

AN EVALUATION OF THE USE OF ARTIFICIAL SUBSTRATES
FOR DETERMINING PRIMARY PRODUCTION IN
FLOWING WATER

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John Charles Peters

AN ABSTRACT

Submitted to the College of Agriculture of Michigan
State University of Agriculture and Applied
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Robert C. Ball

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ABSTRACT

Artificial substrates, plexiglass plates, were used to estimate primary production in flowing waters. Taxonomic investigation showed that the substrates were not selective. Diatoms were found to be the principal group of organisms collected on the substrates.

Three methods were utilized to estimate production (1) the number of organisms per unit area per sampling period; (2) the weight of organic matter per unit area per sampling period; and (3) the amount of phytopigment unit (density of chlorophyll color) per unit area per sampling period. Numericalizations of the relationship between these units were expressed by calculating correlation coefficients. The correlation coefficients expressing the relationship between number of organisms and the phytopigment were high, ranging from .75 to .90. A correlation coefficient of .93 expressed the numerical relationship between the weight of organic matter and the phytopigment unit.

The effect of periodic community changes was considered by comparing individual community regression lines with a common line. The statistical analysis showed a common line could be used to estimate the number of organisms from the phytopigment unit at the sampling site which had the greatest number of individual dominant communities and the widest range of units. A common slope

JOHN CHARLES PETERS

ABSTRACT

was found to exist between 5 diatom communities and the phytopigment unit-weight of organic matter relationship. It is possible that a common line can be used throughout most of the year except during low levels of production (winter period) when a lower intercept can be substituted in the predictor equation.

A close relationship existed between the rate of solar input and the production of organic matter. The possibility of photo-inactivation from high light intensities was considered and rejected. The sampling site which had no shade cover, the lowest nutrient level, and the least stable physical and chemical environmental conditions had the highest level of production.

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INTRODUCTION

The measurement of productivity is a fundamental interest of the science of limnology. Primary productivity of an ecological system, community, or any part thereof, is defined by Odum (1953) as the rate at which energy is stored by photosynthetic or chemosynthetic activity of producer organisms in the form of organic substances which can be used as food materials. Secondary productivity, the rate of energy storage at consumer trophic levels, is dependent upon primary productivity. The key word in the above definition is "rate"; the amount of energy fixed in a given time. The ideal way to measure productivity would be to measure the energy flow through the system, but this has so far proved difficult to do. Most measurements are based on some indirect quantity, such as the amount of substance produced, the amount of material used or the amount of by-product released.

Odum (1956) has studied primary productivity in flowing waters in the large artesian springs in Florida by using diurnal gas curves and the upstream downstream methods of measuring community metabolism. Unfortunately, the methods used in the above procedure are not workable in the warm-water streams in Michigan because of the effects of organic pollution, the rapid change in water temperature,

and the variability in volume flow. The large calcareous artesian springs have environmental conditions that are similar to a controlled laboratory experiment, the temperature and the volume flow are uniform throughout the year.

The first mention of a specific technique for the study of aquatic organisms by means of introducing foreign solid substances was found in a Swedish publication (Naumann, as quoted by Cooke 1956). Since that time many "foreign solid substances" have been used to collect aquatic organisms. Microscope slides, glass plates, stones, cedar shingles, cinder bricks, and plexiglass plates are a few artificial substrates that have been used to study the complex of organisms that have become attached to the substrate. Plexiglass plates were used in this experiment because they are durable and are chemically inert.

Considerable terminology has arisen in the literature describing communities of organisms which become attached to artificial or naturally occurring substrates. A history of the terminology and techniques of measuring this community complex has been presented by Newcombe (1950) and Cooke (1956). The term aufwuchs as used by Ruttner (1953) will be used in this paper to describe the community of organisms that are firmly attached to a substrate but do not penetrate into it (in contrast to plants rooted in the bottom or certain parasites).

When using artificial substrates for measuring organic production two assumptions must be made; (1) the

substrates are not selective for specific organisms, and (2) the production on the artificial substrates occurs at the same rate as on natural substrates in the environment. The technique of collecting aufwuchs from an artificial substrate is not a direct measurement of production. The procedure embodies the collection of the accumulated standing crop over a uniform period of time, which is then used as an index of productivity (Keup, 1958). The larger the standing crop for a given period of time the greater the rate of production. The procedure is similar to the limit concept in calculus. If the time a substrate is allowed to remain in the water is decreased from a week to an hour, the more precise the estimate of productivity would become.

The study was organized so that the use of artificial substrates to estimate production could be closely examined. Three methods were used to ascertain primary production in the experiment: (1) the accumulation of the number of organisms in a given time; (2) the accumulation of the weight of organic matter in a given time; and (3) the accumulation of phytopigment in a given time. Numericalizations of the relationships between these methods were expressed by calculating correlations coefficients.

Identifications of algal organisms were made to compare taxonomic differences between sampling stations and to study community periodicity. However, the major

consideration of the taxonomic work was to see the effects of community changes on the phytopigment unit-number of organisms relationship and the phytopigment unit-weight of organic matter relationship. Regression equations were utilized to compare the individual communities with the common regression line for each sampling site.

A previous study has shown that nutrients are in abundance in the watershed (Brehmer, 1958). An attempt was made to correlate the photosynthetic rate with the rate of solar input. No known studies have been made in the lotic environment to establish the relationship between the photosynthetic rate and the rate of solar input.

DESCRIPTION OF THE STUDY AREA

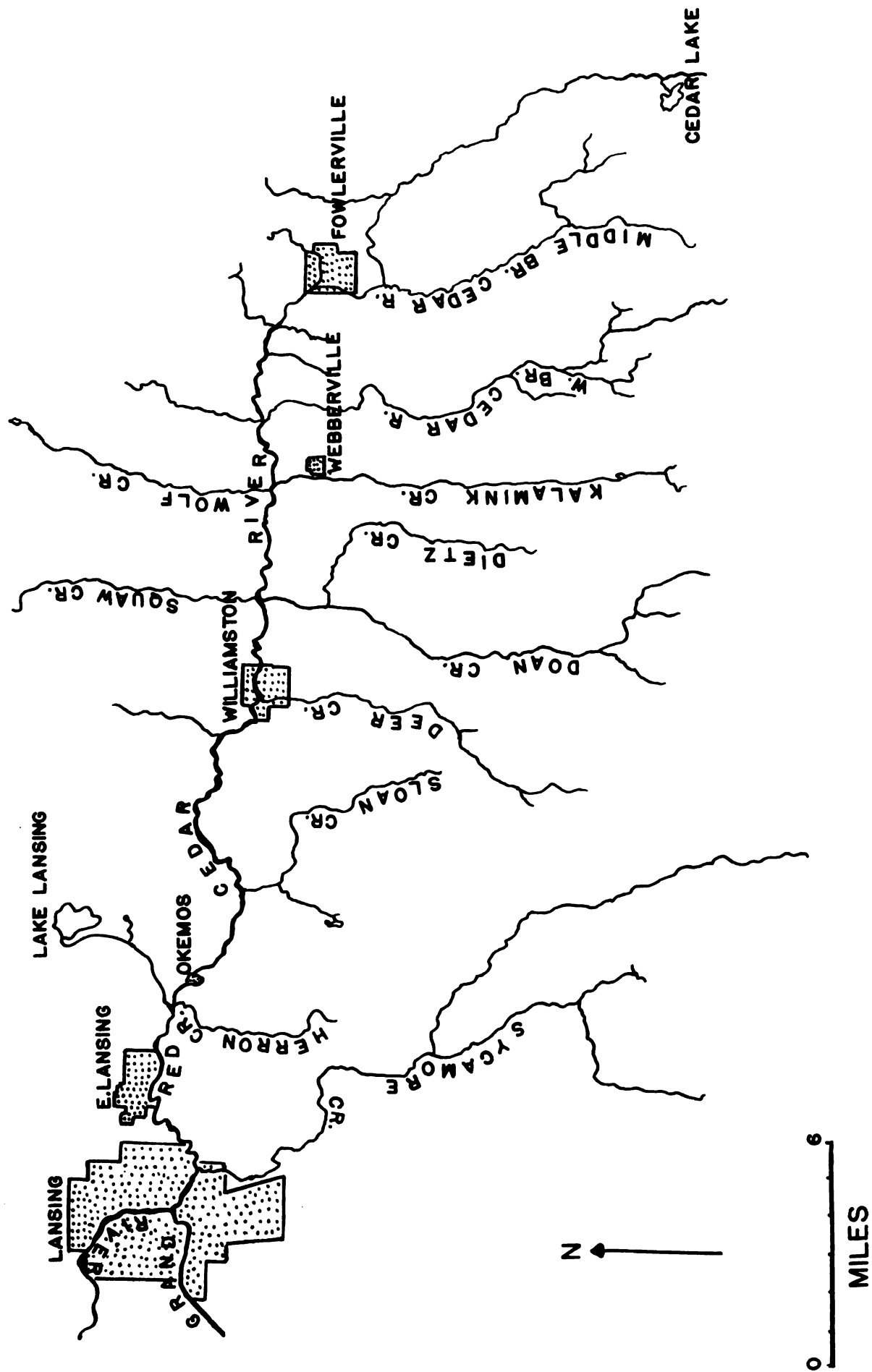
The Red Cedar River is a typical southern Michigan warm-water stream. The upper portions of the watershed have been dredged to straighten and deepen the channels. The major tributaries have been dredged for agricultural purposes. Three artificial impoundments are found on the Red Cedar River. Treated and untreated sewage entered the river throughout its watershed.

The source of the Red Cedar River is Cedar Lake which is located in southwestern Livingston County in Sections 28 and 29, Township 1 North, Range 3 East of the Michigan Meridian. The river flows generally northwestward through Livingston County for approximately 18 miles and then westward through Ingham County for 28 miles, entering the Grand River within the city of Lansing (Fig. 1).

The period of minimum flow usually occurs in the fall of the year and the flow is highest during the late spring. A combination of unthawed ground, melting snow, and heavy rains occasionally brings about serious floods during the late spring. Meehan (1958) has summarized the climate, geology, soils, and land use of the entire watershed.

Three sampling stations were established in the mainstream and one in Deer Creek, a tributary of the river. All four sampling stations were within a half mile radius

Figure I. Drainage area of the Red Cedar
River and its tributaries.

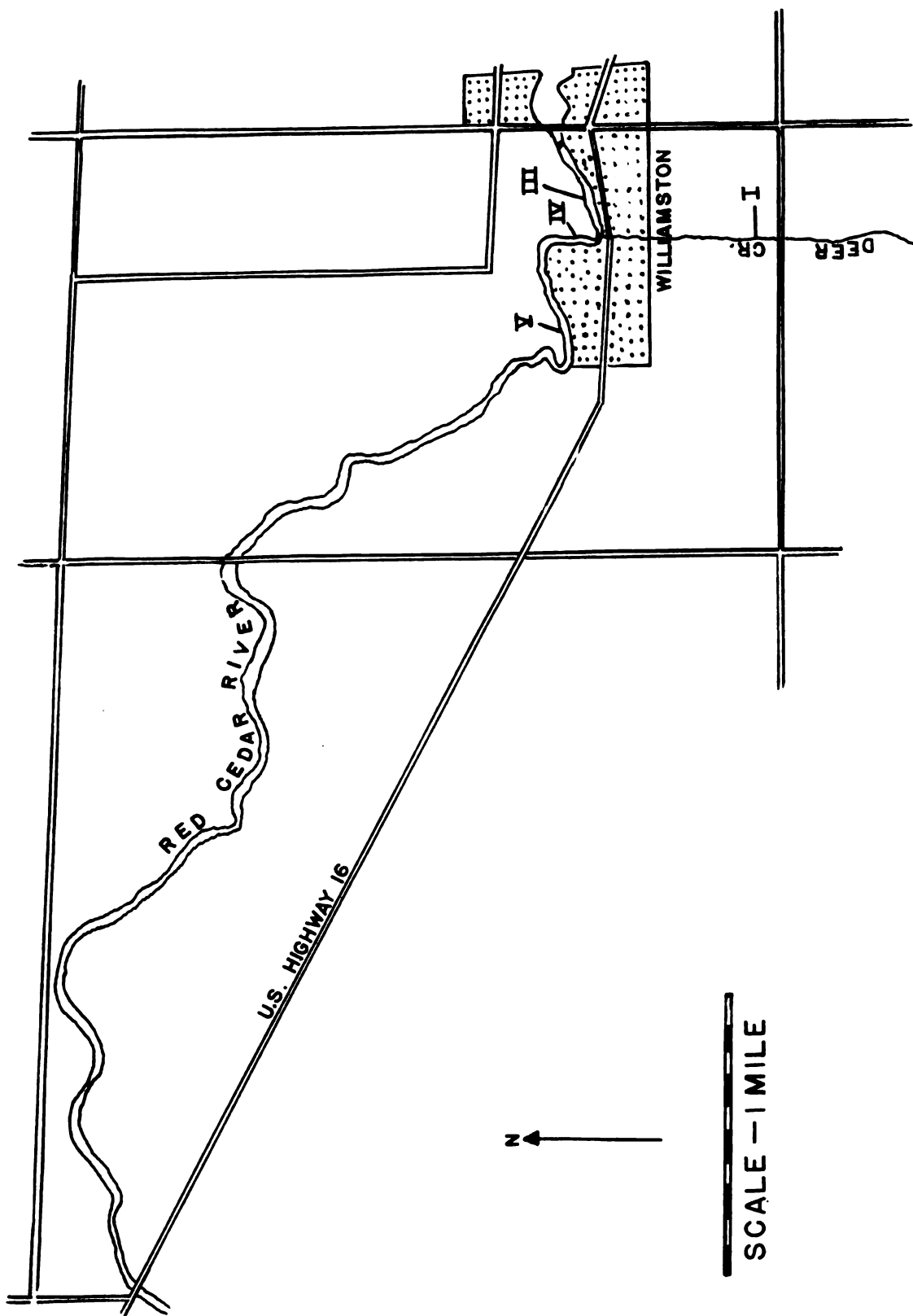


of Williamston, Michigan. The Williamston area was studied because rapid environmental changes occur within a relatively small area of the watershed. An artificial impoundment is located in Williamston. A permanent and intermittent stream enters the river within the city limits. Sewage effluent is being added to the river from the city's sewage treatment plant. The station sites are shown in Figure II.

Station I was established in Deer Creek 100 yards downstream from the bridge crossing Linn Road. The width of the tributary in the area sampled is approximately 8 feet, and the stream bottom material is sand. Deer Creek has been dredged and a levee has been built on both sides of the stream from the dredging.

Station III, located in Section 35, Township 4 North, Range 2 East of the Michigan Meridian, was approximately 0.3 mile below the Williamston dam. Brehmer (1956) reports that this sampling area was downstream from six sewer outfalls which delivered a total estimated flow of raw sewage and septic tank effluent of 100 gallons per minute. Since the completion of the sewage plant in 1957, no raw sewage enters the river in this area. The river is approximately 50 feet in width with the bottom material composed of gravel and small rocks. Upstream from the sampling site are dense beds of Vallesneria americanana. The area is shaded by trees from late spring to early autumn.

Figure II. Red Cedar River and sampling stations
in the vicinity of Williamston,
Michigan.



Station IV was located in Section 35, approximately 0.6 mile below the Williamston Dam and below the confluence with Deer Creek. The area sampled is located immediately upstream from the sewage disposal plant. The river is approximately 40 feet in width with the bottom material composed of fine gravel and small rocks and is shaded similarly to station III.

Station V was downstream approximately 1.0 mile from the Williamston Dam and 0.4 mile from the sewage treatment plant outfall. The width of the stream at this area is 40 feet and the bottom material is composed of silt and decomposed organic matter. The north river bank and its adjacent land is open pasture while the south bank had dense tree cover. There was no evidence of Spaerotilus, the sewage bacterium, often associated with polluted waters.

METHODS AND TECHNIQUES

In limnological and oceanographic studies there are many methods for measuring the productivity of a given environment. These may be summarized in two general categories; one measuring photosynthetic rate and the other by obtaining quantitative estimations of plant material growth in a given period of time. Photosynthetic rate may be determined by the oxygen production in light and dark bottles or by the addition of a radioactive isotope as C^{14} to the medium and its subsequent estimation when fixed in cells after exposure.

Quantitative estimation of plant material growth can be determined in several ways. These include measure of total weight; of constituents characteristic of plant material that can be separated (e.g., chlorophyll) or estimated in mixtures (e.g., carbon, phosphorus; protein); of associated optical properties; and estimates from the counting of morphological units.

