BIOLOGICAL RESPONSES OF FERTILIZATION IN A LAKE AND STREAM

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By

LOWELL EDWARD KEUP

AN ABSTRACT

Submitted to the College of Agriculture of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

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Approved Robert C Ball

ABSTRACT

Hoffman Lake, a hard water low production lake, was fertilized in 1954, 1955 and 1956. Previous authors observed some significant changes in the biology. Periphyton production increased during the three years. Plankton production may have increased in 1956. Bottom fauna studies failed to prove conclusive changes. Some species of fish increased in condition during the fertilization period. The year after fertilization, 1957, the condition of the fish returned to or below prefertilization values.

The West Branch of the Sturgeon River carries nutrients out of Hoffman Lake. The fertilization produced periphyton responses in the river. Bottom fauna and fish production increases are doubtful.

In 1957, fertilizer was added directly to the West Branch of the Sturgeon River for eight days. Phosphorus was observed to be carried by the stream in an abnormal way. A period of delay was followed by a period of general stability. After the period of stability, rapid decreases in the stream's phosphorus content were observed.

Periphyton responded with an increase during the period of fertilization. Bottom fauna changes were not observed. Beds of *Chara* spp. contained considerable greater quantities of invertebrates than gravel riffles.

The trout of the West Branch of the Sturgeon indicated differences in populations at the various stations sampled. This was not observed in 1954. Length-weight and body-scale length relationships are statistically different at the stations sampled. Mean length at time of capture and calculated lengths indicate trends towards differences between the stations.

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INTRODUCTION

Since man first realized the importance of fish to his culture he has undoubtedly been interested in increasing his source of fish in both a quantitative and qualitative aspect. For many centuries fish have assumed an important role in the socio-economic structures of various societies. The earliest culture of fishes began in the Orient, many years before Christ, and in time spread westward into Europe and thence onward into the New World.

The English speaking world recognized that there were significant differences in the fish populations soon after the Renaissance. Izaak Walton discussed these differences as early as 1676 in his classic The Compleat Angler. Discussing trout, Walton mentions the difference in size and quality of the fish in several of the streams of Britain.

Man soon attempted to improve his fishing and the fish. The majority of attempts were based on the following methods: (1) propagation, (2) protection, (3) introduction and (4) habitat alteration. Many times these procedures failed to produce the desired results. With increasing demands on our natural resources by a rising population it is necessary to improve the production of our available renewable resources.

Habitat alteration (stream or lake improvement in fisheries management) is one of the techniques being developed in scientific management of our biological resources. Much work has been done in the fields of physically changing our aquatic habitats. Some of the techniques involve the fluctuation of water levels, building of dams and ponds, introduction of shelter and alterations in the channels of streams. Another technique in attempting to increase the productivity of an area, is to add fertilizers to the habitat. This theory is based on the old adage that "all flesh is grass". All animal life is directly or indirectly dependent on plants for its nutrition. By increasing the amount of available plant nutrients one should increase the production of plant life. A larger crop of plant food may then support more animal life.

This technique of fertilization of aquatic areas is not new; it has been used for many centuries in the Orient and for many decades in Europe. At first attempts were restricted to ponds designed for food sources only. Discussions of this technique in carp ponds are presented by Snieszko (1941) and Coker (1954). In this hemisphere foundation work on sport fish ponds and their fertilization was done by Swingle and Smith (1939), Swingle (1947), Ball and Tait (1952) and others.

Fertilization of larger bodies of water is relatively new when compared to ponds; outstanding work has been done by Smith (1948), Ball (1950), Ball and Tanner (1951) and Nelson and Edmondson (1955). Maciolek (1954) provides an adequate review of the fertilization of lentic environments.

In 1954 a project was established on Hoffman Lake, Charlevoix county, to determine the practicality of fertilization of a large, 120 acres, lake with a high calcium carbonate content. This lake was fertilized twice each summer for three consecutive summers (1954-56). The limnological changes were reported on by Alexander (1956), Anton (1957), and Plosila (1958).

Immediate large changes were not observed in the fish populations of Hoffman Lake. It was thought that long term studies of the fish may indicate a significant change. A portion of this thesis discusses the results of fish sampling for the summer of 1957 in Hoffman Lake.

The outlet of Hoffman Lake forms the West Branch of the Sturgeon

River, a trout stream of low productivity. This geographical situation allowed for studies of changes in the potamology of the stream due to the increased nutrients. This work was presented by Grzenda (1955), Colby (1957) and Carr (M.S.). The experimental fertilization of streams is nearly unknown. The author is familiar with only one published article (Huntsman, 1948).

The three previously mentioned studies on the West Branch of the Sturgeon River indicated very little change in the river, except for the immediate vicinity of the lake's outlet. It was hypothesized that this was due to either the rapid uptake of the nutrients and/or the dilution by the larger volume flow downstream.

A project was then established to determine what affect the direct application of a quantity of fertilizer would have on the biology of a stream. This thesis presents a summary of the biological changes resulting from the direct application of inorganic fertilizer to a trout stream. Another Master's thesis is being presented by David Correll (M.S.) covering biochemical aspects of the stream's fertilization.

DESCRIPTION OF THE STUDY AREA

The area of study lies approximately forty miles South of Michigan's Mackinac Straits. Laboratory facilities were established at the Institute for Fisheries Research station on the Pigeon River, approximately thirteen miles East of Vanderbilt, Otsego county. Hoffman Lake lies seven miles to the West of Vanderbilt in Charlevoix county (T.32N., R.4W., Sec. 26, 27, 34 and 35) (Fig. I). The lake has 120 acres of surface with a maximum depth of 22 feet and a mean depth of 10 feet. The lake is 3,330 feet by 2,600 feet, with a shoreline development of 1.2.

