Achnanthes lanceolata	Achnanthes minutissima	Cocconeis placentula	Diatoma hiemale	Eunotia arcus
7- 8-66					
8-12-66	57				
9- 8-66	56	12			12
10- 9-66	62		33		
11- 9-66	49		16		20
12- 8-66	67		10		
1- 6-67	33		17		42
2- 5-67					
3-11-67					
4- 8-67					
5- 7-67					
6- 7-67	49			21	
7- 6-67	88				
8- 2-67					
8-30-67	46		24		
9-30-67	49		28		
10-28-67	40		27		

Appendix Table 11. Flynn Creek. Rack 9. Percent Relative Abundance of Dominant Species Found on Glass Artificial Substrates, Based on Four Week Exposure Time of Substrates.

Date	Achnanthes lanceolata	Cocconeis placentula	Diatoma hiemale	Eunotia arcus	Gomphonema parvulum
7- 8-66					
8-12-66	63				
9- 8-66	61				
10- 9-66	56				
11- 9-66	55	13			
12- 8-66	66				
1- 6-67	60	15			
2- 5-67	82				
3-11-67	63	16			
4- 8-67	42				18
5- 7-67	38		33		
6- 7-67	80		10		
7- 6-67	57				
8- 2-67					
8-30-67	42		10	11	
9-30-67	18	51		20	
10-28-67	27	17			

Appendix Table 12. Flynn Creek. Variation in Community Structure Found on Glass Artificial Substrates, Based on Distance Equation.

	1966-1967														
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
12 Week															
Rack 8 Rack 9			19			19									52
Rack 7 Rack 9			63												64
Rack 7 Rack 8			64												12
8 Week															
Rack 8 Rack 9	13		30		88								39		32
Rack 7 Rack 9	75		57		55		39			61			76		68
Rack 7 Rack 8	81		75		76								93		89
4 Week															
Rack 8 Rack 9	16	16	29	23	11	52					35	33	28	44	24
Rack 7 Rack 9	33	29	23	28	25	12	27	14	31	55	59	76	63	57	23
Rack 7 Rack 8	34	26	35	37	25	43					30	91	42	33	21

Appendix Table 13. Deer Creek. Variation in Community Structure Found on Glass Artificial Substrates, Based on Distance Equation.

	1966-1967														
	Oct. 1	Oct. 29	Nov.	Dec.	Jan.	Feb.	Mar.	Apr. 2	Apr. 29	May	June	July	Aug.	Sept.	Oct.
12 Week															
Rack 3 Rack 2					61							17			41
Rack 3 Rack 1					90							47			38
Rack 2 Rack 1					70				48			34			79
8 Week															
Rack 3 Rack 2						48							32		
Rack 3 Rack 1						51							20		
Rack 2 Rack 1						55		29			77		41		79
4 Week															
Rack 3 Rack 2	83		31		17		30		11	32	35	44	45	46	43
Rack 3 Rack 1	109	63	27		45		30		24	28	69	77	76	43	43
Rack 2 Rack 1	69		19		53		16	27	21	36	46	34	84	56	39

Appendix Table 14. Needle Branch. Similarity of Community Structure Found on Glass Artificial Substrates, Based on Distance Equation.

	1966-1967															
	Aug.	Sept.	Oct. 1	Oct. 29	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
<u>12 Week</u>																
Rack 6 Rack 5										20			28			5
Rack 6 Rack 4										17			40			34
Rack 5 Rack 4							3			29			42			32
<u>8 Week</u>																
Rack 6 Rack 5			88					40		21				31		4
Rack 6 Rack 4			95					40		17				25		64
Rack 5 Rack 4			26			19		15		21		79		54		67
<u>4 Week</u>																
Rack 6 Rack 5	85	113	112	71	23		15		36	24	94	69	16	20	50	
Rack 6 Rack 4	102	96	113	66	21		11		31	17	94	78	60	44	70	89
Rack 5 Rack 4	38	121	3	15	26	19	68		15	23	92	61	49	46	105	

Appendix Table 15. Estimates of Biomass of the Autotrophic Organisms (Chlorophyll a mg/m^2) Developed in the P-R Trays.