Artificial substrates may be used as a sampling device. Cooke (1956) reviews the literature of fresh water community types and describes the concept of the aufwuchs community. He points out that aufwuchs are those organisms which are firmly attached to a substratum but do not penetrate into it. Aufwuchs comprise all attached organisms,

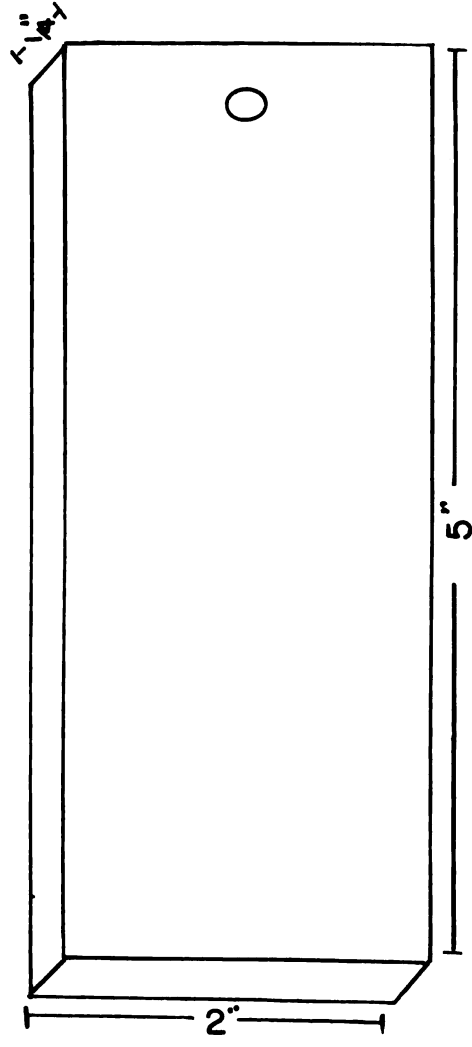
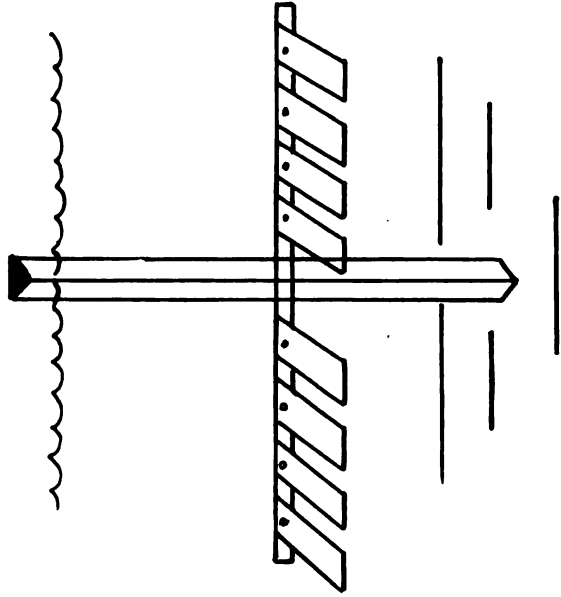
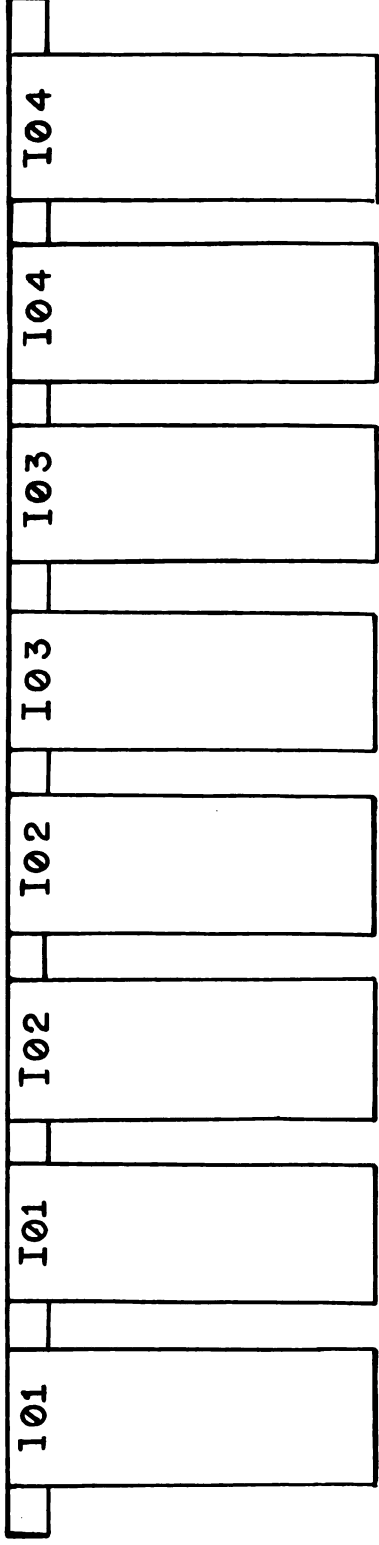
except macrophytes, including both sessile and benthic organisms. The term "sessile" is also applied to organisms which become attached to artificially exposed material used for study of organisms. Therefore, any community of sessile organisms, plant or animal, established on an artificial substrate is an aufwuch community.

The artificial substrates were plexiglass plates which were attached by screws to a wooden rack (Fig. III). The rack was attached to an aluminum bar which was driven permanently into the river bed. The dimensions of the shingles were 5" x 2" x 1/4" and whose area was 1.4 square decimeters.

The substrates were collected in 6--9 days in the summer, 10--14 days in the autumn, and 14--21 days in the winter period. The plexiglass substrates were collected after the aufwuchs growth was plainly visible but before a dense mat had formed. The substrates were removed from the stream, put in individual polyethylene bags, and stored temporarily in a portable ice chest. In the laboratory they were stored in a freezer until the organisms were removed from the plexiglass plates. It was found that freezing the attached organisms facilitated their removal from the substrates.

Eight plexiglass plates were placed at a sampling site; four plates were used to determine the density of chlorophyll color and the remaining four used to determine the number of

Figure III. Plexiglass artificial substrates showing position, method of attachment, and actual size of substrate.



organisms per unit area. At Station IV both the weight of organic matter and chlorophyll were determined from each of four plexiglass plates. The remaining four substrates were also used to estimate the number of organisms per unit area. During a sampling period comparisons could be made between the relationship of numbers and chlorophyll color from each of four pairs of substrates. At Station IV, comparisons were made not only of numbers and density of chlorophyll color but also between weight of organic matter and chlorophyll color.

Counts of Cells

The artificial substrates with algal organisms were thoroughly cleaned by rinsing and brushing the organisms into a 250 ml beaker. The organisms were transferred into a volumetric flask and mixed mechanically by using a Mag Mix. A volumetric pipette was used to draw off an aliquot from the volumetric flask and the subsample was placed in a Millipore Filter which had been partially filled with water. The size of the subsample was determined by the apparent density of the total sample. The water was drawn through the filter pad by vacuum, depositing the residue on the filter pad.

The filter pad was removed from the apparatus, allowed to dry, and placed on a 3" by 1.5" glass slide. After the filter pad was thoroughly dried, one or two drops of immersion oil was placed over the residue and the filter

pad immediately became transparent, adhering to the glass slide. The slides were labeled and stored in slide boxes until counts and identification of organisms could be made.

The Millipore Filter disc type HA used in this experiment has a pore diameter of 0.45 ± 0.02 microns. These pores are distributed randomly over the entire surface and it has been estimated that the structural material makes up only 20 percent of the filter by volume, the remaining 80 percent being voids (Millipore Filter Corporation, 1957). The filters have a total depth of 150 microns. An important structural feature is that the pore diameter is small on one side of the membrane and much wider on the other side; that is, the pores are cone-shaped. The flow is always made to enter at the side of the narrow pore opening. The microscopic and submicroscopic particles are retained upon the filter surface or virtually in a single plane defined by the surface. The small pore diameter allows the filter pad to collect all algal organisms greater than .45 microns.

The diatoms deposited on the filter pads can usually be identified to genus and often identified to species. Apparently, the immersion oil seeps into the striae of the frustrule and pushes out the chloroplast. Counts of the number of organisms were tabulated directly from the pads. The relative frequency of occurrence, the number of times an abundant organism was seen in 30 fields, was also tabulated from the filter pads. If an organism was seen in

20 of 30 fields, the relative frequency of occurrence was 67 percent.

To verify that the organisms were distributed randomly, the following test, which was developed by McGinnis (1934), was made. The formula for his index is as follows:

$$\text{Deviation from randomness } (K) = D/d$$

where D is the actual density or average number of organisms per field as determined by counting and (d) is the theoretical density. The theoretical density is tabled in McGinnis (op. cit.) and is a function of the numbers of fields counted. A (K) value of 1 indicates randomness. Values in the neighborhood of 0.5 or lower indicate that the individuals encountered are more dispersed than would be by chance alone. Values in the neighborhood of 2 or more indicate that the individuals are more aggregated than would be expected by chance (Table I).

The total number of organisms deposited on each filter pad can be calculated by the following formula:

$$m = N\bar{X}$$

where m is an estimate of M, the total number of individuals on the area; N the total number of quadrats comprising the entire area; and $\bar{X}$ is the mean number of individuals per quadrat for a sample of n quadrats randomly chosen from N.

TABLE 1
THE DISTRIBUTION OF AN AUFWUCHS SUBSAMPLE
ON A MEMBRANE FILTER SHOWING A TEST
OF RANDOMNESS*

Species	F	D	d	K=D/d
<i>Cocconeis placentula</i>	90.0	2.21	2.30	0.96
<i>Navicula cryptocephala</i>	76.7	1.58	1.46	1.08
<i>Gomphonema olivaceum</i>	43.3	0.58	0.57	1.01
<i>Cyclotella menehiniana</i>	23.3	0.25	0.26	0.96
<i>Cymbella</i> spp.	16.7	0.18	0.18	1.00
<i>Synedra ulna</i>	10.0	0.10	0.10	1.00
<i>Melosira virians</i>	3.3	0.03	0.03	1.00

*Sample taken from Station I on 7/26/58 from 1.0 ml. aliquot. Organisms scored at 1455 X (oil immersion).

F = relative frequency of occurrence; D = average number of organisms per field; d = theoretical density; K = test for randomness.

Identification of Organisms

As was mentioned previously, qualitative identification can be made directly from the Millipore filter pads. However, the material remaining from the qualitative subsamples was divided equally and stored in two types of algal preservatives; 6-3-1 preservative and concentrated hydrochloric acid. The concentrated acid was used to clean the frustules of the diatoms and the 6-3-1 solution was used to preserve other types of algae which may have been seeded on the substrates. Organisms which could not be identified positively from the filter pads were identified from water mounts. Verification of previous identifications were also made from water mounts. A compound microscope with 10X and 20X objectives was used and all identifications were made under the oil immersion lens.

Chlorophyll Color

Two similar methods were utilized to obtain the density of chlorophyll color data. In the first method the periphyton growth ~~was~~ scraped from the substrates with a "rubber policeman" and allowed to stand in 95 percent ethanol for a minimum of 48 hours while stored in total darkness. Grzenda and Brehmer (ms.) indicate that samples can be stored in this manner for as long as 30 days without a loss of the phytopigments due to decomposition. After the samples were filtered through glass wool, the volume of the filtrate was adjusted to 50 ml by either

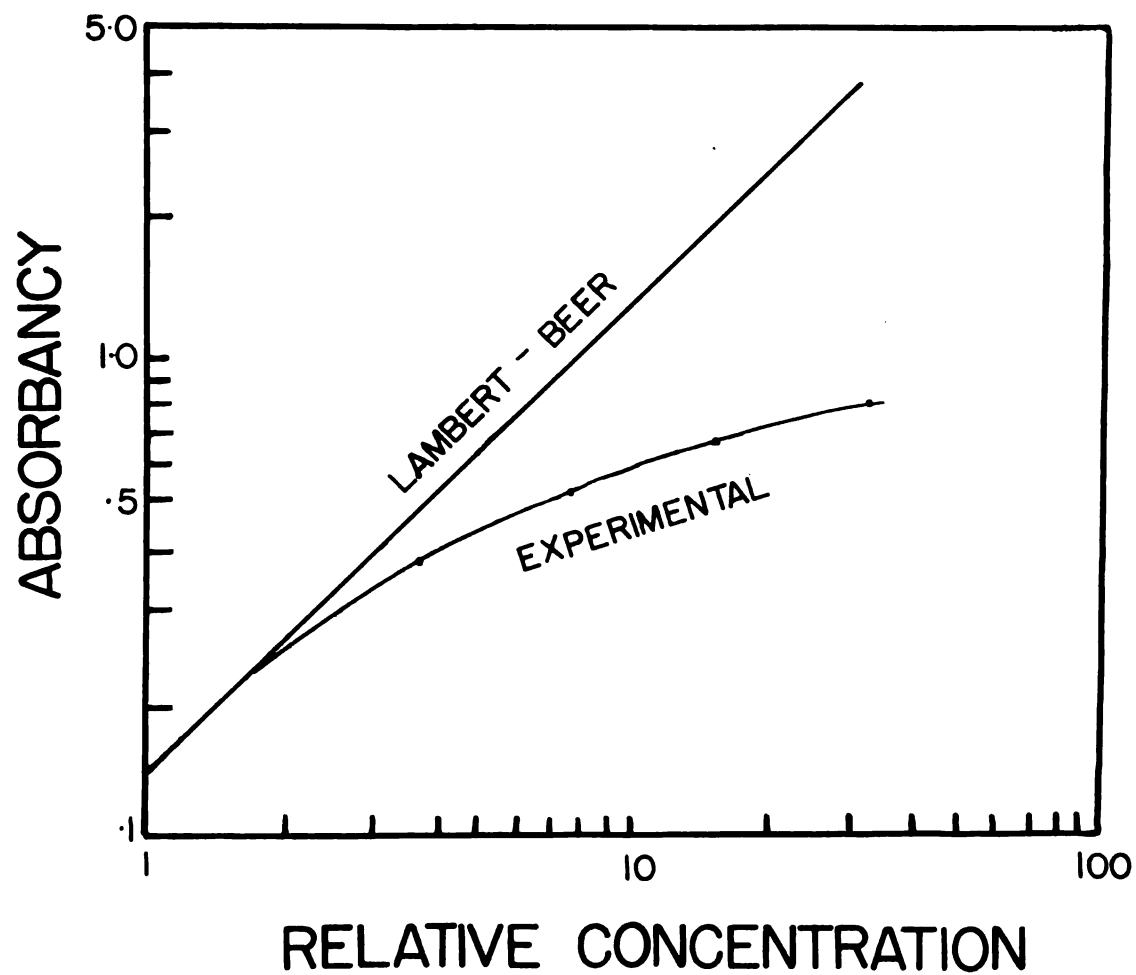
dilution or evaporation. The density of the chlorophyll solution was read on a Klett-Summerson colorimeter using the red filter (640--700 mμ).

In the second method, the procedure was identical except that gooch crucible filtration was used. This technique was utilized in order that both organic matter and chlorophyll color could be obtained from the same substrate.

Experiments by Grzenda and Brehmer (op. cit.) dealing with opticochemical characteristics of 95 percent ethanol phytopigment extracts showed that the absorbancy of broad spectrum light (640--700 mμ) is not linearly related to the concentration except at very low concentrations. They point out that the measured pigment absorbancy may be corrected to correspond with the theoretical absorbancy as related to concentration by constructing a correction graph (Fig. IV). The graph is constructed by plotting absorbancy against concentration as determined by dilution and this portion of the curve corresponds to the line labeled EXPERIMENTAL in Figure IV. The line labeled LAMBERT-BEER corresponds to the theoretical absorbancy of the solution.

The correction graph is used in the following manner. The measured absorbancy is found on the ordinate and is followed horizontally to intercept the experimentally determined line. This intercept is then read vertically

Figure IV. Correction graph for adjusting measured phytopigment absorbancy values to units related to concentration.



to intercept the extrapolated Lambert-Beer line. The absorbancy unit on the ordinate opposite this intercept represents the corrected absorbancy reading.

Organic Matter

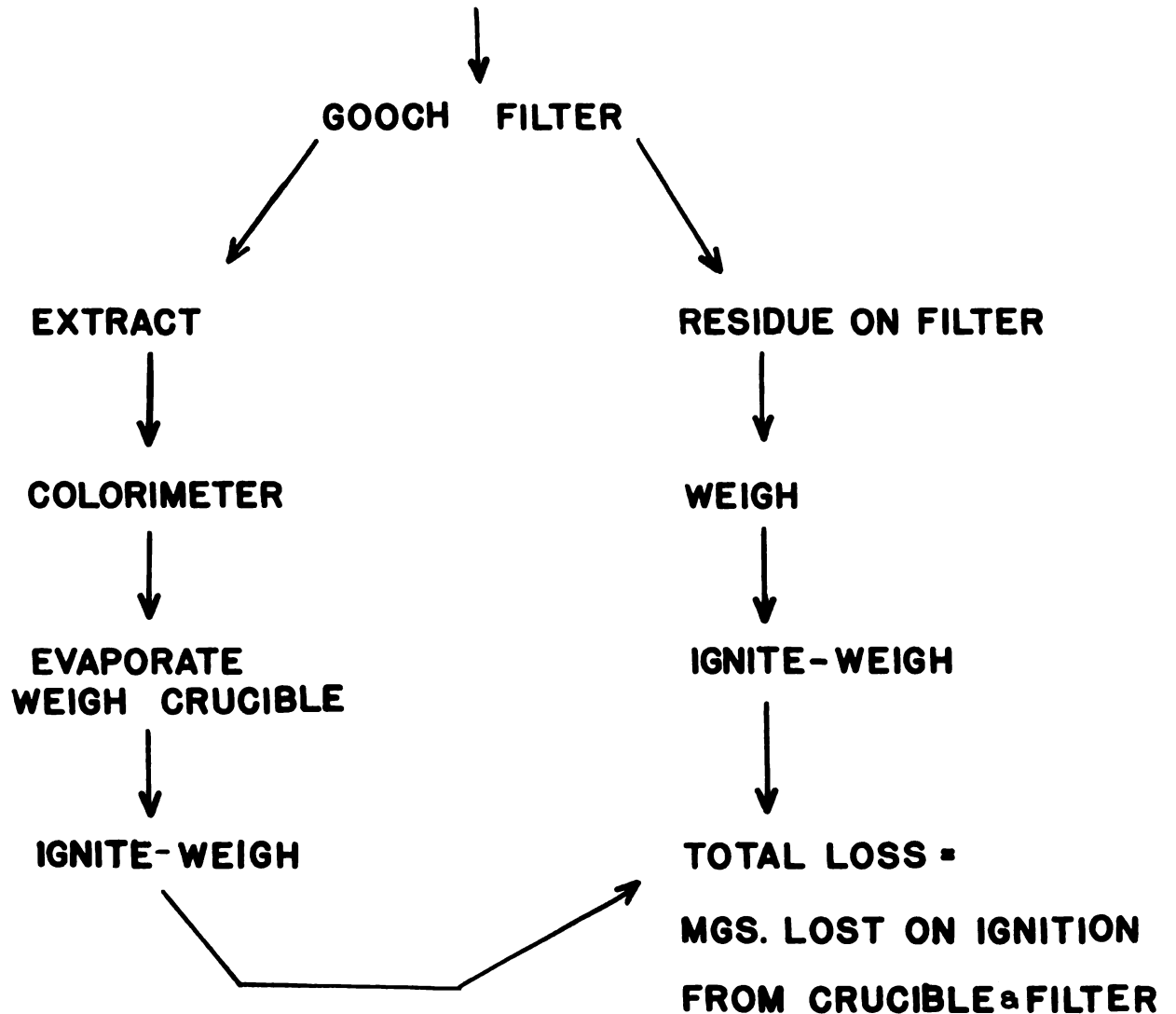
All macro-faunal components of the aufwuchs community were removed from the substrate and weight estimates of the components were made by the following procedure. After the periphyton was removed from the substrate and stored in 95 percent ethanol for at least 48 hours in total darkness, the particulate matter was separated from the solvent by filtration through a Gooch crucible. The crucible was dried to constant weight and the organic weight determined by loss on ignition. The absorbancy of the ethanol-soluble pigments was determined after the solution was adjusted to a volume of 50 ml. The weight of the residue was added to the weight of the particulate matter of the sample; the sum being an estimate of the total organic weight.