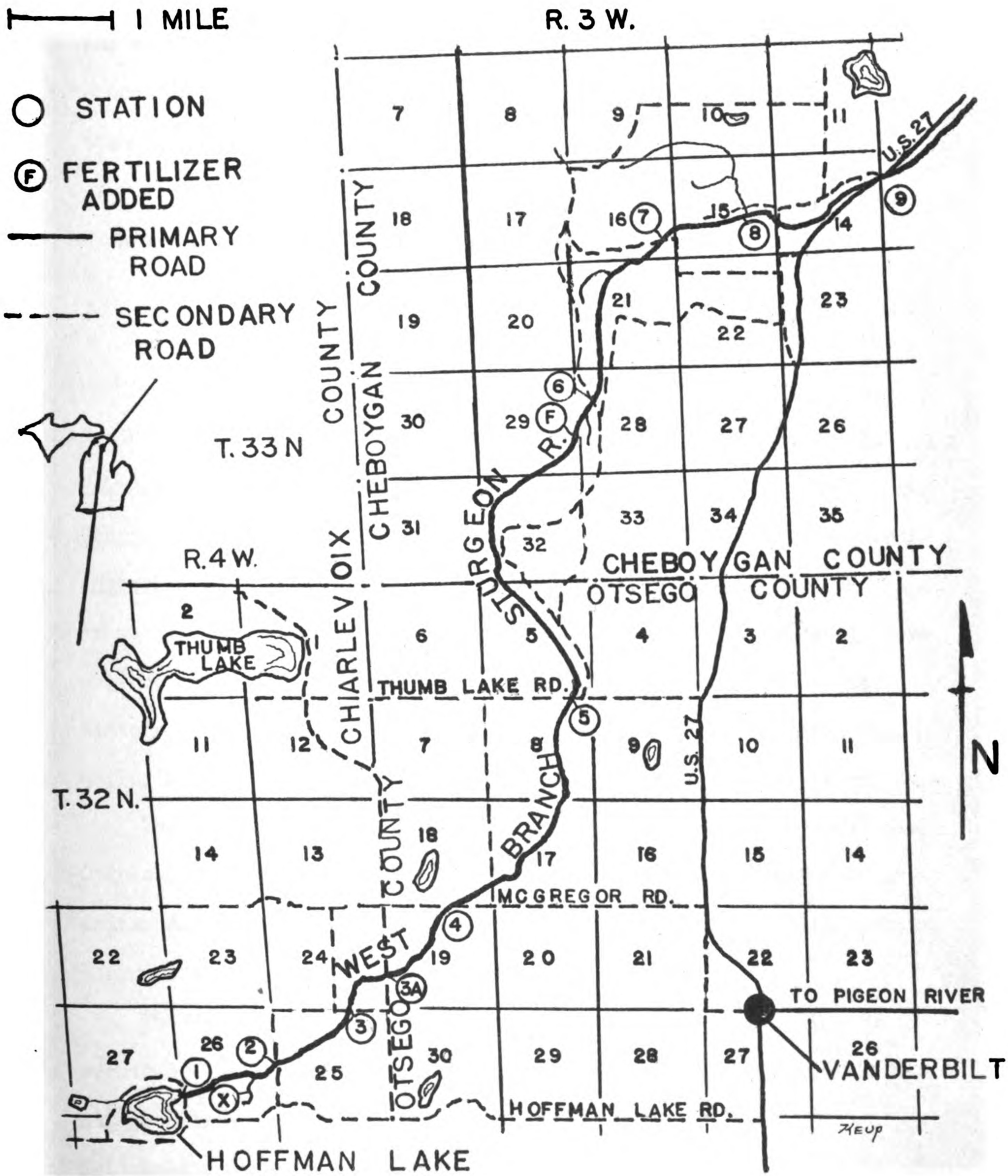
Previous year's data indicate that thermal and chemical stratification is of short duration, if it does occur. The water has approximately 130 p.p.m. alkalinity and pH values in the range of 7.9 to 8.5 (Plosila, 1958). The lake basin is almost entirely covered with marl concretions and softer marl deposits. Plosila (op. cit.) mentions a few shoreline deposits of sand and fibrous peat. The general appearance of the lake is milky-blue, typical of a marl lake. The shoreline is nearly surrounded by logs with heavy marl deposits covering them.

The primary source of water for the lake is through many springs. Springs also feed a small pond, which connects with the lake on the west end via a small creek. Surface water contributions are probably of little importance because of the small watershed.

Plankton consists primarily of Cyanophyta and Chrysophyta. Plosila (1948) recorded the presence of four genera of Chlorophyta following his fertilization treatment, compared to but one genera prior to treatment. The unfertilized complex of blue-green algae and diatoms

Figure I. Map of the West Branch of the Sturgeon River Area, showing stations and major points of access.

WEST BRANCH STURGEON RIVER AREA



is typical of low production, hard-water lakes (Prescott, 1951). The higher aquatic plants are dominated by bulrushes (Scirpus spp.). A limited distribution of white water lilies (Nymphaea spp.) dominates the vegetation of the Western shoreline. Other vegetation is very scarce and consists of scattered plants of Potamogeton spp. and small stands of Chara spp.

The dominate fishes are four species of game fish and one rough fish as follows:

largemouth bass	Micropterus salmoides
rock bass	Ambloplites rupestris
common sunfish	Lepomis gibbosus
yellow perch	Perca flavescens
common sucker	Catostomus commersoni

Roelofs (1941) listed the other fishes present as mimic shiner (Notropis volucellus), creek chub (Semotilus atromaculatus), common shiner (Notropis cornutus), Iowa darter (Poecilichthys exilis), bluntnose minnow (Hyborhynchus notatus) and the log perch (Percina caprodes). The lake is marginal trout water. Two brook trout, Salvelinus fontanalis, were captured in 1954 (Alexander, 1956). Alexander also discusses the history of unsuccessful attempts to introduce montana grayling, Thymallus signifer; rainbow trout, Salmo gairdnerii; and brook trout.

The dominant bottom fauna consists of Ephemeridae, Tendipedidae, Odonata, Sialidae, Amphipoda and Oligochaeta. The mean number of organisms was 132.6 per square foot, with a volume of 0.31 milliliters per square foot in 1956 (Plosila, 1958).

The West Branch of the Sturgeon River arises at the Northeast corner of the lake and flows through its narrow valley to join the Sturgeon River near Wolverine, Cheboygan county. Grzenda (1955) estimated the watershed to cover fourteen square miles. The soils of the watershed are podzolic and developed from limy glacial drift. (Whiteside, Schneider and Cook, 1956). The topography is steep and rolling glacial morainic. The majority of the area is covered with second growth maple and poplar. The upper reaches of the stream has a narrow border of confierous swamp, primarily cedar.