Date	Needle Branch	Flynn Creek	Deer Creek
7-29-64		96.0	
8-19-64	59.1		
9-11-64		60.6	
9-16-64	43.5		
10- 3-64	31.9		
11-14-64	33.0	33.0	
11-27-64	34.6		
7- 6-67			95.2
7-19-67		68.8	
7-26-67			62.2
8- 2-67		64.4	
8- 8-67	2.6		
8- 9-67	12.0		
8-16-67		53.8	
8-23-67			47.2
8-30-67			68.9
9- 7-67	12.7		
9-23-67			64.1
9-30-67		27.7	
10-14-67		19.0	
10-21-67			90.8

Appendix Table 16. Estimated Mean Daily Respiration of the Community During Studies of Primary Production (g $O_2/m^2/day$).

Date	Needle Branch	Flynn Creek	Deer Creek
7-15-64	1.82		
7-22-64	1.12		
7-29-64		1.97	
8- 5-64		1.25	
8-12-64	1.28		
8-19-64	0.92		
8-25-64		2.08	
9-11-64		0.92	
9-16-64	0.84		
9-22-64	0.52		
10- 3-64	0.86		
10-17-64	1.08		
10-31-64		0.96	
11-14-64		0.40	
11-27-64	0.63		
10- 7-65			2.37
10-13-65	1.04		
10-21-65		0.55	
4-30-66	2.31		
5-21-66			0.87
6-12-66			1.52
6-19-66			1.74
7- 3-66			1.40
7-19-66			2.15
8-18-66			1.74
8-24-66		0.48	
9- 8-66		1.06	
10- 1-66			0.95
10-15-66			0.88
10-29-66			1.00
11- 8-66		0.20	
5-13-67	1.33		
5-27-67			1.39
6-15-67	1.41		
6-16-67	1.69		
6-21-67		1.32	
6-28-67			1.32
7- 6-67			0.96

Appendix Table 16 Continued.

Date	Needle Branch	Flynn Creek	Deer Creek
7-12-67	2.02		
7-19-67		1.15	
7-26-67			0.68
8- 2-67		0.79	
8- 8-67	0.73		
8- 9-67	0.76		
8-16-67		0.99	
8-23-67			0.78
9- 7-67	1.07		
9-30-67			
10-14-67			
10-21-67			1.26

Appendix Table 17. Estimated Gross Primary Production ($g\ O_2/m^2/day$).

Date	Needle Branch	Flynn Creek	Deer Creek
7-15-64	2.44		
7-22-64	1.76		
7-29-64		3.35	
8- 5-64		2.27	
8-12-64	2.04		
8-19-64	1.27		
8-25-64		3.11	
9-11-64		1.71	
9-16-64	1.76		
9-22-64	0.98		
10- 3-64	1.07		
10-17-64	1.26		
10-31-64		1.42	
11-14-64		0.63	
11-27-64	0.84		
10- 7-65			3.08
10-13-65	1.56		
10-21-65		0.51	
4-30-66	2.59		
5-21-66			2.29
6-12-66			3.46
6-19-66			2.99
7- 3-66			2.41
7-19-66			3.42
8-18-66			3.34
8-24-66		1.31	
9- 8-66		2.12	
10- 1-66			1.99
10-15-66			1.85
10-29-66			1.48
11- 8-66		0.49	
5-13-67	2.06		
5-27-67			1.71
6-15-67	1.89		
6-16-67	1.88		
6-21-67		1.79	
6-28-67			1.15
7- 6-67			0.54
7-12-67	2.54		

Appendix Table 17 Continued.

Date	Needle Branch	Flynn Creek	Deer Creek
7-19-67		1.70	
7-26-67			0.98
8- 2-67		0.82	
8- 8-67	0.73		
8- 9-67	0.70		
8-16-67		0.63	
8-23-67			0.81
9- 7-67	1.75		
9-30-67			
10-14-67			
10-21-67			1.31

Appendix Table 18. Mean Monthly Maximum Stream Temperatures (C) for the Clearcut Watershed, Needle Branch, and Control Watershed, Flynn Creek.

Month	Needle Branch		Flynn Creek	
	1965	1967	1965	1967
January	8.5	9.5	8.0	8.0
February	8.0	10.3	8.0	8.0
March	7.0	10.3	7.5	8.0
April	8.0	12.5	8.5	9.0
May	9.0	18.5	9.5	10.2
June	12.0	21.5	11.5	12.5
July	13.0	21.8	12.5	13.5
August	13.5	22.5	13.0	14.0
September	12.0	18.5	12.0	13.1
October	11.5	14.5	10.5	10.5
November	10.5	12.0	9.0	9.0
December	8.5	9.5	8.0	8.0

Appendix Table 19. Range and Mean (mg/l) of some Water Quality Constituents, January 1964 through September 1965, before Road Building and Tree Harvesting.