The Gooch crucibles and evaporating dishes at each step in the procedure were stored in a drying oven at 55° C and cooled to room temperature in a desiccator before they were weighed on an analytical balance. The sample was said to be at constant weight when two consecutive readings of ± 0.5 mg were obtained after an interval of 12 hours. A flow chart for each step in the procedure is shown in Figure V. Comparisons were made between weight

Figure V. Flow chart showing procedure for obtaining estimates of organic matter from organisms attached to the substrates.

GRZENDA TECHNIQUE

SAMPLE + 95% ETHYL ALCOHOL PIGMENT



of organic matter and phytopigment units by calculating a correlation coefficient to express the relationship.

Linear Regression and Correlation

A linear regression was fitted to the phytopigment unit-weight relationship by the formula given in Walker and Lev (1953). The relation between Y_1 (weight) and X_1 (phytopigment unit) is called the regression equation and, for linear regression, is given by the formula

$$\tilde{Y}_1 = \bar{Y} + b_{yx} (X_1 - \bar{X})$$

In this formula $\tilde{Y}$ is an estimate of the unknown weight from a known phytopigment unit (X_1). $\bar{X}$ is the calculated sample mean of the phytopigment units and $\bar{Y}$ is the calculated sample mean of the weight of organic matter. An estimate of the slope or the linear regression coefficient, b_{xy} , is calculated by the following formula:

$$b_{xy} = \frac{N \sum XY - (\sum X)(\sum Y)}{N \sum X^2 - (\sum X)^2}$$

where N is the sample size; X is a known phytopigment unit, and Y is a corresponding weight for a given phytopigment unit.

The correlation coefficient, r , is a numeralization of the observed phytopigment unit and the weight of organic matter. Correlation coefficients vary between +1 and -1 according to the closeness of the relationship in the

population sampled. A correlation of $\pm .91$ would indicate a close relationship while a coefficient of $\pm .25$ would indicate a poor relationship. A positive value for a correlation coefficient would show a direct relationship and a negative value would show an inverse relationship. The linear correlation coefficient may be calculated by the following formula:

$$r = \frac{N \sum XY - (\sum X)(\sum Y)}{[N \sum X^2 - (\sum X)^2][N \sum Y^2 - (\sum Y)^2]}$$

where N is the sample size; X is a known phytopigment unit, and y is a corresponding weight for a given phytopigment unit. Linear regression equations and correlation coefficients were also developed for the phytopigment unit-number of organisms relationship using the same procedure.

Water Temperature

Water temperatures recorded for individual stations were taken with a pocket thermometer held approximately three inches under the water surface. The temperatures reported in Appendix A were recorded on a Taylor recording thermometer permanently located ten miles upstream from the mouth of the river and ten miles downstream from Williamston. At most there was 0.5° C. difference between water temperatures recorded with the pocket thermometer and those with the recording thermometer.

Solar Radiation

Solar radiation data were obtained from the Michigan Hydrologic Research Station which maintains an Eppley pyrhelometer on the Michigan State campus. The pyrhelometer is located approximately 10 miles west of the area studied in the vicinity of Williamston, Michigan. Pyrhelometric stations measure "insolation," the rate at which solar energy is received on a horizontal surface at the surface of the earth.

The unit of measure used in pyrhelometry, the gram-calorie, may be defined as the quantity of heat necessary to change the temperature of one gram of water from 3.5°C . to 4.5°D . (Crabb, 1950). The intensity of radiation is defined as the radiant energy emitted in a specific direction per unit area of surface per solid angle, hence, gram-calories per square centimeter. The average amount of light intensity was calculated for each sample period and is shown in Table 14.

RESULTS AND CONCLUSIONS

Qualitative

Trophodynamic ecology cannot be separated naturally from community ecology; they are complimentary. Productivity rates will vary not only between unlike communities during different seasons but also between like communities in the same season. The concept of the aufwuchs community was useful in delimiting the major producer complex responsible for primary production in the area studied.

Many ecological studies have been made of the phytoplankton of the lotic environment. Kofoid (1903, 1910) made complete studies of the plankton in the Illinois River, and Eddy (1932) studied the Sangamon River phytoplankton in Illinois. The plankton of the San Joaquin River, California was investigated by Allen (1920). The upper Mississippi River's plankton was considered in a study by Reinhart (1931). Other workers who investigated phytoplankton in rivers and streams in the United States were Shelford and Eddy (1929), Brinley (1942), Lackey (1942, 1943), and Hooper (1947).

Butcher's series of papers (1932, 1940, 1946, 1947) on studies of the ecology of rivers in Great Britain have led investigators to describe a new community type of algal organisms other than phytoplankton which are found

in great abundance in flowing water. This is the aufwuchs community, that group of organisms which are attached to a substrate but do not penetrate into it. Unfortunately, considerable terminology has arisen in the literature describing this community association. Sessile, benthic, epiphytic, periphyton are a few of the terms used but are synonymous with aufwuchs. Workers who have described an aufwuchs community in studies of flowing water include Blum (1954, 1957), Douglass (1958), Guntow (1955), Odum (1957), and Whitford (1956).

A community of aufwuchs was sampled in the Red Cedar using artificial substrates. Butcher (1932) reports that no observed differences in sessile algae were found on the artificial substrates (glass slides) than found on natural substrates in the river. On alternate sampling periods organisms were scraped from natural substrates in the river and compared with organisms from the artificial substrates. The artificial substrates were not selective, but had the same dominant organisms attached as did rocks, wood, and other naturally occurring substrates.

The importance of diatoms as primary producers in the lotic environment cannot be overestimated. Reinhart (1931) points out that diatoms were at all times the most important constituents of the plankton in the Mississippi River from a volumetric viewpoint. The aufwuchs communities in the area sampled in the Red Cedar River

are composed almost entirely of diatoms. Patrick (1952) states that the bottom microflora in the Des Moines River was composed almost wholly of diatoms and this undoubtedly is an important constituent of phytoplankton. Butcher (1932) states that diatoms comprise the largest and most prevalent group of algae in a river. He lists three distinct sessile diatom communities: (1) a Diatoma-Gomphonema olivaceum community; (2) a Navicula viridula-Cymbella ventricosa community; and (3) a Synedra ulna community. In the Saline River, Michigan, Blum (1954) describes two winter diatom communities; (1) a Diatoma community, and (2) a Gomphonema community.

Seven diatom communities were found in the aufwuchs complex in the Red Cedar River near Williamston; a Navicula cryptocephala community, a Cocconeis placentula community, a Gomphonema olivaceum community, a Diatoma hiemale community, a Synedra ulna community, a Cymbella tumida community, and a Cyclotella meneghiniana community. Some of these communities were short-lived while others persisted for relatively long periods (Table 2).

Community periodicity refers to cyclic changes in the activities of organisms which produce regularly recurring changes in the complexion of the community as a whole. Ecologists studying terrestrial and fresh water communities in temperate regions have found that early and late spring or early and late summer are as different

TABLE 2

A LIST OF DOMINANT ORGANISMS AT EACH STATION
ON DATES OF OCCURRENCE

Dominant Organism	Dates of Occurrence
Station I	
Cocconeis placentula	7/17/58 to 9/11/58
Navicula cryptocephala	7/17/58 to 8/18/58
Navicula cryptocephala	9/3/59 to 9/11/58
Cymbella tumida	9/11/58 to 9/21/58
Navicula cryptocephala	9/21/58 to 11/7/58
Diatoma hiemale	11/7/58 to 11/26/58
Synedra ulna	11/26/58 to 1/6/59
Navicula cryptocephala	1/6/59 to 2/8/58
Station III	
Navicula cryptocephala	7/17/58 to 8/18/58
Cocconeis placentula	8/18/58 to 9/11/58
Navicula cryptocephala	9/21/58 to 9/30/59
Synedra ulna	9/30/58 to 11/26/58
Diatoma hiemale	12/6/58 to 12/20/58
Synedra ulna	12/20/58 to 2/8/59
Station IV	
Navicula cryptocephala	7/19/58 to 8/26/58
Cocconeis placentula	7/19/58 to 9/30/58
Cyclotella meneghiniana	9/3/58 to 9/21/58
Navicula cryptocephala	9/11/58 to 10/28/58
Synedra ulna	10/28/58 to 1/6/58
Gomphonema olivaceum	1/6/58 to 2/8/58
Station V	
Navicula cryptocephala	9/30/58 to 11/7/58
Synedra ulna	10/28/58 to 1/25/59
Gomphonema olivaceum	1/25/59 to 2/8/59

from each other as autumn and winter. Odum (1953) suggests that the factors responsible for periodicity may be: (1) extrinsic--entirely dependent on an external environmental stimulus; (2) intrinsic--synchronized with an environmental stimulus but capable of persisting in its absence; and (3) inherent--independent of environmental changes.

Transeau (1913), Pearsall (1932), and Hutchinson (1944) describe fresh water periodicity in lakes and attempt to correlate factors responsible for algal periodicity. However, there is some doubt whether or not periodicity occurs in the flowing water environment. Butcher (1940, 1947) points out there is no seasonal variation in dominant species in the Hull and Itchen Rivers in Great Britain. He has found seasonal periodicity in the Lark and Tees Rivers (1932). Guntow (1955) reports periodicity in the West Gallatin River, Montana and Blum (1957) has found definite cyclic changes in the algal communities of the Saline River, Michigan. Data from the Red Cedar River show a marked seasonal periodicity of algal organisms which become attached to artificial substrates (Figs. VI and VII).

Navicula cryptocephala. This tiny diatom was found in great abundance at all sampling stations from the beginning of the sampling in July and persisted until late November. However, at Station I it began to reappear in

FIGURE VI. Seasonal periodicity of algal organisms which become attached to artificial substrates at Station I

STATION I

- SYNEDRA ULNA
- DIATOMA HIEMALE
- COCconeis PLACENTULA
- NAVICULA CRYPTOCEPHALA

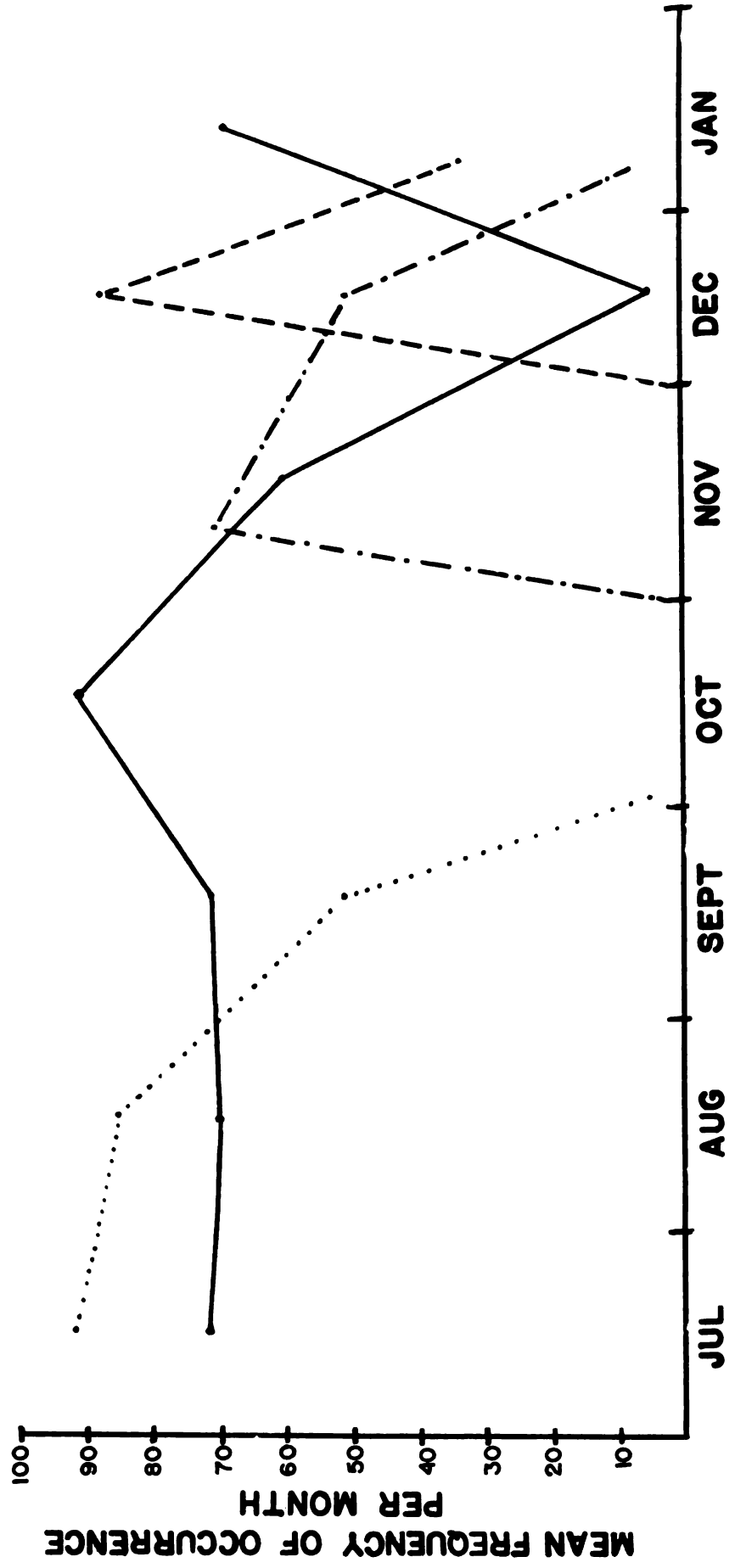


FIGURE VII. Seasonal periodicity of algal organisms which became attached to artificial substrates at Station III.