The watershed has a few small dairy farms which provide the relatively small amount of cleared land. Much of the cleared land lies fallow and some has recently been incorporated into tree farms. There are several private summer homes located on Hoffman Lake and a few cottages scattered along the valley. In the vicinity of U.S. highway 27, a few motels and resorts have been developed.

A total of eleven sampling stations has been established along the stream. These stations have been used intermittently in the past four years. Each station will be briefly discussed.

Station 1. This station is in essence the outlet of Hoffman Lake. The water is briefly impounded behind a road fill and passes through twin culverts to form the lotic environment of the stream. The stream is approximately three feet wide at this point and still exhibits characteristics of the lake. The bottom is primarily marl depositions. This station was abandoned in 1957.

Station X. A small tributary that arises from a cluster of small springs and joins the main stream a short distance from Station 2. This station exhibits very cold ground water. The area was used as a control during the years 1954, 1955 and 1956; and was abandoned in 1957.

Station 2. Located at a small bridge approximately one mile below the lake. The stream has gained considerable volume from ground water at this point. The bottom is primarily silt and sand. The river supports brook trout here and has been used for fish sampling for the four years research has been carried on.

Station 3. Located about one-fourth mile due West of the Charlevoix-Otsego county line. The river here is broad and shallow with a heavy silt bottom. This area was at one time the backwater for a now inactive beaver dam. The area supported large quantities of water cress, *Nasturtium officinale*: and some rafts of filamentous algae in August of 1957. Many minnows were observed from the bridge here. The station was abandoned in 1957.

Station 3a. Located at the crossing of the stream by the Charlevoix-Otsego county line road. The stream meanders through dense cedar swamps and in places exhibits a tendency to become morphologically a braided stream. The bottom is made up of gravel interrupted with small expanses of silt and sand. Portions of this area are interlaced with fallen trees. Where logs are in the water, marl deposits are common. Brook trout were readily observed here. This station was established for all types of sampling, except fish, for the summer of 1957. Stream improvement devices are first observed here in the form of an anchored log. These devices increase in number and complexity as one proceeds downstream.

Station 4. Located where the stream crosses McGregor Road in Otsego county. The stream is cut down in its valley here and is surrounded by dense swamp. The bottom is coarse gravels. This area has brook trout along with a few rainbow trout. This station was not used in 1957.

Station 5. Located at the crossing of Thumb Lake Road in Otsego county. The stream here is also surrounded by dense swamp. This station was used for fish sampling in 1954, 1955 and 1956 but was abandoned in 1957. Fishes present are brook, brown (*Salmo trütta*) and rainbow trout.

Station 6. The first station in Cheboygan county. This is locally refered to as the Shingle Mill Bridge and lies approximately seven miles below Hoffman Lake. At this point the river has become considerably larger in both width and volume flow. The volume flow is estimated at thirty cubic feet per second. A small tributary enters a short distance upstream from this point. The river is relatively open and bordered by only a narrow band of swamp. This station was used for all types of sampling in the summer of 1957.

The bottom is composed of gravels and sands with some silt behind stream deflectors. Small patches of Chara spp. and Ranunculus spp. constitute the higher aquatic vegetation present. The immediate vicinity of the bridge has many logs lying in the stream. Fishes present are brook, brown, and rainbow trout. Approximately one-fourth mile upstream from this station the fertilizer treatment was begun.

Station 7. Located at a wooden bridge crossing the stream in section 16, T.33N.,R.3W.. The stream here flows through an area with poplar covered banks and adds to its volume with numerous small springs along its banks and a small tributary stream. The bottom is composed of gravels with some marl conglomerates.

Within the stream, bars have developed from sand and organic detritus. On these bars heavy beds of Chara spp. grow. Other plants present are small stands of Ranunculus spp. and limited numbers of Potamogeton spp. Fishes present here consist of brook, brown and rainbow trout. This station was used for all types of sampling, except fish, in 1957.

Station 8. Located approximately nine miles from the lake. A moderate sized tributary, Fulmer Crrek, enters the stream here. The stream is quite open and banked with poplar trees. The bottom is composed of gravels, flanked with narrow strips of silt supporting Chara spp. and Ranunculus spp.. This station has been used continuously for the past four years. Fishes present are primarily brown and rainbow trout. Brook trout are present but not common.

Station 9. A newly established station in 1957. It is located at the crossing of U. S. Highway 27. The stream and its banks are relatively open here due to some light farming, cottages and a roadside park. This station was used for water samples only, for a short period before and during the application of fertilizer.

METHODS AND PROCEDURES

Fertilization

In previous years fertilization of Hoffman Lake was accomplished by pouring the fertilizer into shallow water from the stern of an outboard powered boat. Two applications were made each summer within a short period in late July and early August. The following quantities were added for each summer (Plosila, 1958):

Year	Pounds	Analysis (N-K-P)
1954	5,900	10-10-10
1955	10,000	12-12-12
1956	4,960	12-12-12

In the summer of 1957, the fertilizer was added directly to the stream. Four hundred (400) pounds of diammonium phosphate (Ammonium orthophosphate, mono-H; $(NH_4)_2HPO_4$) was used in the treatment. The analysis of this fertilizer is 21-0-53 (N-K-P). The fertilizer is highly soluble in water. The fertilizer was added at a calculated rate to increase the stream's phosphorus content to 85 parts per billion; from August 8 to August 17.

The fertilizer was preweighted and transported to the point of application in polyethylene bags (11.4 pounds per bag). Each bag was emptied into a large tub and thoroughly mixed with ten gallons of strained river water. This solution was poured into one of two barrels.

One barrel, 55 gallons, was placed in an upright position with its top knocked out. Another barrel, approximately 35 gallons, was placed on its side and held in position by a sawhorse (Fig. II). The two barrels were connected together with a siphon of copper tubing. Two barrels were used to minimize the difference in head, thereby providing

Figure II. Photograph showing arrangement of the equipment used in fertilizing the West Branch of the Sturgeon River.

for a more uniform output of fertilizer.