Constituent	Needle Branch		Flynn Creek		Deer Creek	
	Range	Mean	Range	Mean	Range	Mean
Sodium	4.3-5.5	4.9	4.7-6.0	5.2	5.1-6.4	5.6
Potassium	0.5-1.1	0.7	0.5-1.3	0.8	0.5-1.3	0.8
Phosphate, total	0.01-0.23	0.06	0.1-0.32	0.07	0.02-0.34	0.09
Phosphate, ortho	0.01-0.13	0.03	0.1-0.22	0.04	0.01-0.10	0.06
Nitrate	0.01-0.75	0.17	0.53-3.19	1.13	0.65-3.17	1.12

Data collected by the Federal Water Pollution Control Administration, Pacific Northwest Laboratory, Corvallis, Oregon. Summarized by Dr. Richard B. Marston.

Appendix Table 20. Range and Means (mg/l) of some Water Quality Constituents, October 1965 through September 1967, after Road Building and Tree Harvesting.

Constituent	Needle Branch		Flynn Creek		Deer Creek	
	Range	Mean	Range	Mean	Range	Mean
Sodium	3.2-7.0	5.1	3.6-5.9	5.0	4.1-6.5	5.4
Potassium	0.5-4.4	1.1	0.5-1.3	0.8	0.4-1.2	0.8
Phosphate, total	0.02-1.15	0.18	0.02-0.42	0.08	0.02-5.00	0.26
Phosphate, ortho	0.01-0.12	0.04	0.01-0.05	0.03	0.01-0.09	0.04
Nitrate	0.05-2.10	0.37	0.41-2.70	1.23	0.10-2.70	1.15

Data collected by the Federal Water Pollution Control Administration, Pacific Northwest Water Laboratory, Corvallis, Oregon. Summarized by Dr. Richard B. Marston.

Appendix Table 21. Dissolved Oxygen in Surface Water of Needle Branch, Deer Creek, and Flynn Creek. Data Collected at or Near the Weir on Each Stream.

Date	Needle Branch		Flynn Creek		Deer Creek	
	Range	Mean	Range	Mean	Range	Mean
October 1965*	11.20-11.68	11.55	10.00-10.58	10.27	9.81-11.50	10.24
May 1966	8.70- 9.60	9.12	10.60-12.20	11.32	10.52-11.12	10.86*
June	4.70- 7.70	6.14	10.20-11.60	10.92	10.04-11.30	10.56*
July	4.90- 8.20	6.32	9.90-10.90	10.41	9.71-11.17	10.32*
August	5.20- 9.00	7.54	9.40-11.00	10.15	8.76-10.45	9.68*
September	6.70- 8.60	7.89	9.80-10.80	10.21	-	-
October	8.30-10.30	9.30	10.20-11.30	10.71	10.14-11.40	10.66*
May 1967*	9.22-10.60	9.77			10.00-11.70	10.86

*Data taken by this author during gross primary productivity runs. All other data taken by Oregon State Game Commission during Alsea Watershed Study.

Appendix Table 22. Stream Discharge in Cubic Feet per Second Measured at the Weir on Each Stream.

	Needle Branch		Flynn Creek		Deer Creek	
Date	Range	Mean	Range	Mean	Range	Mean
Oct. 63-Sept. 64	0.03-18.0	1.49	0.19-44.0	4.42	0.41-64.0	6.44
Oct. 64-Sept. 65	0.01-41.0	1.61	0.12-115.0	5.00	0.22-177.0	7.37
Sept. 65-Sept. 66	0.01-22.0	1.36	0.11-60.0	3.89	0.21-92.0	5.80
July 7, 1966* (gauge to 2000', slash in stream)	Discharge = 0.42 Travel time = 625 minutes					
August 15, 1968* (gauge to 2000', all debris removed from stream)	Discharge = 0.1 Travel time = 3333 minutes					

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*Personal communication with Dr. George Brown, Dept. of Forest Management, Oregon State University.

All other data collected by United States Department of the Interior, Geological Survey, Water Resources Division.