STATION III

--- SYNEDRA ULNA
 COCCONEIS PLACENTULA
 — NAVICULA CRYPTOCEPHALA
 XXXXXX GOMPHONEMA OLIVACEUM

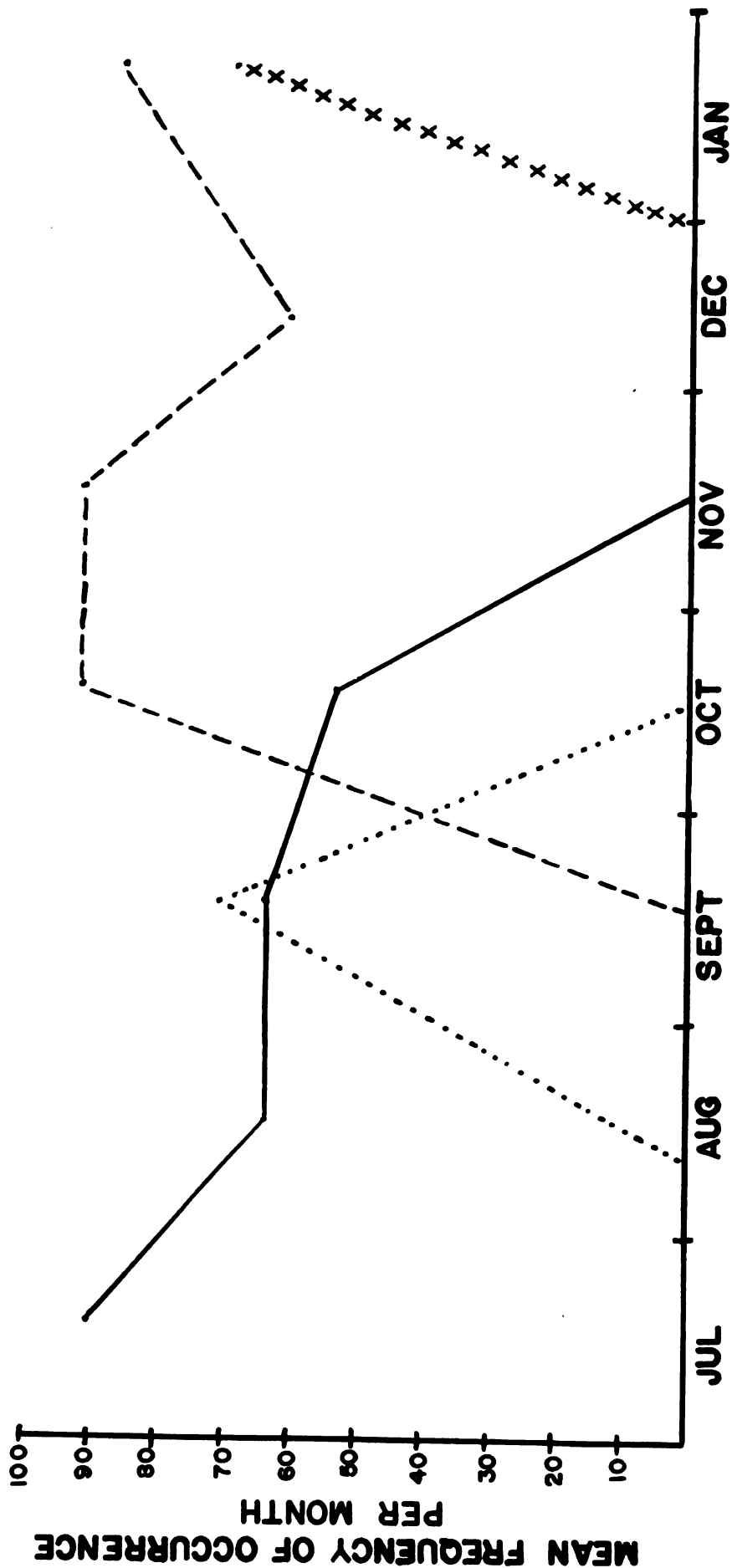


FIGURE VIII. Seasonal periodicity of algal organisms which became attached to artificial substrates at Station IV

STATION IV

--- SYNEDRA ULNA
 COCCONEIS PLACENTULA
 XXXXXXXX GOMPHONEMA OLIVACEUM
 — NAVICULA CRYPTOCEPHALA
 CYCLOTELLA MENEGHINIANA

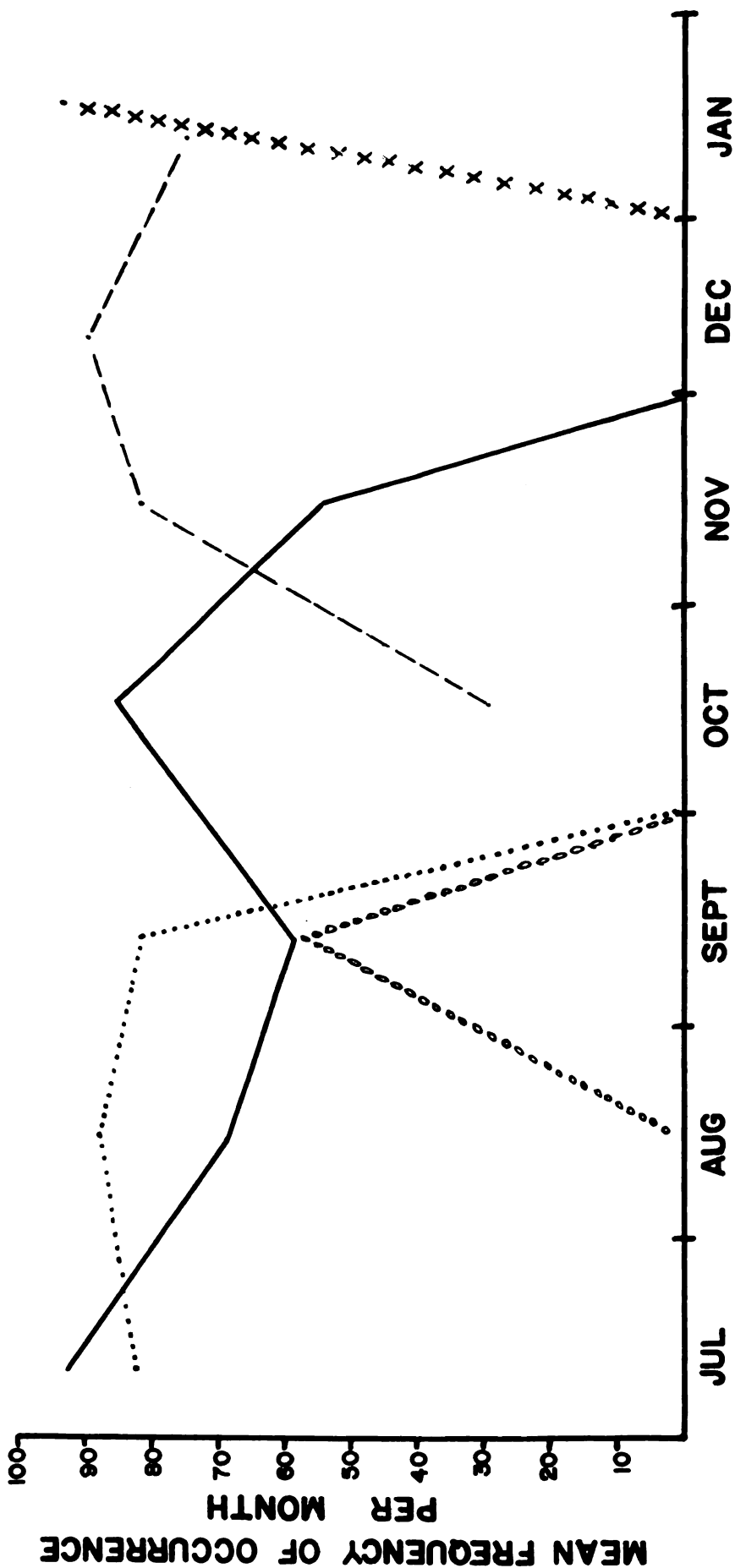
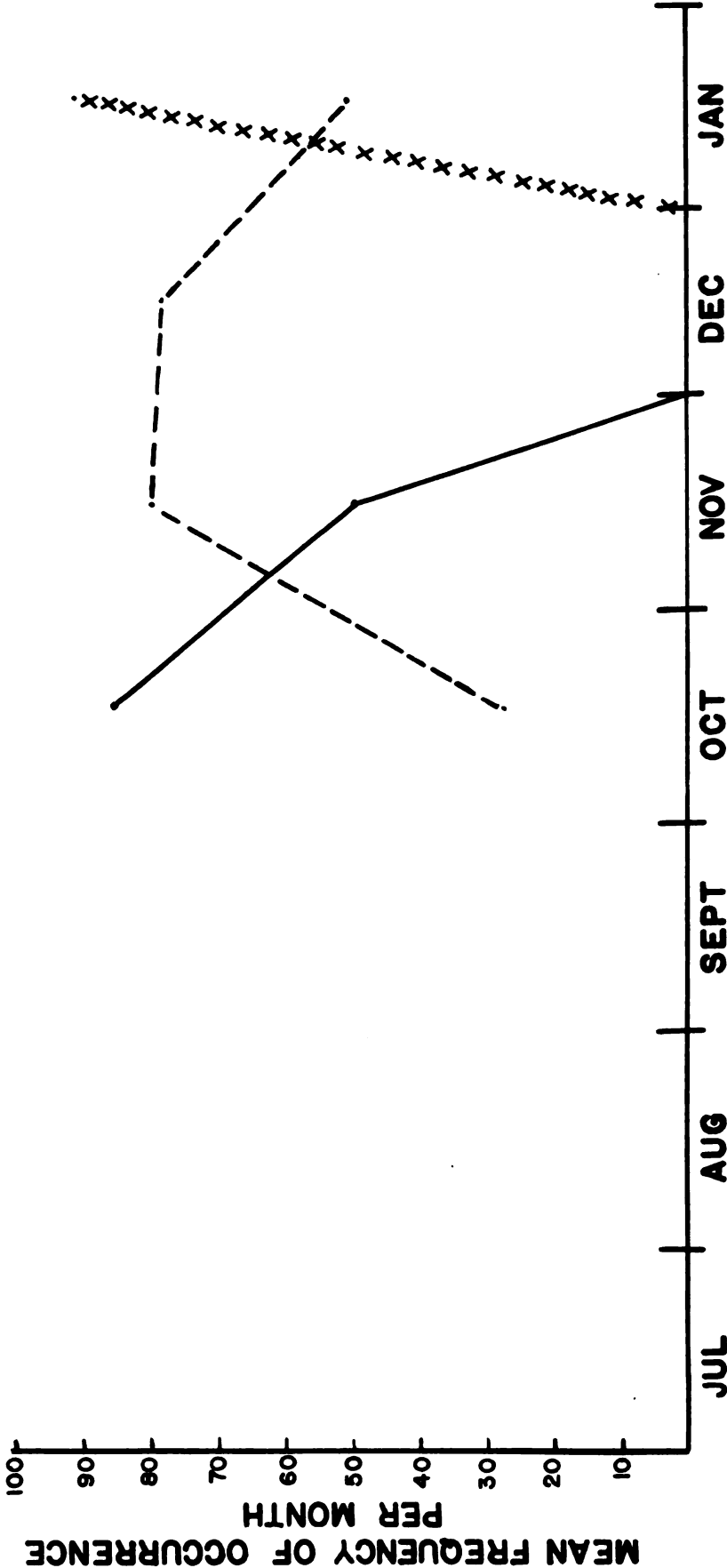


FIGURE IX. Seasonal periodicity of algal organisms which became attached to artificial substrates at Station V

STATION V

----- SYNEDRA ULNA
----- NAVICULA CRYPTOCEPHALA
xxxxxxx GOMPHONEMA OLIVACEUM



great numbers in January. There is no apparent means of attachment found in this diatom. Blum (1957) found N. cryptocephala to occur dominantly throughout the summer in the Saline River. Guntow (1955) mentions that Navicula was most abundant during August--September but became predominant again during early December and remained in this position through March.

Cocconeis placentula. This diatom occurred with N. cryptocephala to form a Navicula cryptocephala--Cocconeis placentula community during the summer. It did not persist in abundance with N. cryptocephala and declined rapidly when the water temperature fell below 15° C. Butcher (1932) found this species as late as October but it never occurred abundantly during the winter. It is attached to the substratum by the whole of one surface.

Synedra ulna. The largest diatom found in the aufwuchs complex, this species first appeared in abundance in October. This winter species was capable of persisting in great numbers through January in low temperature (0° C.) and under cover. Butcher (1932) mentions that this species occurs most abundantly during the winter months but Blum (1957) lists this as an abundant form in the summer microflora of the Saline River, Michigan. This means of attachment to a substratum is by a mass of mucilage at one end of the frustule.

Gomphonema olivaceum. Another winter species, this alga was beginning to reach abundance in January. The species was part of the winter diatom community in the Saline River and disappeared in mid-April with the general rise in water temperature (Blum, 1957). A massive colonial form, it has individual cells which attach to a substratum by branched or unbranched mucilaginous pedicels. These colonies are often macroscopically visible.

Diatoma hiemale. Occurring at Stations I and II, its maximum abundance was during November and December and it did not persist under ice cover. It attaches to a substratum by a mass of mucilage at one end of the frustule.

Cymbella tumida. This species was found only in Deer Creek, a tributary of the river. Each unit of vegetation is attached by the whole of one surface. It occurred abundantly for one week in September. Blum (1957) lists C. tumida as occurring abundantly during the summer.

Cyclotella meneghiniana. The only centrate diatom occurring in the samples, this alga was abundant during the month of September at station IV. There is no visible means of attachment for this organism. Plates of the dominant forms and a few of the rare species are in Appendix B.

Quantitative Results

Three methods are used to estimate primary production (1) the number of organisms per unit area per sampling period; (2) the weight of organic matter per unit area per sampling period; and (3) the amount of phytopigment unit per unit area per sampling period. The results from these methods are enumerated in Appendix D. Numericalizations of the relationships between these methods are expressed by correlation coefficients. The nature of period community changes at each station are considered by comparing the individual community regression lines with the common regression line for that station. Levels of production between stations are compared and the solar input rate-production rate relationship is considered.

The relation between phytopigment units and the number of organisms. The coefficients of linear correlations calculated for the four stations were .90, .84, .75, and .86. These results are excellent for biological data and indicate a close relationship between the independent variable, the phytopigment unit, and the dependent variable, the number of organisms sampled. The probability of obtaining correlations as great as these through chance alone is less than .001 (Snedecor, 1957).

Identification of the diatom communities in the watershed near Williamston, Michigan have shown the greatest number of individual dominant communities occurring

in Deer Creek. The range of phytopigment units shows the widest fluctuation in Deer Creek compared with the other sampling sites (Appendix D). However, this station has the highest correlation coefficient calculated.

A comparison of the individual correlation coefficients indicate there may be differences between Deer Creek, the tributary of the main stream, and the sampling sites in the main stream (Table 3).

TABLE 3

A COMPARISON OF THE REGRESSION COEFFICIENTS
AND CORRELATION COEFFICIENTS EXPRESSING THE
PHYTOPIGMENT UNIT-NUMBER OF ORGANISMS
RELATIONSHIP FROM THE FOUR
SAMPLING SITES

Station	Correlation Coefficient	Regression Coefficient	Intercept
I	.90	14.4	-.83
III	.84	9.11	.53
IV	.75	7.18	.24
V	.86	7.89	.16

A test of the hypothesis that the individual correlation coefficients were from the same population shows a significant difference at the 5 percent level (Table 9). There is evidence the ratio of phytopigment units to number of organisms may be larger in Deer Creek than for the stations in the mainstream (Figs. X--XIII).

TABLE 4

A STATISTICAL COMPARISON OF FOUR CORRELATION
COEFFICIENTS TAKEN FROM THE PHYTOPIGMENT
UNIT-NUMBER OF ORGANISMS RELATIONSHIP
IN THE RED CEDAR WATERSHED*

Station	N	N-3	r	Zr	(N-3)Zr	(N-3)Zr ²	Corrected Zr.
I	79	76	.903	1.488	113.088	168.275	1.483
III	76	73	.837	1.211	88.403	107.056	1.205
IV	80	77	.750	.986	75.922	74.859	.981
V	44	41	.855	1.275	52.275	66.651	1.266
		267	3.345		329.688	416.841	

$$\text{Average } r = 3.345/4 = .836$$

$$\text{Average Zr} = 329.688/267 = 1.235$$

$$(N - 3)Zr \bar{Zr} = 329.688 \times 1.235 = 407.165$$

$$(N - 3)Zr^2 - (N - 3)Zr \bar{Zr} = 416.841 - 407.165 = 9.626$$

$$\chi^2_{3df} = 9.626$$

Reject if $9.678 > 7.80$ at 5% level.

Reject if $8.076 > 11.3$ at 1% level.

Therefore, reject at 5% level; accept at 1% level.

$$(N - 3) \text{ Corrected Zr} = 328.116$$

$$\text{Average Corrected Zr} = 328.116/267 = 1.229$$

$$\text{Average } r = .8417$$

*Test taken from Snedecor (1956) indicate:

N = total number of samples

r = linear correlation coefficient

Zr = log transformation from r to a quantity Z which has a normal distribution

Corrected

Zr = accounts for small bias in Zr when unequal samples are used

The high correlation coefficients may be a result of the type of organisms sampled. Tucker (1949) found a good correlation (.84) between number of units of phytoplankton counted and density of pigment extracted. In population he studied, over 90 percent of the organisms sampled were diatoms. Lower correlations were found for heterogenous groups of phytoplankton algae.

At least two major dominant community types developed at each station during the sampling period from July, 1958 through February, 1959. In a given sampling period, a maximum of 11 genera and approximately 20 species were enumerated from a subsample of a single substrate. The periodic change in community structure and the number of individual species found in a single subsample indicate variability. Yet, high correlations were found and the similarity between regression coefficients indicate that number of organisms may be estimated from phytopigment units by using artificial substrates. The good correlation might be attributed to the size of the organisms, all the diatoms sampled being relatively the same size except Synedra ulna. Since most organisms are approximately the same size, a given volume of chlorophyll would be extracted from each organism.

An estimate of the total number of organisms found on a substrate can be calculated from the following formula:

$$m = N\bar{X}K$$

where m is the total number of organisms per 1.4 sq. dm.; N is the total number of fields (44,484) on the filter pad under the oil immersion lens; $\bar{X}$ the mean number of organisms per 30 fields; and K is 100, a multiplicative constant which considers the size of the subsample.

A tentative hypothesis that the community structure might be grossly altered because of the addition of nutrients from the sewage disposal plant was rejected. No gross differences in community structure were observed between station V, the sampling site 0.4 mile below the sewage disposal plant, and the other sampling sites in the river. It should be noted that a sampling site was not established at this location until September 30, 1958 while sites were established during July at the other stations. An increase in nutrients during the summer may change the level of productivity or alter the community structure.

If phytopigment units were used to estimate the number of organisms on an artificial substrate throughout the entire year, the effect of periodic community changes should be considered. The results of an analysis of covariance between dominant communities at each station show that one regression line may be used to estimate number of organisms except at station III (Tables 5-8). The sampling site in Deer Creek was the only station where a common slope could be used in estimating the number of organisms. Individual community regression lines are

FIGURE X. The common regression line expressing the phytopigment unit-number of organisms relationship compared with the individual regression lines for 4 communities at Station I.