A polyethylene tube was then used to siphon the solution from the horizontal barrel to near stream level. This siphon was attached to a filter made of copper tubing and a quart jar (Fig. III). A nozzle was joined to the filter. This nozzle was prepared by heating a piece of polyethylene tubing and drawing it out to a fine diameter. By clipping this nozzle, short distances at a time, the flow of the jet into the stream was calibrated.

It was necessary to provide a packing in the filter, which was originally designed as a sediment trap. Colloidal particles, larger precipitates and particles from the barrel, were found to plug the required small jet. Glass wool was tried but was found to trap the very small particles and stop the flow. Sacks of fiberglass cloth attached to the inlet and outlet of the filter provided the best answer to this problem. Additions of loosely packed fiberglass cloth in the jar functioned as baffles providing eddies to allow the settling out of the finer particles.

Physical and Chemical

<u>Temperature</u>. Temperatures were recorded for both air and water with a Taylor Pocket thermometer. The degree of overcast was recorded at the time temperatures were taken. These data were taken at times of convenience.

<u>Stage</u>. Stage was recorded from a strip of U.S.G.S. river stage measuring scale. This was fastened to the bridge at Station 7.

<u>Conductivity</u>. Conductivity was determined with a portable conductivity cell- wheatstone bridge apparatus as described in Standard Methods

Figure III. Photograph showing details of the filter used in applying fertilizer to the West Branch of the Sturgeon River.

(A.P.H.A., 1955). Mechanical difficulties made readings at critical periods impossible and may have invalidated some of the remaining data; thus the results of conductivity will be disregarded.

Alkalinity. Total alkalinity was determined by titrating the water sample with N/50 sulfuric acid as described by Welch (1948). Determinations of alkalinity in the early phases of the project, indicated that alkalinity values corresponded very closely with values for total hardness. Following are comparisons of values obtained for June 27, 1957:

Station	Total alkalinity p.p.m.	Total hardness p.p.m.
3a	190	192
6	190	188
7	191	190
8	189	188

These ranges are within the accuracy of the test for alkalinity (A.P.H.A., 1955); thus the determination of alkalinity was discontinued early in the project in favor of the more rapid hardness test.

Hardness. Total hardness was determined by the Hach modifications of the compleximetric or EDTA titration method as outlined in Standard Methods (A.P.H.A.,1955).[1.]

Hydrogen Ion Concentration. Hydrogen ion concentration (pH) was determined with a line-operated Beckman pH meter.

Total Phosphorus. Total phosphorus was determined by a slight modification of the method outlined by Ellis, Westfall and Ellis (1948). The modification consisted of neutralizing equal portions of the digested sample with concentrated sodium hydroxide prior to the addition of the acidified ammonium molybdate reagent. Phenolphthalein indicator is used as the end point for neutrality in one of the subsamples, an equal quan-

1.The particular reagents used were MonoVer and TitraVer, trade names of the Hach Chemical Company; Ames, Iowa.

tity of the sodium hydroxide is then added to the other subsample, on which the Ellis, et. al. procedure is carried on. It is believed that this procedure, before proceeding into the colorimetric phase of determination, stabilizes the determinations by starting them from a uniform pH. Colorimetric determinations were made on a Klett-Summerson colorimeter.

Acid-soluble Phosphorus. Acid-soluble phosphorus was determined by using a fifty milliliter sample and proceeding directly into the "method" outlined by Ellis, et. al. (op. cit.). Digestion of the sample is not used. It is believed that this method determines the inorganically combined phosphorus. Some organic phosphorus may be detected this way, but it is believed that most of the phosphorus tied up in organisms and organic detritus is not measured with this technique.

Ammonia. Ammonia determinations were made by direct Nezzlerization as outlined by Dobie and Moyle (1956). The apparent low ammonia values of the West Branch of the Sturgeon River did not raise the colorimetric values into the sensitive range. One determination shortly after fertilization indicated ammonia nitrogen in the order of 0.1 part per million at Station 6. Subsequent tests failed to disclose the presence of ammonia nitrogen.

Biological

Periphyton. Periphyton is that assemblage of organisms that grows attached to or on a substrate without entering into the substrate. There is confusion in the literature as to the exact term to be applied to this complex. Etymologically, periphyton means around or about plants. The meaning, as used in recent literature, has been construed beyond that of just plants to include all immobile substrates. European literature prefers the term aufwuchs as used by Ruttner (1953). A history of terminology and techniques of measurement has been presented by Newcombe (1950). In this discussion periphyton includes all forms of benthic algae and invertebrates.

Many types of substrates have been used for the measurement of periphyton. Some of these substrates are stones (Gumtow, 1955), glass slides (Patrick, 1949), cinder bricks (Grzenda, 1955), plastic slides (Brehmer, 1958) and cedar shingles (Grzenda, op. cit.). Methods of enumeration vary. Actual counts have been made by Young (1945). Weights have been used by Newcombe (1950).

Harvey (1934) devised a method and standard for the extraction of plant pigments; by using alcohol as a solute. In this method the organisms are filtered out of the water and placed in alcohol. The pigments extracted by the alcohol are measured colorimetrically for their density. The density reading is converted to compare with that of an artificial standard, the "Harvey unit". One "Harvey unit" consists of 25 mg. of potassium chromate and 430 mg. of nickel sulphate per liter of water.

Further refinements of this method included the addition of a red filter in the colorimeter to remove the interferences of non-plant pigments (Manning and Juday, 1941). The advantages of this system is the rapidity at which an index determination can be made (Tucker, 1949). Recent unpublished work by Morris Brehmer and Alfred Grzenda indicates that these values hold true to approximately one hundred "Klett units".[2] Above this value the determinations are drastically reduced as higher pigment concentrations are reached. Through the courtesy of Mr. Brehmer

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[2] A unit of optical density on the Klett-Summerson Colorimeter.

and Mr. Grzenda a correction graph was provided to redetermine values in this higher range (Fig. IV).[3]

Periphyton determinations on the West Branch of the Sturgeon River were made by attaching a cedar shingle, three by twelve inches, to submerged logs in the stream (Fig. V). These shingles and their associated periphyton assemblages were removed after a two week period and replaced by another shingle in an identical position. The removed shingles were placed in polyethylene bags and transported to the laboratory.

In the laboratory, the shingles were brushed and washed off in a pan. This mixture was poured into a Buchner funnel and filtered with the aid of filter flasks and a vacuum pump. The filter paper and organisms were removed and placed in a one ounce bottle. Ninety-five percent ethyl alcohol was added to the bottle. The bottles were then stored in darkness until completion of the field work. The pigment solutions were again filtered and made up to a uniform fifty milliliters with additional alcohol. This filtered solution was then read on a Klett-Summerson colorimeter and corrections determined by the method outlined above.

Bottom fauna. Ten bottom fauna samples were collected from Stations 3a, 6, 7 and 8. These samples were obtained from gravelly riffle areas on a weekly basis. The samples were taken with a square-foot Surber sampler. A cross-stream transect was used to determine the position of the sample and ten samples were collected across this transect. The following week the transect was moved a couple of feet upstream to minimize the effects of the previous weeks sampling.

The samples were preserved with formalin in pint jars. The samples

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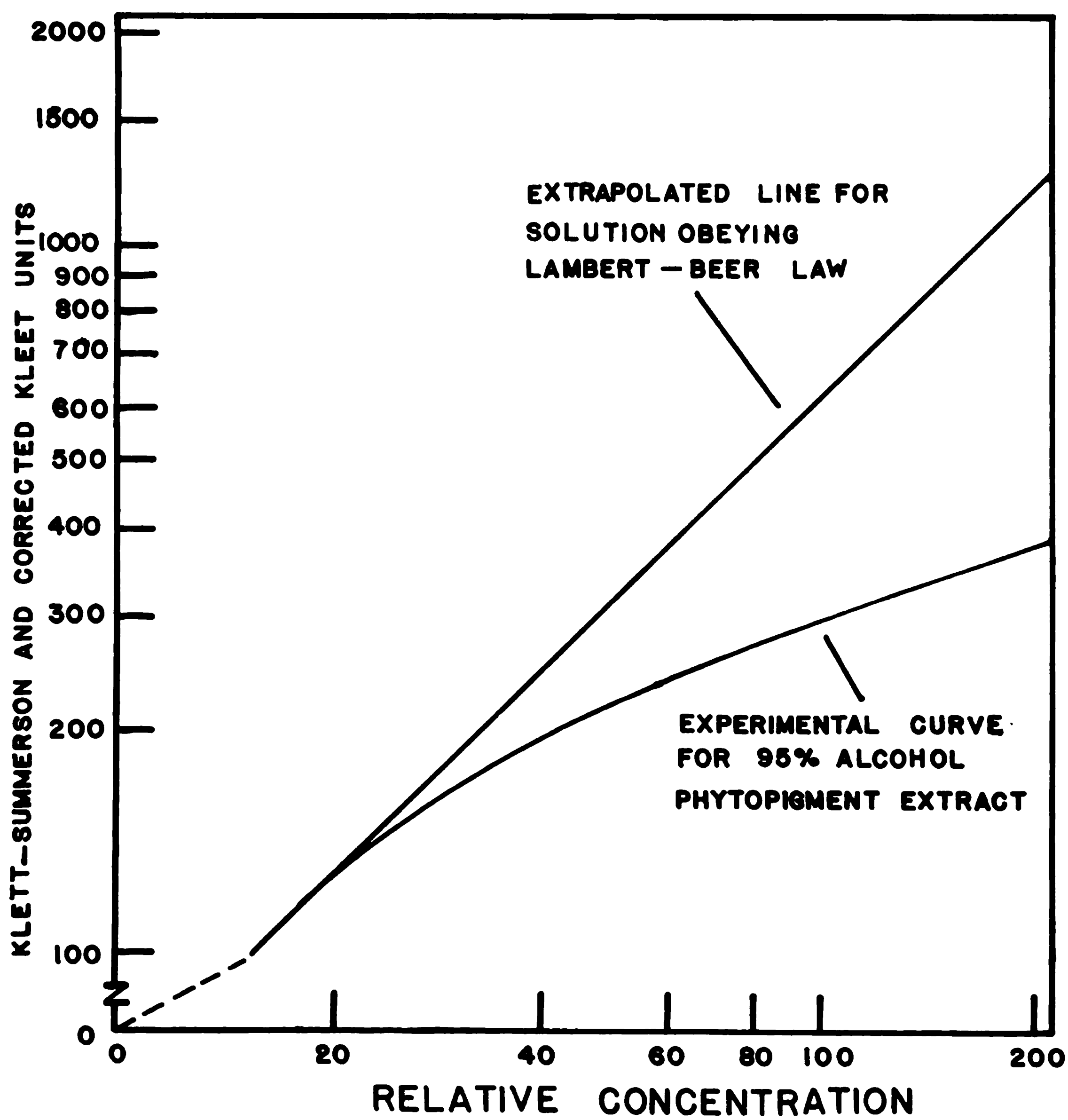
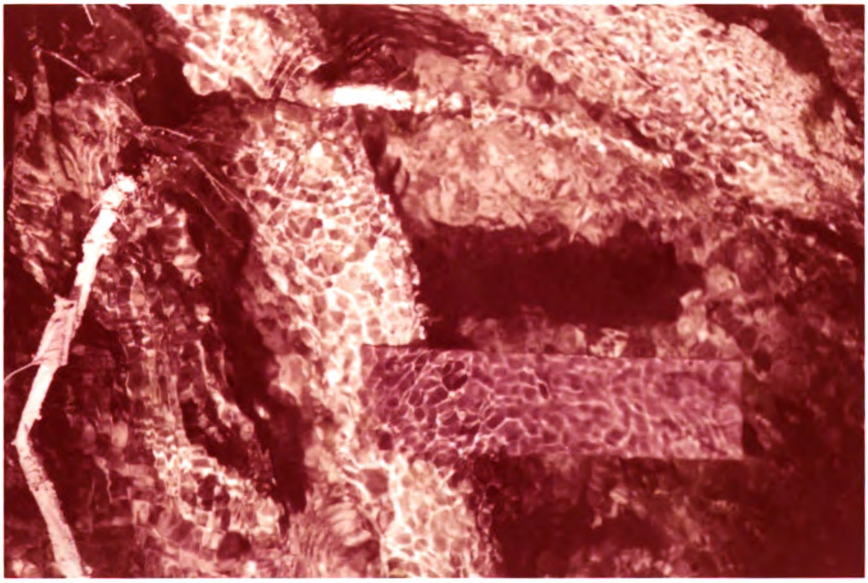
[3] For examples of original "Klett unit" readings, "Harvey units" and corrected klett units see Appendix (Table B).