STATION I

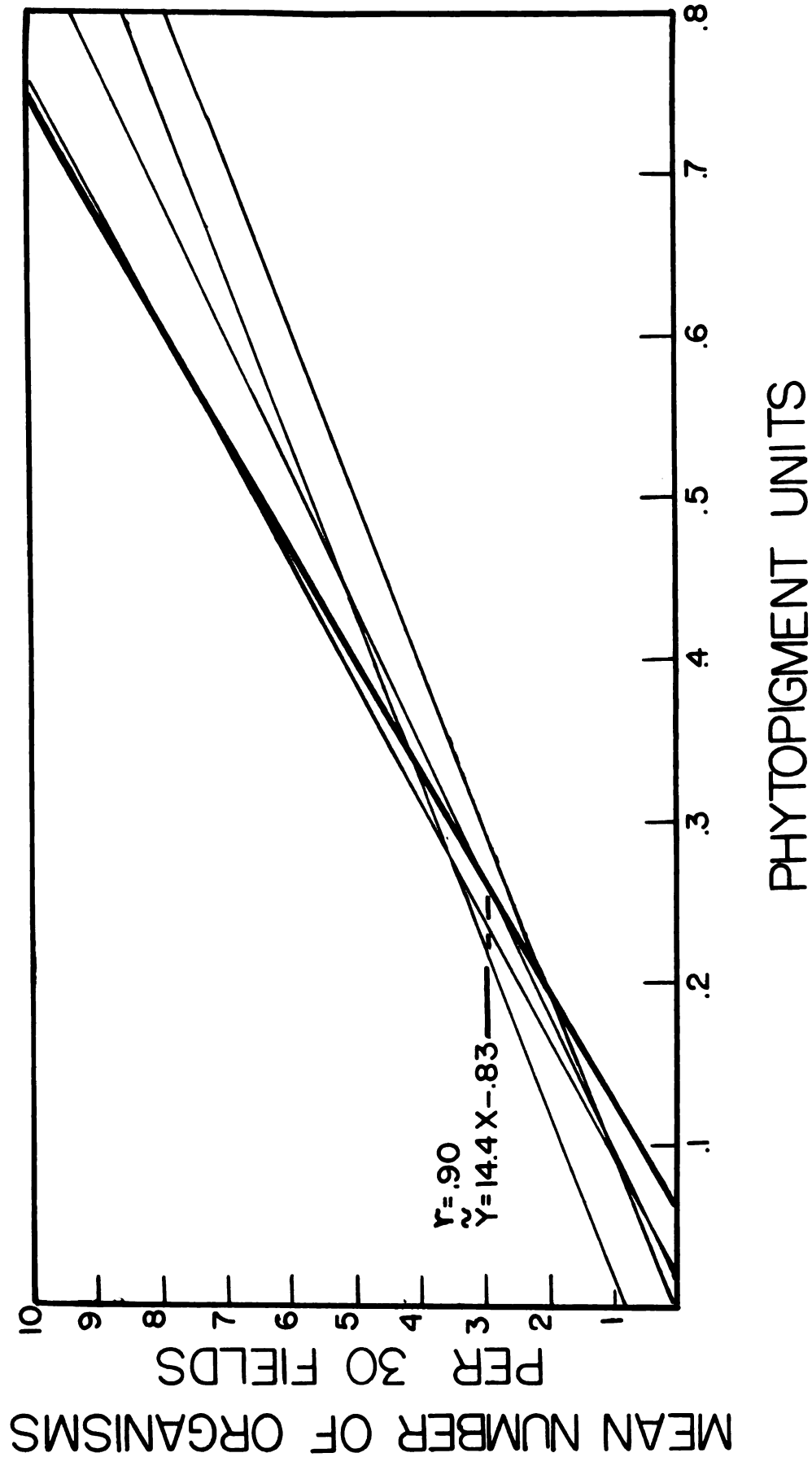


TABLE 5

A COVARIANCE ANALYSIS BETWEEN REGRESSION LINES
FOR PHYTOPIGMENT UNITS AND NUMBER OF ORGANISMS
FOR 4 COMMUNITIES AT STATION I

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
TOTAL	77	208.812	---
1. Can one regression line be used for all observations?			
Gain from separate regressions over general regression	3	4.04	1.3467
Deviations from separate regressions	74	204.77	2.7672
("F" = .4866, answer is Yes)			
2. Can a common slope be used for the separate regression lines?			
Further gains from fitting separate regressions (difference between slopes)	3	7.82	2.6066
Deviations about separate regressions	71	196.948	2.7739
("F" = .9396, answer is Yes)			

FIGURE XI. The common regression line expressing the phytopigment unit-number of organisms relationship compared with the individual regression lines for 4 communities at Station III.

STATION III

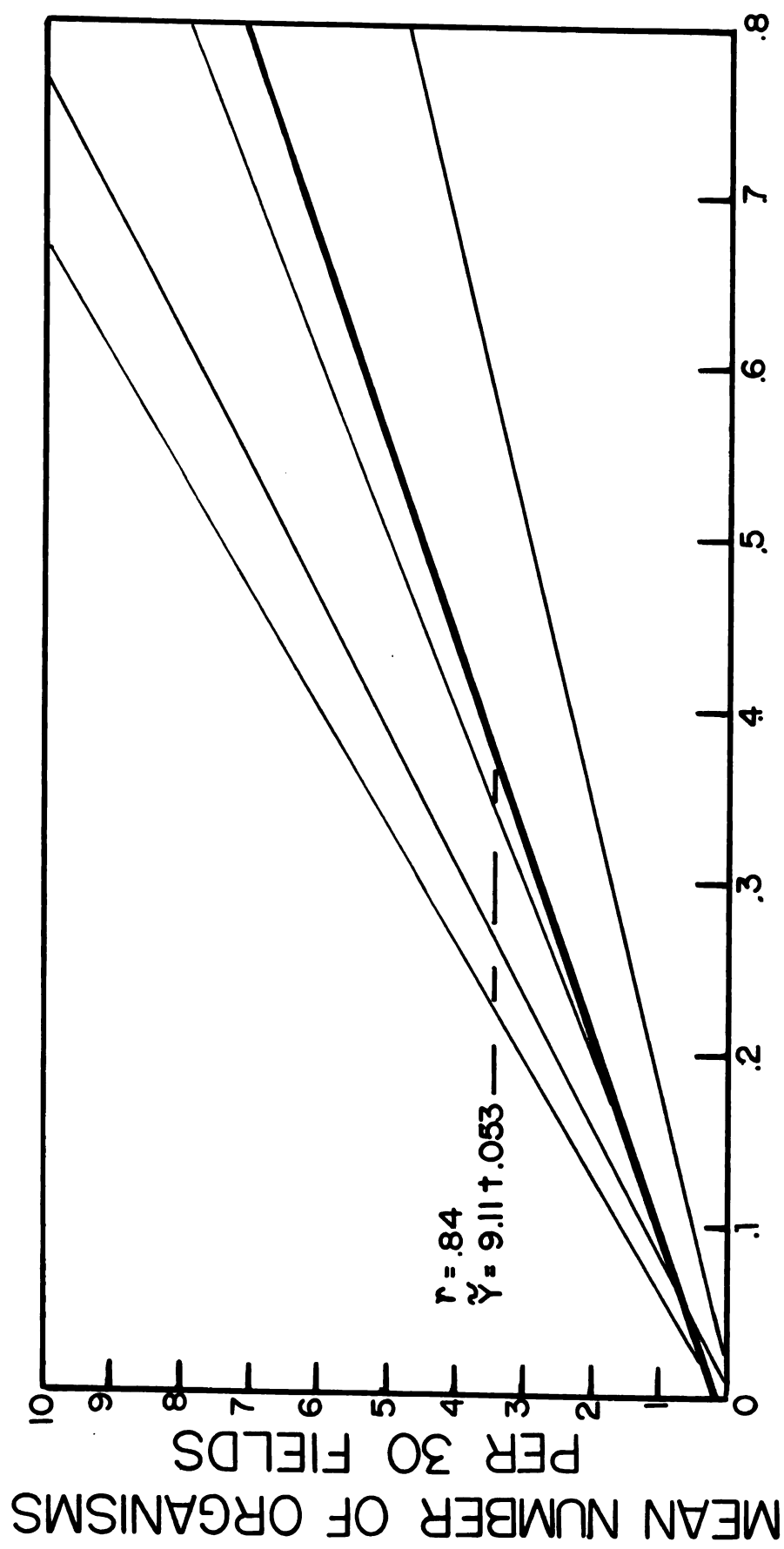


TABLE 6

A COVARIANCE ANALYSIS BETWEEN REGRESSION LINES
FOR PHYTOPIGMENT UNITS AND NUMBER OF ORGANISMS
FOR 4 COMMUNITIES AT STATION III

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
TOTAL	74	35,0968	---
1. Can one regression line be used for all observations?			
Gain from separate regressions over general regression	3	5.3964	1.7988
Deviations from separate regressions	71	29.7004	.4183
("F" = 4.30, answer is No)			
2. Can a common slope be used for the separate regression lines?			
Further gains from fitting separate regressions (difference between slopes)	3	9.047	3.0156
Deviations about separate regression	68	20.6534	.3037
("F" = 9.93, answer is No)			

FIGURE XII. The common regression line expressing the phytopigment unit-number of organisms relationship compared with the individual regression lines for 5 communities at Station IV.

STATION IV

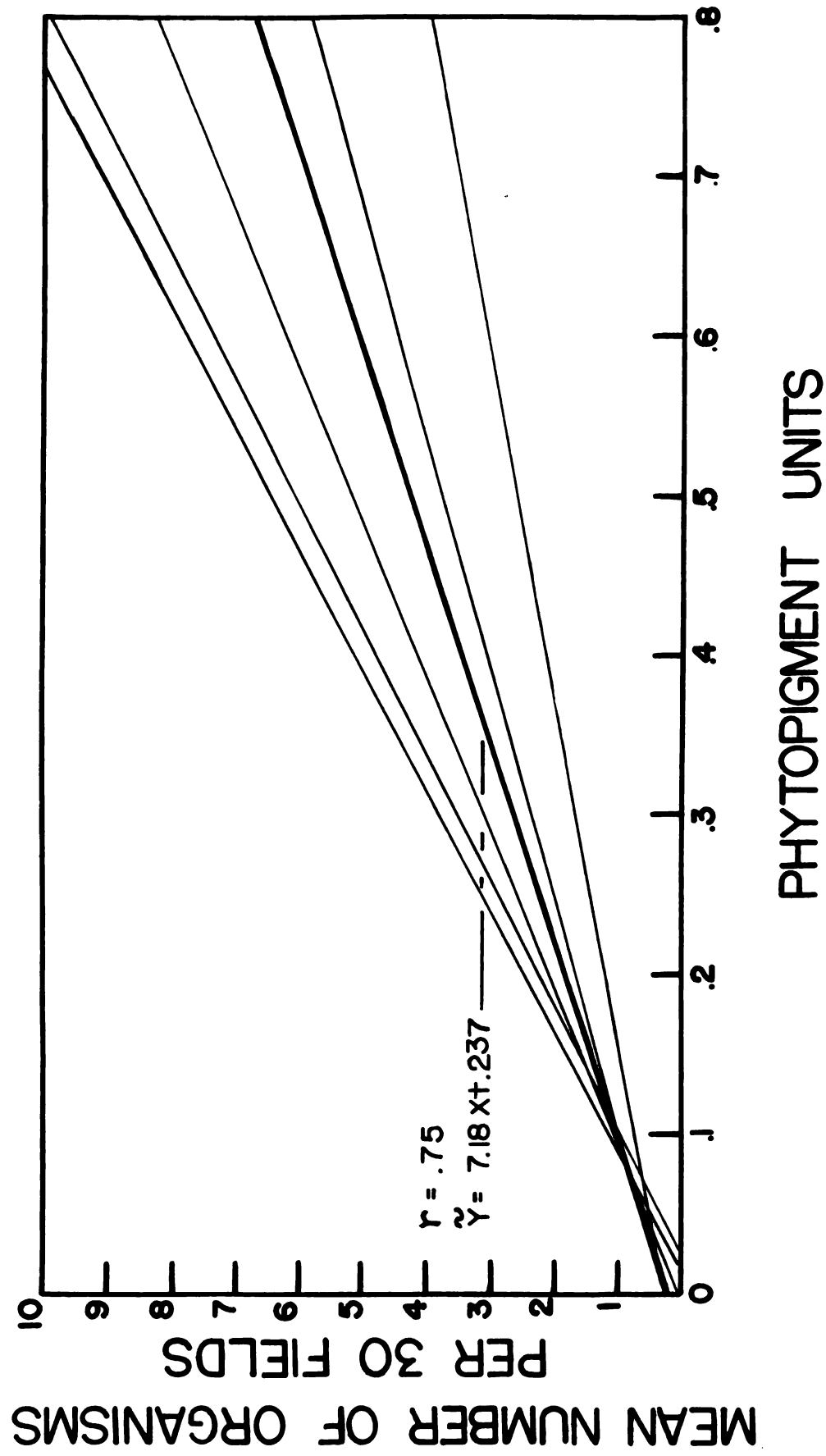


TABLE 7

A COVARIANCE ANALYSIS BETWEEN REGRESSION LINES
FOR PHYTOPIGMENT UNITS AND NUMBER OF ORGANISMS
FOR 5 COMMUNITIES AT STATION IV

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
TOTAL	78	41.6418	---
1. Can one regression line be used for all observations?			
Gain from separate regressions over general regression	4	2.6641	.6660
Deviations from separate regressions	74	38.9777	.5265
("F" = 1.26, answer is Yes)			
2. Can a common slope be used for the separate regression lines?			
Further gains from fitting separate regressions (difference between slopes)	4	6.4060	1.6015
Deviations about separate regressions	70	32.5717	.4653
("F" = 3.44, answer is No)			

FIGURE XIII. The common regression line expressing the phytopigment unit-number of organisms relationship compared with the individual regression lines for 2 communities at Station V.

STATION V

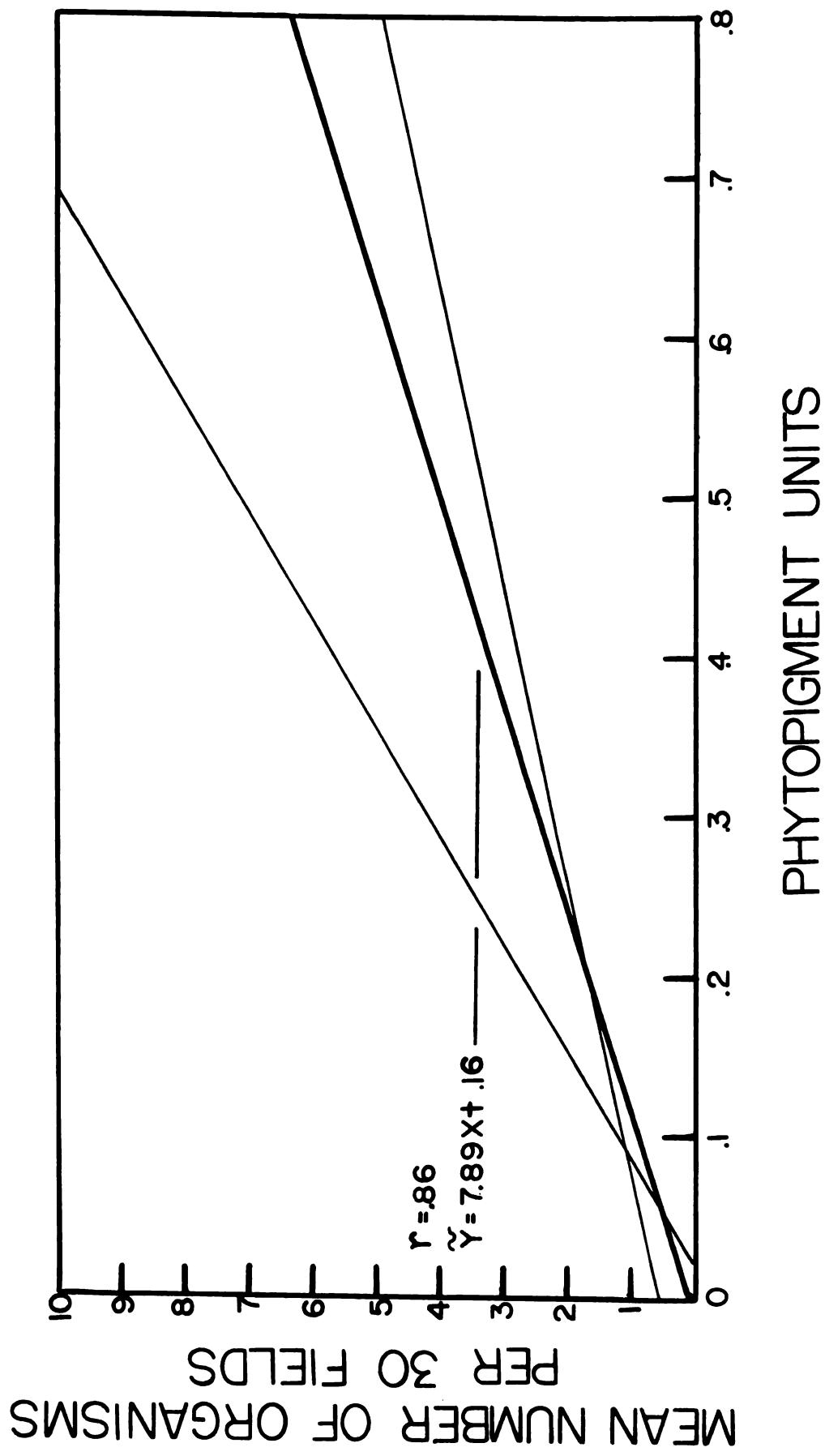


TABLE 8

A COVARIANCE ANALYSIS BETWEEN REGRESSION LINES
FOR PHYTOPIGMENT UNITS AND NUMBER OF ORGANISMS
FOR 2 COMMUNITIES AT STATION V

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
TOTAL	38	17.0442	.4485
1. Can one regression line be used for all observations?			
Gain from separate regressions over general regression	1	1.0709	1.0709
Deviations from separate regressions	37	15.9733	.4317
("F" = 2.48, answer is Yes)			
2. Can a common slope be used for the separate regression lines?			
Further gains from fitting separate regressions (difference between slopes)	1	9.4889	9.4889
Deviations about separate regressions	36	6.4844	.1801
("F" = 52.68, answer is No)			

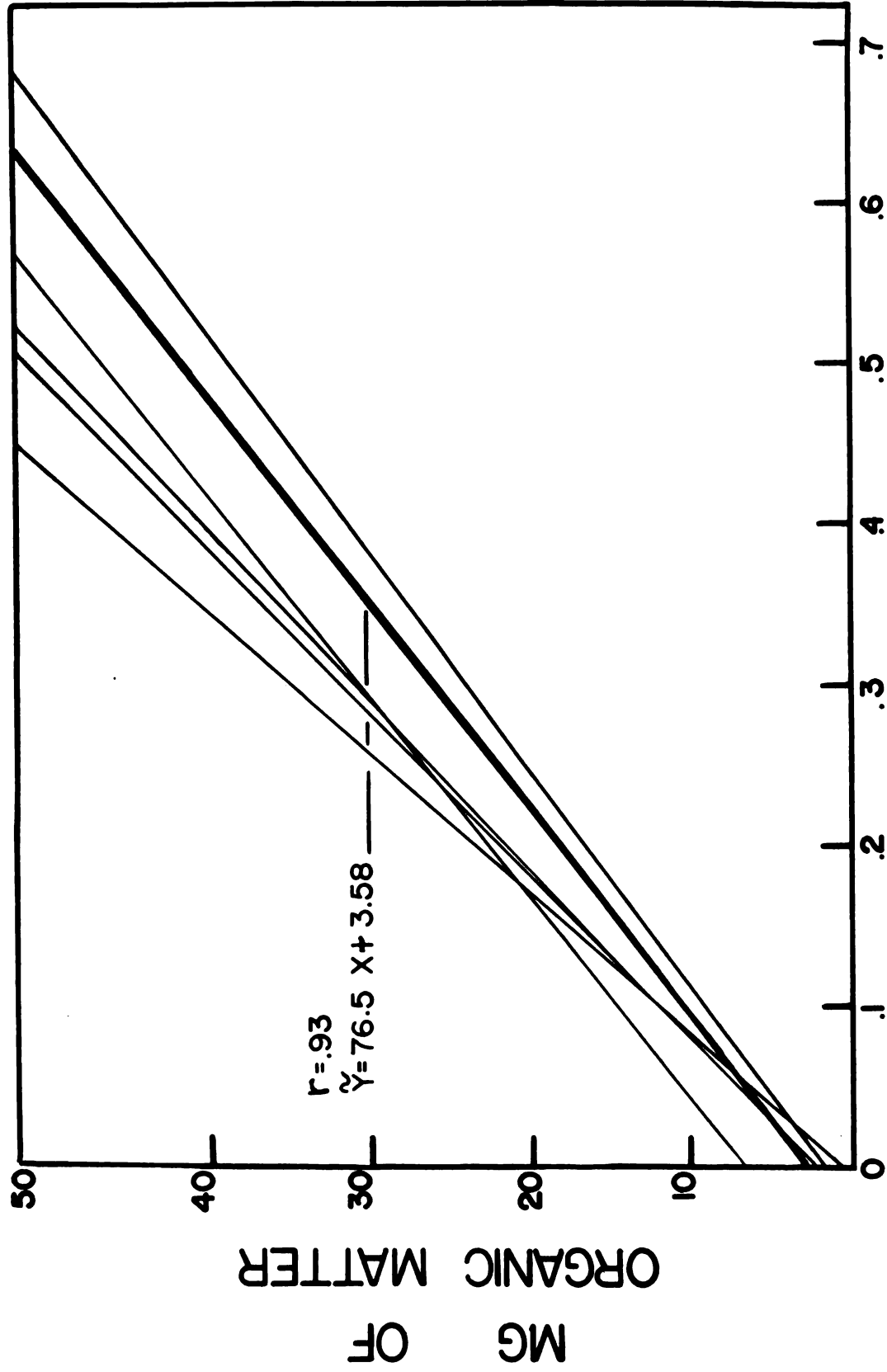
compared with the common regression line in Figures X through XIII.

The relation between the phytopigment unit and weight of organic matter. A good correlation (.93) was found between the phytopigment unit-weight of organic matter relationship (Fig. XIV). Taxonomic work pointed out that five distinct communities developed on the artificial substrates from July, 1958 through February, 1959. A covariance analysis was used to ascertain the effect of community change on the common linear regression line, $Y = 7.65X + 3.58$. The results of the test indicate that one regression line cannot be used to estimate the weight of organic matter from the five communities but a common slope could be used for the separate regression lines (Table 9). In other words there is evidence that community changes significantly effect the relationship between the weight of organic matter and the phytopigment units.

The seasonal changes in levels of production may be responsible for rejection of the hypothesis that one regression line can be used to estimate the weight of organic matter from the phytopigment unit. Levels of productivity during the summer are higher than levels of productivity during the winter (Fig. XV). Walter and Lev (1953) state that if a single common line fits all the communities, the regression estimates based on deviations

FIGURE XIV. The common regression line expressing the phytopigment unit-weight of organic matter relationship compared with the individual regression lines for 5 communities at Station IV

STATION IV



PHYTOPIGMENT UNITS

TABLE 9

A COVARIANCE ANALYSIS BETWEEN REGRESSION LINES
FOR PHYTOPIGMENT UNITS AND WEIGHT OF ORGANISMS
FOR 5 COMMUNITIES AT STATION IV

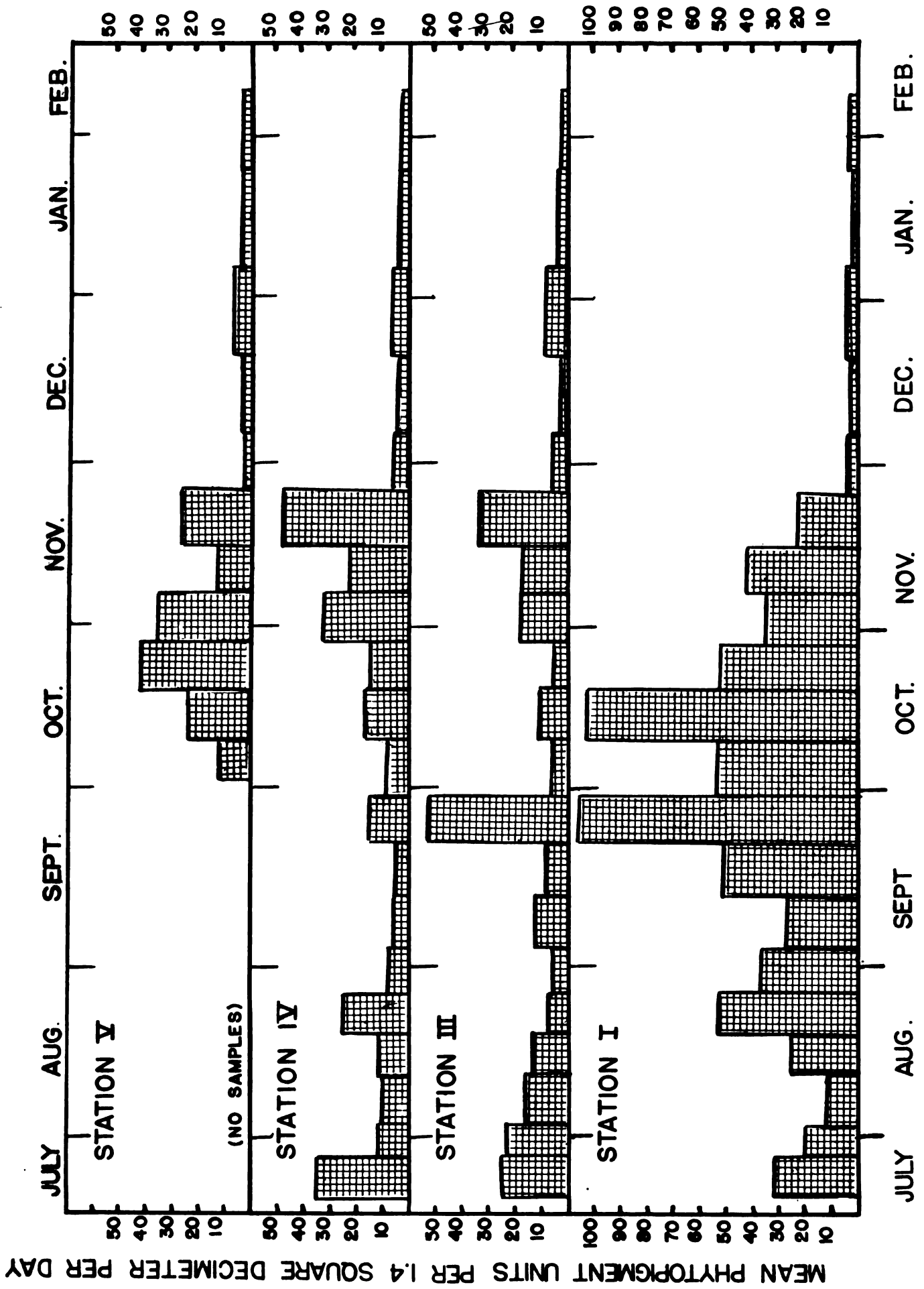
Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
TOTAL	78	839.48	---
1. Can one regression line be used for all observations?			
Gain from separate regression over general regression	4	349.66	87.4150
Deviation from separate regression	74	489.82	6.6192
("F" = 13.206, answer is No)			
2. Can a common slope be used for the separate regression lines?			
Further gains from fitting separate regressions (difference between slopes)	4	41.23	10.3075
Deviations about separate regressions	70	448.59	6.4084
("F" = 1.61, answer is Yes)			

within groups from a line with a common slope. The low level of productivity occurring during the winter months would be significantly different from the common mean and the common line. This can be depicted graphically by five parallel lines with a common slope but one of these lines significantly lower than the other four lines. The lower line in this case represents the low level of winter production.

The development of a reliable predictor equation for estimating the amount of organic matter from the phytopigment unit would be an excellent tool for estimating primary productivity. Any estimation of the amount of organic matter produced on a substrate involves considerable laboratory time. The phytopigment unit can be obtained in a short period of time. However, the weight of organic matter can be converted into energy units and the efficiency of primary producers can be estimated. The predictor equation calculated in this experiment for estimating the weight of organic matter of diatoms from the phytopigment unit can be used except during low levels of production.

Variation in primary production. The aufwuchs production in the Red Cedar River near Williamston, Michigan demonstrated both seasonal variation and variation between individual stations (Fig. XV). Brehmer (1958) indicated that there was a decrease in production of organic material

Figure XV. Levels of production from July 19, 1958 to February 8, 1959 expressed in phytopigment units per 1.4 square decimeters per day.



1958

1959

through the fall period in 1957 and an absence of the characteristic autumn maximum frequently recorded for a lentic environment. A general increase in phytopigment production was recorded for the autumn period in 1958. A sharp decrease in phytopigment production was evident as ice cover developed on the river system. During the winter period the ice cover reached a maximum thickness of 14 inches in Deer Creek and was frequently covered with 12 inches of snow. This excluded a large portion of the available light from the producer organisms and greatly reduced primary production.

Using a randomized block experiment with 4 phytopigment units within a cell, a two-way analysis of variance was made to statistically determine variability in production. The results show that there is significant difference in means between stations, between dates, and the interaction between stations and dates (Table 10 and Table 12). Duncan's Multiple Range Test (1955) was utilized to ascertain which station means were significantly different from one another and which were not. The results in Tables 11 and 13 indicate that the production between sampling stations in the mainstream is not significantly different but Deer Creek shows significantly greater production than found at any station in the river.

TABLE 10
ANALYSIS OF VARIANCE OF THREE STATIONS IN THE
RED CEDAR WATERSHED FROM JULY 19, 1958 TO
SEPTEMBER 30, 1958

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	"F"
TOTAL	5,075,764	107	--	--
Cells	3,975,611	26	152,908.1	11.258
Dates	1,756,687.3	8	219,585.9	16.167
Stations	1,005,553.5	2	502,766.8	37.017
Dates x Stations	1,213,390.2	16	75,836.1	5.584
Residual (error)	1,100,153	81	13,582.1	--

1. Are the means between dates equal?
("F" = 16.17, answer is No)
2. Are the means between stations equal?
("F" = 37.02, answer is No)
3. Are the means from the interaction between
dates and stations equal?
("F" = 5.58, answer is No)

TABLE 11

DUNCAN'S MULTIPLE RANGE TEST SHOWING SIGNIFICANT
DIFFERENCES BETWEEN STATION MEANS FROM
JULY 19, 1958 TO SEPTEMBER 30, 1959

Standard Error of a Station Mean

$$S_m = \sqrt{\text{Residual}/4} = \sqrt{13,582.1/4} = \sqrt{3,395.53} = 58.24$$

Station Means Ranked in Order

IV	III	I
109.2	135.9	325.9

Shortest Significant Ranges

p:	(2)	(3)
5% Table Values	2.86	3.01
Rp:	166.57	175.30

$$\begin{aligned} \left\{ \begin{array}{l} \text{I} - \text{IV} \\ \text{I} - \text{III} \end{array} \right\} &= \begin{array}{l} 325.9 - 109.2 = 216.7 \\ 325.9 - 135.9 = 190.0 \end{array} \begin{array}{l} > 175.30 \\ > 166.57 \end{array} \text{ sig. dif.} \\ (\text{III} - \text{IV}) &= 135.9 - 109.2 = 26.7 < 166.57 \end{aligned}$$

TABLE 12
ANALYSIS OF VARIANCE OF FOUR STATIONS IN THE
RED CEDAR WATERSHED FROM OCTOBER 1, 1958
TO FEBRUARY 8, 1959

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	"F"
TOTAL	6,605,795.9	175	---	--
Cells	5,956,978.2	43	138,534.4	28.184
Dates	2,541,395.1	10	254,139.5	51.705
Stations	758,719.0	3	252,906.3	51.453
Dates x stations	2,656,864.1	30	88,562.1	18.018
Residual (error)	648,817.7	132	4,915.3	

1. Are the means between dates equal?
("F" = 51.70, answer is No)
2. Are the means between stations equal?
("F" = 51.45, answer is No)
3. Are the means from the interaction between
dates and stations equal?
("F" = 18.02, answer is No)

TABLE 13

DUNCAN'S MULTIPLE RANGE TEST SHOWING SIGNIFICANT
DIFFERENCES BETWEEN STATION MEANS FROM
OCTOBER 1, 1958 TO FEBRUARY 8, 1959

Standard Error of a Station Mean

$$S_m = \sqrt{\text{Residual}/4} = \sqrt{4,915.3/4} = \sqrt{1228.8} = 35.01$$

Station Means Ranked in Order

III	IV	V	I
113.73	147.43	148.20	284.75

Shortest Significant Ranges

p:	(2)	(3)	(4)
5% Table Values	2.86	3.01	3.10
Rp:	100.10	105.35	112.50

{ I - III }	=	284.75 - 113.73 = 171.02	➤ 112.50	Sig. Dif.
{ I - IV }	=	284.75 - 147.43 = 137.32	➤ 105.35	Sig. Dif.
{ I - V }	=	284.75 - 148.20 = 133.73	➤ 100.10	Sig. Dif.
{ V - III }	=	148.20 - 113.73 = 34.97	⚡ 105.35	
{ V - IV }	=	148.20 - 147.43 = 1.27	⚡ 100.10	
{ IV - III }	=	147.43 - 113.73 = 33.70	⚡ 100.10	

The nutrient levels in the mainstream of the watershed are in gross abundance compared to those found in the tributary according to Mr. Robin Vannote, a graduate student studying the nutrient levels in the Red Cedar River watershed. He also points out that there is a greater stability of physical and chemical conditions in the mainstream than found in the tributary. However, organic production was found to be greater in the tributary even under seemingly adverse conditions.

Solar radiation. The effect of light intensity, that amount of energy reaching the earth's surface, has not been studied for the lotic environment. It has been shown that the rate of photosynthesis in a lentic environment is frequently lower at the surface than at 3 meters' depth (Nelson and Edmonson, 1955; Schomer and Juday, 1935; Manning and Juday, 1941). These observations are interpretable on the basis that the saturation intensity of light for photosynthesis by a number of algae is quite low relative to the intensity of full sunlight, and moreover actual inhibition due to photo-inactivation of the photosynthetic mechanism may take place in bright light. However, certain littoral algae species do not show inhibition at high light intensities (Manning, Juday, and Wolf, 1938; McMillan and Verduin, 1935).

Precise estimates of light intensity were not taken at each sampling site, but light data were obtained from

a pyrheiliometric station 10 miles from the sampling area. It seems that the photosynthetic rate is correlated with the energy input rate (Fig. XVI). Moreover, there is evidence that light intensity does not inhibit the aufwuchs communities. The levels of production were significantly higher during the summer in Deer Creek which had no shade cover than the levels of production in the main-stream which had shade cover. When the foliage was completely removed by the end of October the differences between all stations in the level of production were negligible (Fig. XV). Apparently the producers are protected from the inhibitory effect of light intensity by the color and turbidity associated with warm-water streams.

A characteristic fall pulse in the lotic environment may be a result of two interacting factors (1) an increase in the energy input rate due to the removal of shade cover, and (2) an increase in the nutrient levels due to a decrease in the volume flow. However, if the water levels are raised sufficiently by rainfall during this period, a subsequent increase in turbidity and the dilution of the nutrient levels would eliminate the possibility for a fall maximum in production.

The low levels of production in the winter can be attributed to ice cover which reduces the amount of energy available to the producer complex. Following the winter solstice which occurs about the 20th of December, a gradual

Figure XVI. Mean accumulative amounts of organic matter per 1.4 square decimeters per day per sampling period and gram-calories per square centimeter per day per sampling period plotted against time.