Figure IV. Correction graph for determining the density of phyto-pigments (Klett-Summerson colorimeter). (From unpublished data of Morris Brehmer and Alfred Grzenda).



KLETT-SUMMERSON AND CORRECTED KLEET UNITS
2000
1500
1000
900
800
700
600
500
400
300
200
100
0
EXTRAPOLATED LINE FOR SOLUTION OBEYING LAMBERT — BEER LAW
EXPERIMENTAL CURVE FOR 95% ALCOHOL PHYTOPIGMENT EXTRACT
0
20
40
60
80
100
200
RELATIVE CONCENTRATION

Figure V. A photograph of a cedar shingle used for the collection of periphyton in the stream.



were picked at a latter date through the facilities of the Institute for Fisheries Research. A saturated sugar solution was used to bouy up the organisms which are picked from the surface, with a fine-mesh wire scoop. The preserved specimens were then counted and volumes determined by water displacement with ten milliliter graduated centrifuge tubes and a ten milliliter burette.

Bottom fauna samples were also obtained from beds of Chara spp. at Station 7. A slight modification of the Wilding-type sampler (A.P.H. A., 1955) was used. This sampler had a diameter of twelve inches (an area of 113 square inches). This sampler was forced into the bottom. The water, aquatic vegetation and bottom material, to a depth of approximately two inches, were dipped out of the sampler and washed in a thirty-mesh bottom screen. These samples were picked immediately and stored in alcohol. The samples were sorted and volumes determined with a ten milliliter graduated centrifuge tube and a ten milliliter burette.

Fish. Five species of fish were sampled in Hoffman Lake. These fish were procured with triangular wire-mesh traps. Weights and total lengths were taken in grams and millimeters (lengths were converted to inches via a conversion table to correspond with previous years data). Scale samples were taken. The right pectoral fin was clipped on each fish scale-sampled to avoid duplication of data.

Scale samples were embossed on pieces of acetate with the aid of a pressure-roller system as described by Smith (1954). The scale impression was used in a micro-projector to determine age and distance between annuli. The lengths of annuli were recorded on ruled scale cards.

The length-weight relationships were determined by a modification of a formulae by Lagler (1952). This modification is as follows:

$$\ln A = \frac{\Sigma \ln W \times \Sigma(\ln L)^2 - \Sigma \ln L \times \Sigma(\ln L \times \ln W)}{N \times \Sigma(\ln L)^2 - (\Sigma \ln L)^2}$$

$$n = \frac{\Sigma \ln W - (N \times \ln A)}{\Sigma \ln L}$$

Where:

$\ln A$ = Y-axis intercept of the regression line
n = slope of the line
$\ln W$ = natural logarithm of the weight
$\ln L$ = natural logarithm of the length
N = number of specimens

This results in the equation for the exponential curve; $\ln W = \ln A + N \ln L$.

Body-scale relationships were assumed to have a zero intercept, as in previous years (Plosila, 1958). Thus direct proportion methods were used to determine the fishes length at a given annulus. A nomograph and the ruled scale cards were used to determine these lengths.

Fish in the West Branch of the Sturgeon River were sampled with a 220 volt direct-current shocker as described by Rounsefell and Everhart (1953). Methods used were essentially the same as those outlined for the Hoffman Lake fish. Body length-scale length relationships were determined by the following formulae:

$$b = \frac{\Sigma FS - \frac{\Sigma F \Sigma S}{N}}{\Sigma S^2 - \frac{(\Sigma S)^2}{N}}$$

$$n = \frac{\Sigma F - (N \times b)}{\Sigma S}$$

Where:

b = Y-axis intercept of the regression line
n = slope of the regression line
F = total length of the fish
S = Anterior scale radius
N = number of specimens

This results in the equation; $F = b + nS$. The calculated lengths at a annulus were determined by this formulae.

RESULTS

Physical and Chemical

Temperature. Temperature is a relative complex factor in a river. In lakes the temperature is reasonably stable on a diurnal basis. The immediate surface may exhibit major temperature changes from day to night but on the whole the epilimnion and other stratified layers show slow long-term fluctuations. In the stream the complete water mass is renewed in a matter of few hours. The West Branch of the Sturgeon River contains mostly ground water. Within a few hours after sunset the solar warmed water is discharged and replaced. This incoming ground water has a stable temperature in the high forties. The next day the water mass is rewarmed again. The degree of rewarming depends primarily on how open the stream is above the area concerned and how intense the solar radiation. The effect of temperature changes on the biota of the stream may be only hypothesized.

The Q_{10} law states that biochemical reactions are approximately doubled for every ten degree rise in temperature. From this one may conclude that a ten degree rise in temperature will double the metabolic rates of the plants and thereby approximately double the rate of production. Strickland (1958) presents a short discussion on the influence of temperature on productivity. Some of the things that must be taken into account in evaluating temperatures are species involved, temperature ranges in which the temperature change is taking place, availability of nutrients and other ecological factors, such as intensity of illumination.

Lotka (1956) quotes G. W. Martin as stating that lower temperatures may actually increase production. This is based on the increased solubility of carbon dioxide in cooler water. Carbon dioxide is one of the primary building blocks in sugar and starch production. This reasoning probably has little application to the production rate of the flora of the West Branch of the Sturgeon River since it has been shown that the majority of aquatic plants can secure adequate quantities of carbon dioxide from the half-bound carbonates (Welch, 1952) which are in excess in the river water.

Data were collected for the summer of 1957 on the West Branch of the Sturgeon River which indicate that there probably is a greater seasonal fluctuation in the temperatures of the river than previously expected. The mean of the temperatures recorded indicates that there is a negligible difference between stations (table 1). Carr (M.S.) found that in 1956 there was a strong tendency for the stream to become cooler as one proceeds downstream. The 1957 data fails to bear this out.[4]

Table 1

MEANS AND RANGES OF TEMPERATURE (F°) RECORDS ON THE WEST BRANCH OF THE STURGEON RIVER, 1957.

	Air		Water	
Station	Mean	Range	Mean	Range
3a	65.9	54-77	57.8	49-67
6	68.2	58-83	55.3	50-60
7	67.4	59-83	56.1	49-65
8	66.6	59-86	56.3	49-65
9	65.4	60-77	54.1	49-59

The diurnal fluctuations were found to excede those expected. it was believed that the large proportion of ground-water in the stream's

[4]For a summary of records of temperatures recorded, see appendix, Table A.

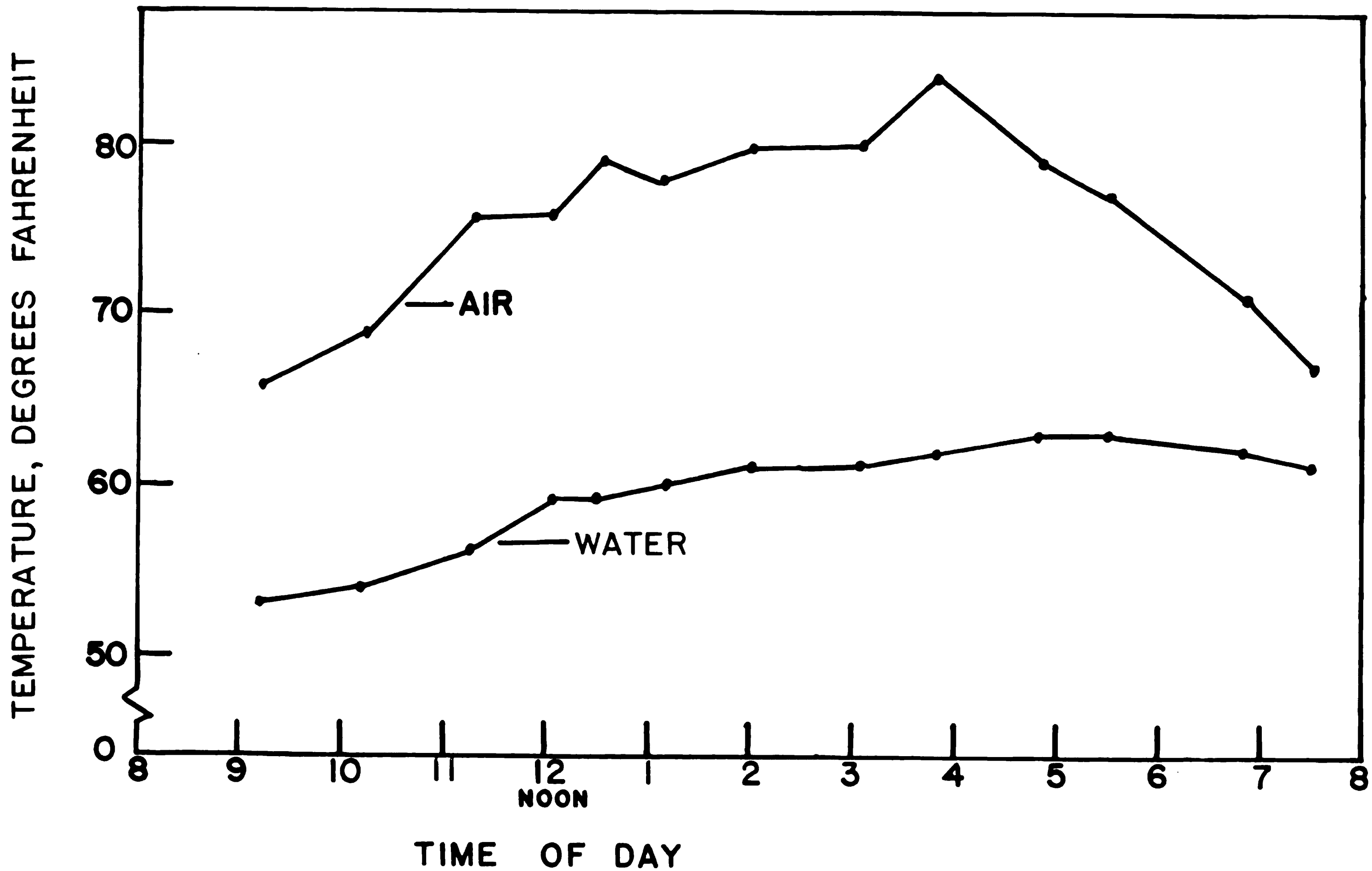
volume would stabilize the temperature. At each station, proceeding downstream, the volume flow increases due to the addition of groundwater. It was expected that this continual addition would provide for very little fluctuation. On July 17 a series of approximately hourly temperature readings were taken at Station 7. These indicate that the stream temperature may raise ten degrees in nine hours. The time of day and temperature readings are as follows:

Time	Air temp.	Water temp.
9:15	66	53
10:15	69	54
11:05	76	56
Noon	76	57
12:35	79	59
1:10	78	60
2:00	80	61
3:05	80	61
3:45	84	62
4:50	79	63
5:30	77	63
6:45	71	62
7:30	67	61

The temperatures are graphically depicted in figure VI. This graph shows the lag in temperature responses of the water to the atmosphere.

Stage. The West Branch of the Sturgeon was found to have a very stable water level. During the period between July 18 and September 17 the river fluctuated only twenty-four hundredths of a foot, or approximately three inches (table 2; for a graphical presentation of fluctuations about the mean Fig. VII). There was a period in early July, prior to installing the gauge, that the river was higher than actually recorded. This deviation was not abnormally high and was accompanied by a slight increase in color from the normally very clear condition, and an increase in organic debris being carried by the stream.

Figure VI. A portion of the diurnal temperature fluctuation of the West Branch of the Sturgeon River.