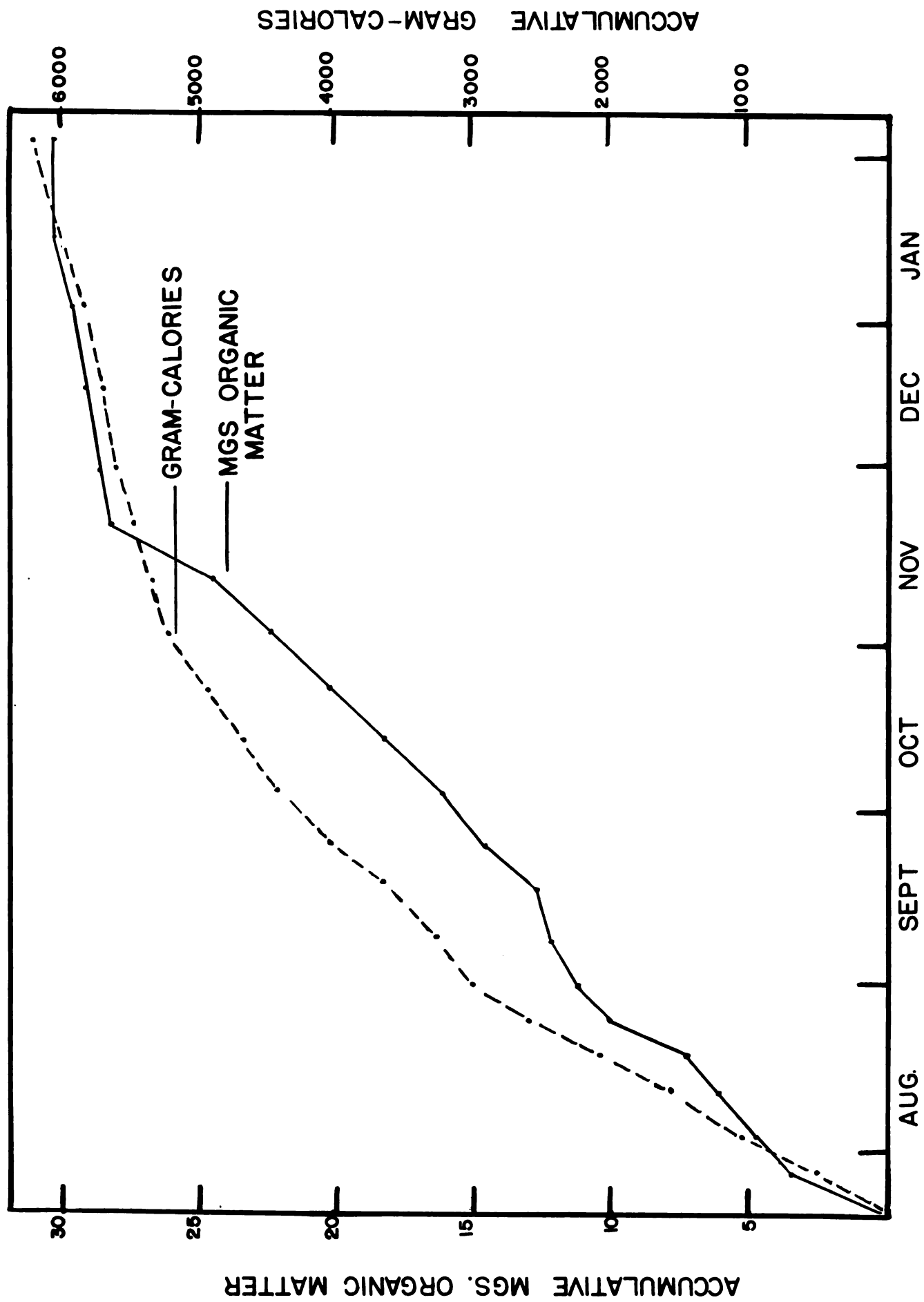


TABLE 14

THE AVERAGE LIGHT EXPRESSED IN GRAM-CALORIES
PER SQUARE CENTIMETER PER DAY DURING EACH
SAMPLING PERIOD

Dates	gm-cal/sq. cm/day
7-20-58 to 7-26-58	587.0
7-27-58 to 8-2-58	475.5
8-3-58 to 8-11-58	535.3
8-12-58 to 8-18-58	562.4
8-19-58 to 8-26-58	448.1
8-27-58 to 9-3-58	399.6
9-4-58 to 9-11-58	345.7
9-12-58 to 9-21-58	359.9
9-22-58 to 9-30-58	350.1
10-1-58 to 10-10-58	355.4
10-11-58 to 10-19-58	326.1
10-20-58 to 10-28-58	219.8
10-29-58 to 11-7-58	261.9
11-8-58 to 11-16-58	119.0
11-17-58 to 11-26-58	156.8
11-27-58 to 12-6-58	111.4
12-7-58 to 12-20-58	132.4
12-21-58 to 1-5-59	133.3
1-6-59 to 1-25-59	144.2
1-26-59 to 2-8-59	257.1

increase in light intensity occurs until March 20 when the period of light and darkness are the same. The ice cover increases throughout the winter and subsequent snow cover does not allow the producers to respond to the increase in light intensity on the earth's surface. After the ice disappears and the turbid spring floods recede, a characteristic spring maximum may occur (Brehmer, 1958).

SUMMARY

Four sampling sites were established in the Red Cedar watershed near Williamston, Michigan. Artificial substrates, plexiglass plates with an area of 1.4 square decimeters, were used to sample the aufwuchs communities from July, 1958 through February, 1959. Taxonomic investigation showed that the substrates were not selective, the same dominant organisms were found on both the artificial substrates and the natural substrates in the river.

A marked periodicity occurred in the area studied. The sampling site in Deer Creek showed the greatest number of dominant communities in the 8-month sampling period. The mainstream sampling sites showed no major differences in the occurrence of dominant organisms. Diatoms were found to be the principal group of organisms collected, the only other organism collected was a species of green algae.

Good correlations were found between phytopigment units and the number of organisms. Linear predictor equations were calculated for each station and the regression coefficients between stations were found to be similar. In Deer Creek where the greatest number of individual communities developed, it is possible to

estimate the number of organisms from phytopigment units using a common slope and a common regression line.

A good relationship was found between phytopigment units and the weight of organic matter. A common slope could be used to predict the weight of organic matter of diatom communities from the phytopigment unit. It was hypothesized that a common regression line could not be used throughout the year to estimate the weight of organic matter from the phytopigment unit because of the low level of production during the winter sampling period. The same regression coefficient (common slope) could be used for all communities, only a lower intercept would be needed during the winter sampling period.

There is variability between the tributary and the mainstream, the tributary having significantly higher levels of production in the summer sampling period. No significant differences were found between the three sampling sites in the mainstream. An increase in nutrients from the sewage treatment plant showed no increase in production at the sampling site below the treatment plant compared with the other stations in the river.

A good correlation was found between the rate of energy input and the production of organic matter. The possibility of photo-inactivation from high light intensities was considered and rejected. The sampling site in Deer Creek with no shade cover responded with a greater

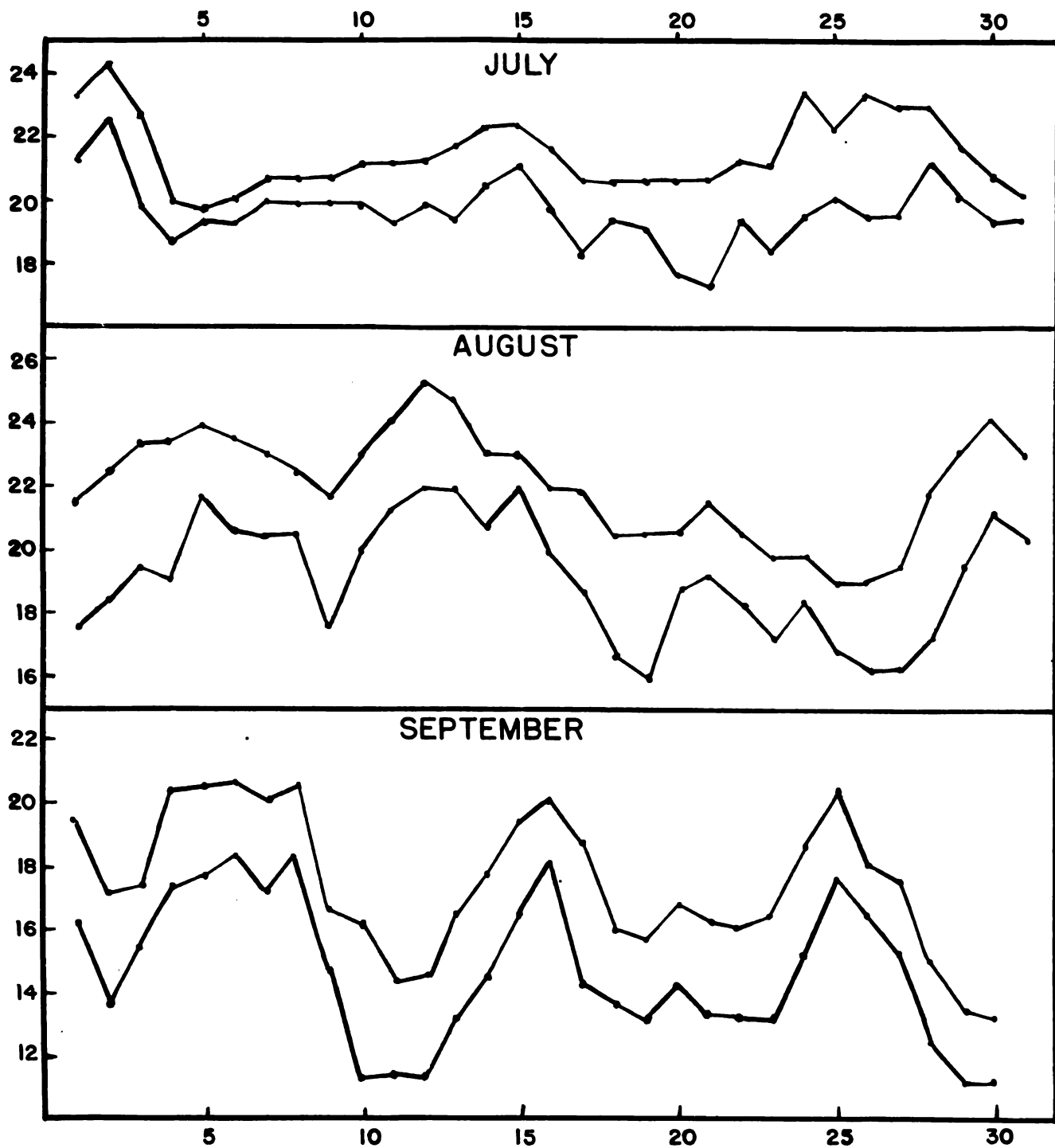
phytopigment production than those sites which had shade cover. After the shade cover was removed in the fall, there were no significant differences in phytopigment production between all the stations. A sharp decrease in phytopigment production was evident as ice cover developed in the watershed.

APPENDICES

APPENDIX A

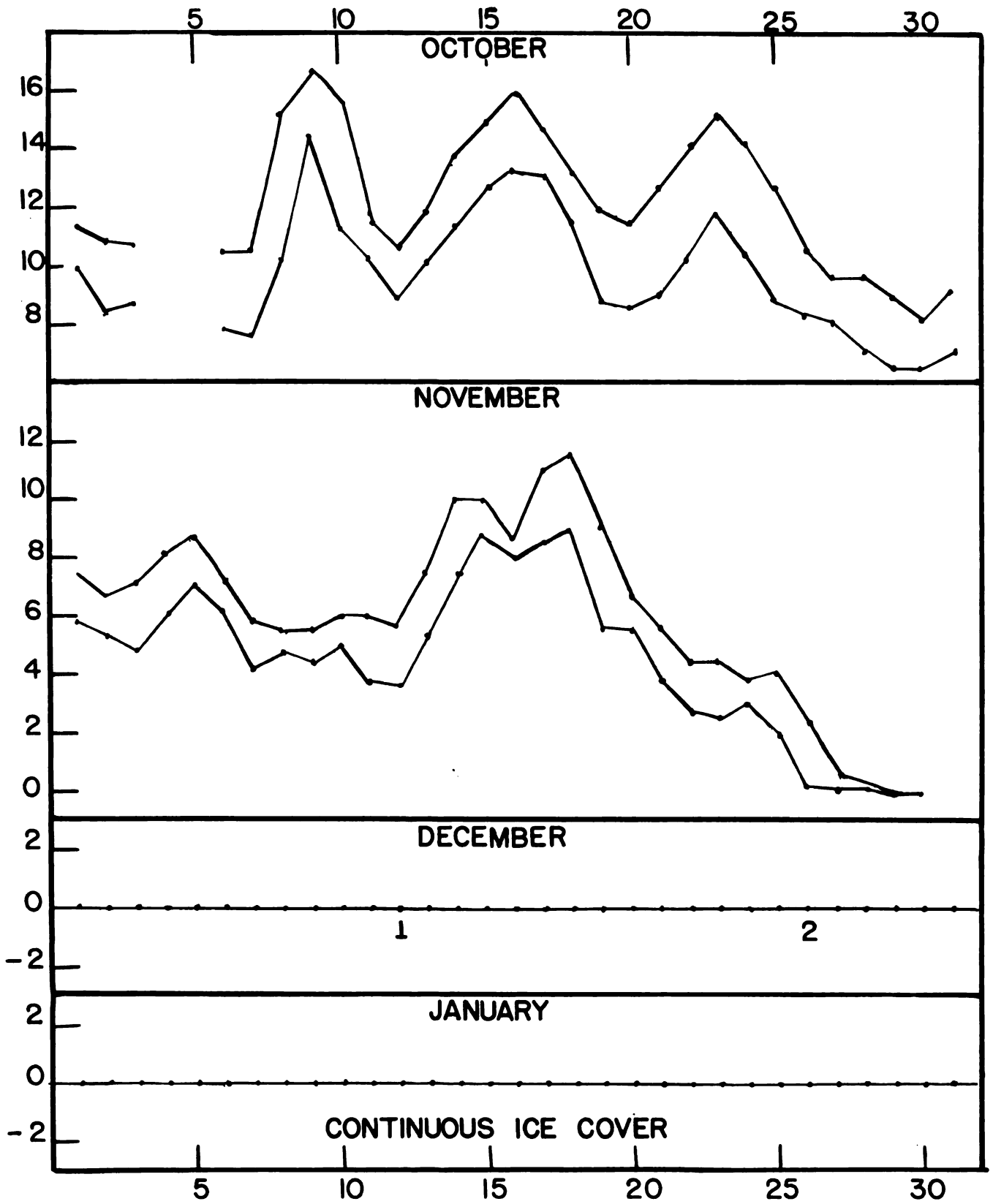
Daily High and Low Water Temperatures
Recorded at Station 10 Miles Upstream
from the Mouth of the Red Cedar River

DATE



DATE

86



1 ICE COVER AT STATION I&V

2 CONTINUOUS ICE COVER AT ALL STATIONS

APPENDIX B

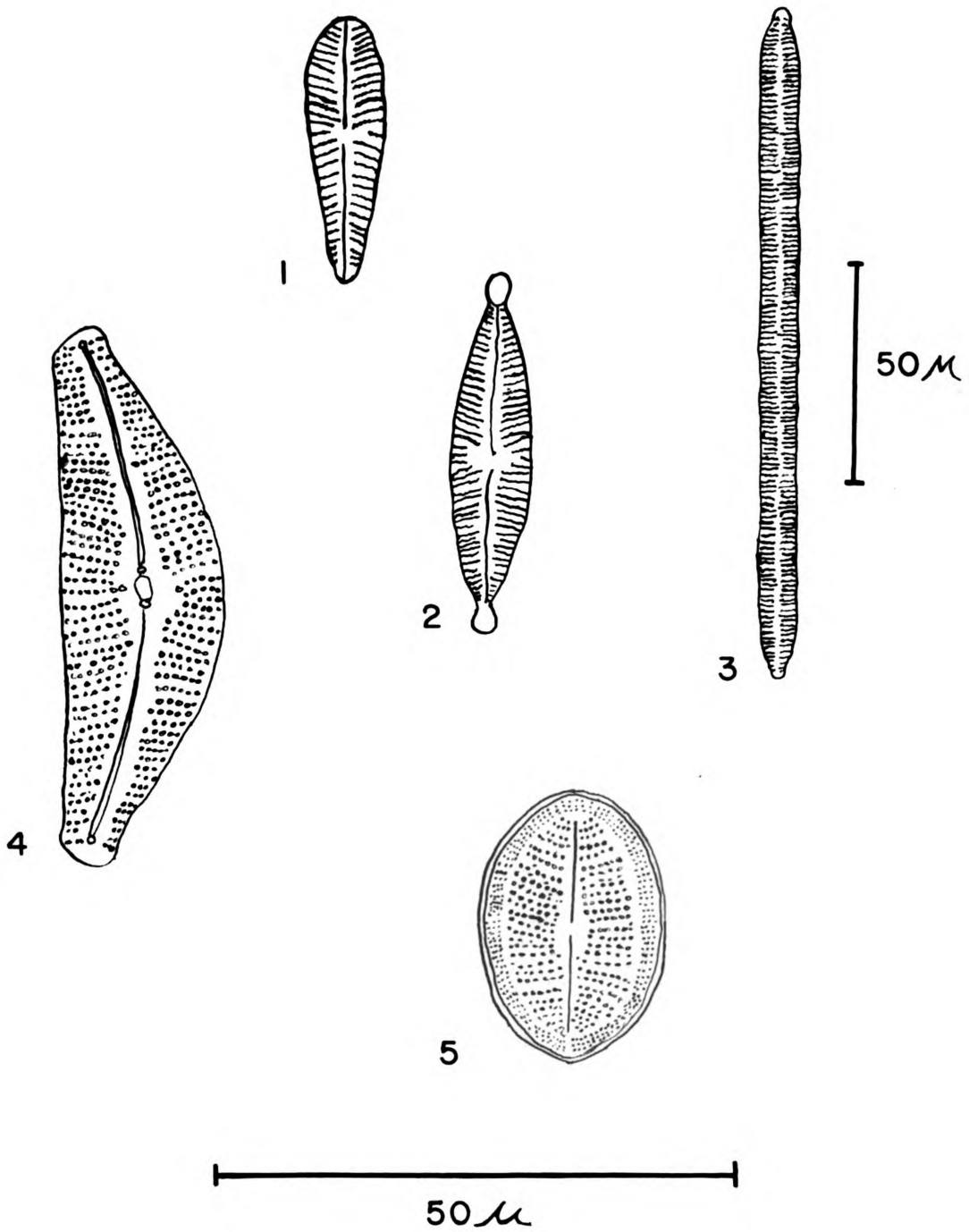
Plates Showing Abundant and Rare
forms of Diatoms Occurring in
the Red Cedar Watershed

DESCRIPTION OF PLATE I*

1. Gomphonema olivaceum Ehrenb. 11.5 striae in 10 u.
2. Navicula cryptocephala Kutz. var. intermedia.
11-13 striae in 10 u.
3. Synedra ulna var. aequalis Kutz. 8-10 striae in 10 u.
4. Cymbella tumida Breb. 9.5 striae in 10 u.
5. Cocconeis placentula Ehrenberg.

*The plates were taken from Smith (1955).

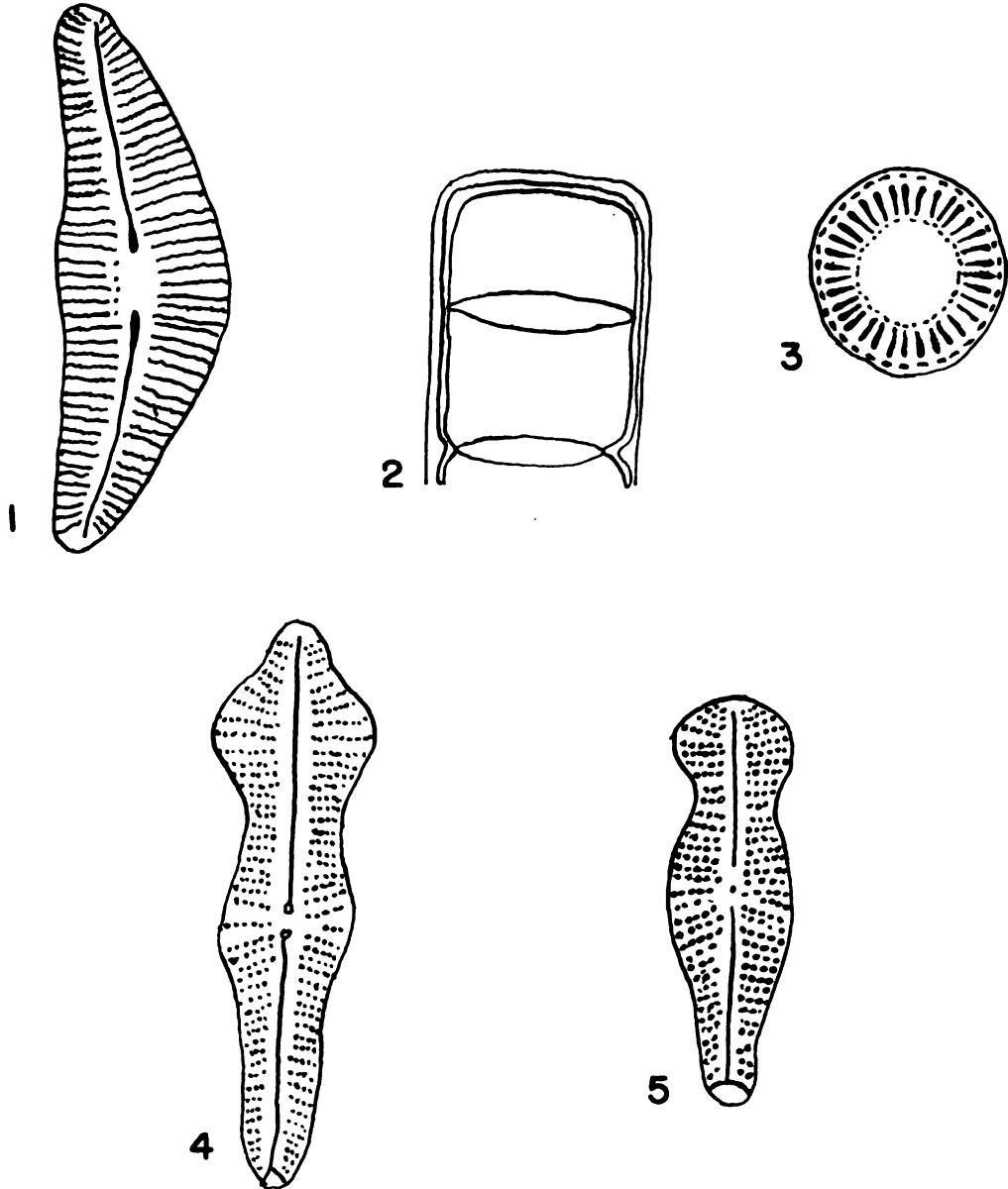
PLATE I



DESCRIPTION OF PLATE II

1. Cymbella cistula (hempr.) Van Heurck. 8-9 striae in 10 u.
2. Melosira varians Ag.? Diameter of valve 18 u.
3. Cyclotella meneghiniana Kutz.? Diameter of valve 19 u.
4. Gomphonema acuminatum var. laticeps Ehrenb. 9.5 striae in 10 u.
5. Gomphonema constrictum Ehrenb. 10-12 striae in 10 u.

PLATE II



50 μ

APPENDIX C

List of Dominant and Rare Species
Occurring on Natural and Artificial
Substrates in the Red Cedar Watershed

Dominants

Cymbella tumida
Navicula cryptocephala
Cocconeis placentula
Diatoma hiemale
Cyclotella meneghiniana
Synedra ulna
Gomphonema olivaceum

Rare Occurrence

Cymbella triangulum
Cymbella cistula
Cymbella spp.
Gomphonema constrictum
Gomphonema acuminatum var. laticeps
Melosira varians
Microspora sp.
Navicula radiosa
Navicula spp.
Amphora ovalis
Amphora sp.
Cymatopleura solea var. vulgaris
Gyrosigma kuetzingii
Rhoicosphenia curvata
Synedra sp.

This list is based on the Taxonomic keys presented in Tiffany and Britton (1952). The dominant diatoms have been identified to species and the algae that were of rare occurrence have been identified as far as possible or practical in the limited time available.

APPENDIX D

List of Quantitative Units in a Chronological
Sequence Taken from Artificial Substrates from
4 stations in the Red Cedar Watershed

STATION I

Date	Sample Number	Kletts	Phyto. Units	Mean No. Organism per 30 Fields
7-26 58	1	86	.172	2.24
	2	140	.295	2.40
	3	118	.241	1.23
	4	172	.403	4.64
8-2-58	1	36	.072	0.72
	2	43	.086	4.68
	3	80	.160	3.03
	4	119	.243	1.56
8-11-58	1	32	.064	0.34
	2	36	.072	0.60
	3	58	.116	0.68
	4	31	.062	0.24
8-18-58	1	67	.134	2.12
	2	41	.082	1.22
	3	103	.206	1.58
	4	120	.245	2.36
8-26-58	1	24	.048	1.54
	2	36	.072	3.08
	3	175	.415	4.16
	4	258	.910	8.68
9 3-58	1	76	.152	3.18
	2	72	.144	3.38
	3	185	.440	8.04
	4	165	.380	5.70
9-11-58	1	55	.110	2.60
	2	60	.120	1.19
	3	122	.257	3.20
	4	155	.340	6.55
9-21-58	1	162	.368	2.57
	2	202	.532	4.20
	3	160	.360	4.37
	4	206	.556	6.64
9-30-58	1	264	.952	14.37
	2	212	.600	12.37
	3	268	.984	7.37
	4	300	1.340	19.70
10-10-58	1	130	.265	3.04
	2	240	.760	4.24
	3	181	.435	3.99
	4	232	.696	5.34

STATION I

Date	Sample Number	Kletts	Phyto. Units	Mean No. Organism per 30 Fields
10-19-58	1	270	1.000	14.37
	2	270	1.000	10.93
	3	232	.696	9.87
	4	278	1.080	9.40
10-28-58	1	185	.455	5.53
	2	195	.500	4.73
	3	183	.445	6.95
	4	197	.508	5.74
11-7-58	1	184	.450	4.78
	2	177	.421	5.20
	3	114	.232	2.80
	4	165	.380	2.90
11-16-58	1	202	.532	5.93
	2	202	.532	5.33
	3	111	.223	3.70
	4	144	.311	4.97
11-26-58	1	159	.356	1.83
	2	91	.182	1.27
	3	76	.152	0.63
	4	131	.268	1.60
12-6-58	1	8	.016	0.28
	2	26	.052	0.54
	3	19	.038	0.41
	4	17	.034	0.43
12-20-58	1	18	.036	0.45
	2	18	.036	1.05
	3	32	.065	--
	4	12	.024	0.39
1-6-59	1	24	.048	0.31
	2	30	.060	0.20
	3	15	.030	0.19
	4	19	.038	0.11
1-25-59	1	10	.020	0.11
	2	13	.026	0.17
	3	10	.020	0.13
	4	8	.016	0.11
2-8-59	1	19	.038	0.11
	2	6	.012	0.09
	3	12	.024	0.05
	4	9	.018	0.15

STATION III

Date	Sample Number	Kletts	Phyto. Units	Mean No. Organism per 30 Fields
7-26-58	1	102	.204	3.00
	2	60	.120	1.08
	3	70	.140	1.20
	4	80	.160	2.04
8-2-58	1	90	.180	2.08
	2	58	.116	1.56
	3	58	.116	3.64
	4	99	.198	1.08
8-11-58	1	103	.206	5.12
	2	53	.106	2.72
	3	45	.090	1.04
	4	64	.128	2.08
8-18-58	1	41	.082	1.32
	2	50	.100	1.06
	3	24	.048	0.32
	4	41	.082	0.68
8-26-58	1	22	.044	0.58
	2	30	.060	0.34
	3	18	.036	0.56
	4	23	.046	0.38
9-3-58	1	18	.036	0.22
	2	11	.022	0.18
	3	18	.036	0.36
	4	24	.048	0.52
9-11-58	1	25	.050	0.50
	2	77	.154	0.97
	3	29	.058	0.63
	4	23	.046	0.53
9-21-58	1	30	.060	0.77
	2	51	.102	1.70
	3	37	.074	0.77
	4	49	.098	0.77
9-30-58	1	220	.630	4.73
	2	172	.406	3.83
	3	185	.455	4.27
	4	159	.356	4.90
10-10-58	1	29	.058	0.40
	2	24	.048	0.42
	3	44	.088	0.54
	4	29	.058	0.39

STATION III

Date	Sample Number	Kletts	Phyto. Units	Mean No. Organism per 30 Fields
10-19-58	1	67	.134	1.37
	2	49	.098	1.00
	3	49	.098	0.47
	4	22	.044	0.83
10-28-58	1	19	.038	--
	2	33	.066	--
	3	30	.060	--
	4	8	.016	--
11-7-58	1	47	.094	1.40
	2	105	.210	2.03
	3	108	.216	2.07
	4	119	.243	2.10
11-16-58	1	101	.202	2.03
	2	63	.126	1.57
	3	80	.160	1.93
	4	84	.168	1.60
11-26-58	1	165	.380	3.13
	2	192	.488	3.47
	3	96	.192	2.25
	4	152	.331	1.69
12-6-58	1	36	.072	0.12
	2	24	.048	0.17
	3	20	.040	0.14
	4	46	.092	0.21
12 20-58	1	25	.050	0.17
	2	48	.096	0.21
	3	24	.048	0.26
	4	22	.044	0.19
1-5-59	1	53	.106	0.81
	2	75	.150	0.99
	3	75	.150	0.88
	4	74	.148	0.84
1-25-59	1	28	.056	0.39
	2	32	.064	0.20
	3	22	.044	0.24
	4	12	.024	0.34
2-8-59	1	21	.042	0.09
	2	11	.022	0.23
	3	16	.032	0.31
	4	30	.060	0.19

STATION IV

Date	Sample Number	Kletts	Phyto. Units	Mg Organic Matter	Mean No. Organism per 30 Fields
7-26-58	1	142	.303	26.2	2.60
	2	67	.134	22.1	3.20
	3	119	.243	26.1	3.68
	4	142	.303	28.2	5.76
8-2-58	1	40	.080	9.3	0.68
	2	37	.074	8.2	0.40
	3	35	.070	7.0	1.24
	4	43	.086	7.2	2.44
8-11-58	1	38	.076	11.2	0.62
	2	36	.072	8.1	0.22
	3	33	.066	5.3	0.36
	4	58	.116	17.3	0.40
8-18-58	1	40	.080	7.9	0.54
	2	25	.050	5.1	0.46
	3	33	.066	8.2	0.56
	4	35	.070	7.0	0.78
8-26-58	1	88	.176	23.2	0.80
	2	70	.140	16.6	0.56
	3	90	.180	17.4	1.04
	4	112	.226	19.7	2.24
9-3-58	1	36	.072	5.3	0.90
	2	31	.062	7.1	0.70
	3	19	.038	6.8	0.40
	4	40	.080	12.4	1.02
9-11-58	1	30	.060	5.8	0.80
	2	21	.042	4.2	0.67
	3	26	.052	6.3	0.68
	4	31	.062	9.4	0.88
9-21-58	1	32	.064	6.3	0.70
	2	27	.054	7.2	0.40
	3	32	.064	8.3	0.64
	4	26	.052	7.2	0.59
9-30-58	1	30	.060	8.2	0.50
	2	67	.134	20.2	0.44
	3	54	.108	14.3	1.67
	4	124	.315	28.2	1.43
10-10-58	1	39	.078	11.1	0.63
	2	55	.110	21.2	0.70
	3	67	.134	16.3	0.87
	4	33	.066	7.3	0.57

STATION IV

Date	Sample Number	Kletts	Phyto. Units	Mg Organic Matter	Mean No. Organism per 30 Fields
10-19-58	1	75	.150	20.1	1.32
	2	70	.140	16.6	0.74
	3	55	.110	18.3	0.39
	4	119	.243	26.2	1.90
10-28 58	1	75	.150	16.5	1.14
	2	64	.128	19.3	0.79
	3	70	.140	20.5	0.95
	4	75	.150	17.2	1.50
11-7-58	1	128	.261	18.4	3.28
	2	125	.255	20.2	1.39
	3	135	.280	22.6	2.55
	4	156	.342	23.6	2.39
11-16-58	1	107	.214	16.1	2.13
	2	89	.178	19.2	1.20
	3	58	.116	17.3	1.60
	4	172	.406	29.2	3.03
11-26-58	1	198	.512	39.6	3.63
	2	109	.218	19.3	4.45
	3	206	.556	42.2	2.37
	4	202	.506	43.1	3.29
12-6-58	1	30	.060	5.2	0.51
	2	47	.094	10.1	0.29
	3	23	.046	4.1	0.42
	4	15	.030	4.2	0.51
12-20-58	1	14	.028	3.3	0.21
	2	22	.044	5.1	0.12
	3	21	.042	4.3	0.35
	4	21	.042	4.0	0.38
1-5-59	1	38	.076	6.8	0.99
	2	20	.040	4.5	0.63
	3	54	.108	15.9	0.75
	4	46	.092	8.3	0.79
1-25-59	1	32	.064	5.1	0.48
	2	31	.062	6.3	0.34
	3	15	.030	4.2	0.23
	4	30	.060	6.8	0.41
2 8-59	1	15	.030	3.6	0.29
	2	12	.024	4.2	0.28
	3	17	.034	4.2	0.21
	4	19	.038	3.7	0.45

STATION V

Date	Sample Number	Kletts	Phyto. Units	Mean No. Organism per 30 Fields
10-19-58	1	58	.116	1.60
	2	52	.104	1.07
	3	27	.054	0.87
	4	37	.074	1.37
10-19-58	1	67	.134	1.10
	2	70	.140	1.15
	3	137	.286	1.00
	4	133	.274	1.00
10-28-58	1	147	.319	3.03
	2	156	.344	2.80
	3	187	.465	3.70
	4	165	.380	3.03
11-7 58	1	177	.421	2.93
	2	141	.299	2.50
	3	152	.331	2.13
	4	165	.380	2.53
11-16-58	1	52	.104	0.63
	2	50	.100	0.97
	3	72	.144	1.57
	4	59	.118	1.87
11-26 58	1	113	.229	3.37
	2	145	.315	3.93
	3	120	.245	3.87
	4	111	.223	3.60
12-6-58	1	8	.016	0.12
	2	12	.024	0.11
	3	14	.028	0.18
	4	10	.020	0.12
12-20-58	1	14	.028	0.17
	2	18	.036	0.28
	3	23	.046	0.14
	4	13	.026	0.11
1-5-59	1	63	.126	0.76
	2	50	.100	0.91
	3	32	.064	0.45
	4	45	.090	0.65
1-25-59	1	22	.044	0.62
	2	28	.056	0.49
	3	20	.040	0.36
	4	32	.064	0.29
2-8 59	1	18	.036	0.32
	2	20	.040	0.48
	3	16	.032	0.25
	4	14	.028	0.25

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