STATION 7; JULY 17, 1957

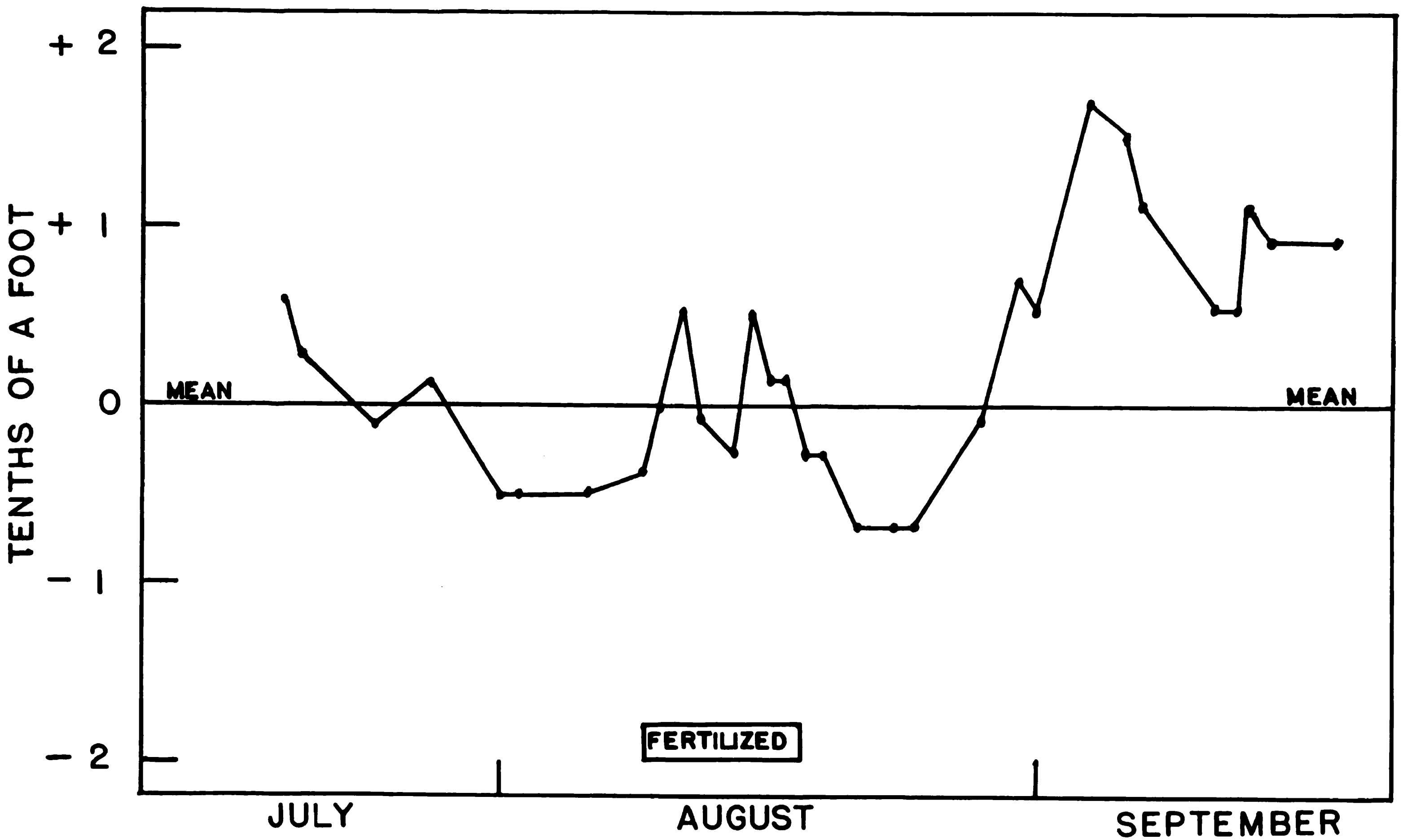
Table 2

FLUCTUATIONS IN STAGE OF THE WEST BRANCH
OF THE STURGEON RIVER, 1957

Date	Gauge reading feet	Deviation* From mean	Date	Gauge reading feet	Deviation* From mean
July 18	8.33	+6	Aug. 16	8.28	+1
" 19	8.30	+3	" 17	8.24	-3
" 23	8.26	-1	" 18	8.24	-3
" 26	8.28	+1	" 20	8.20	-7
Aug. 1	8.22	-5	" 22	8.20	-7
" 2	8.22	-5	" 23	8.20	-7
" 5	8.22	-5	" 27	8.26	-1
" 8	8.23	-4	" 29	8.34	+7
" 9	8.25	-3	" 30	8.32	+5
" 9	8.31	+4	Sept. 3	8.44	+17
" 10	8.32	+5	" 5	8.42	+15
" 11	8.26	-1	" 6	8.38	+11
" 13	8.24	-3	" 10	8.32	+5
" 14	8.32	+5	" 11	8.32	+5
" 15	8.28	+1	" 12	8.38	+11
			" 13	8.36	+9
			" 17	8.36	+9
			MEAN	8.27	

* in hundredths of a foot.

Figure VII. Fluctuations in stage about the mean of the West Branch of the Sturgeon River.


+ 2
+ 1
0
− 1
− 2
TENTHS OF A FOOT
MEAN
MEAN
FERTILIZED
JULY
AUGUST
SEPTEMBER

Hardness. The total hardness of the West Branch of the Sturgeon River is quite constant. Occasionally during long periods of heavy rain and its resulting contribution of run-off water, the hardness drops. (see table 3, July 4). The ranges of parts per million hardness, disregarding the fourth of July, for the various stations are as follows:

Station	3a	187-199
"	6	187-197
"	7	186-196
"	8	188-202
"	9	195-200

There were no detectable changes in hardness due to fertilization (For a graphical picture of the hardness changes, Fig. VIII).

Hydrogen Ion Concentration. Hydrogen ion concentration or pH, fluctuated around a value of approximately 8.1 (table 4 and Fig. IX). The range was from 7.8 to a maximum of 8.4. A water-mass with the quantities of half-bound carbonates that the West Branch of the Sturgeon has is highly buffered and retains a stable pH value.

There was a drop in pH during the fertilization period. It is doubtful if this was the result of the addition of fertilizer. The quantity of fertilizer added to the stream was not large. The water level fluctuated during the period the pH dropped and may have influenced the pH values.

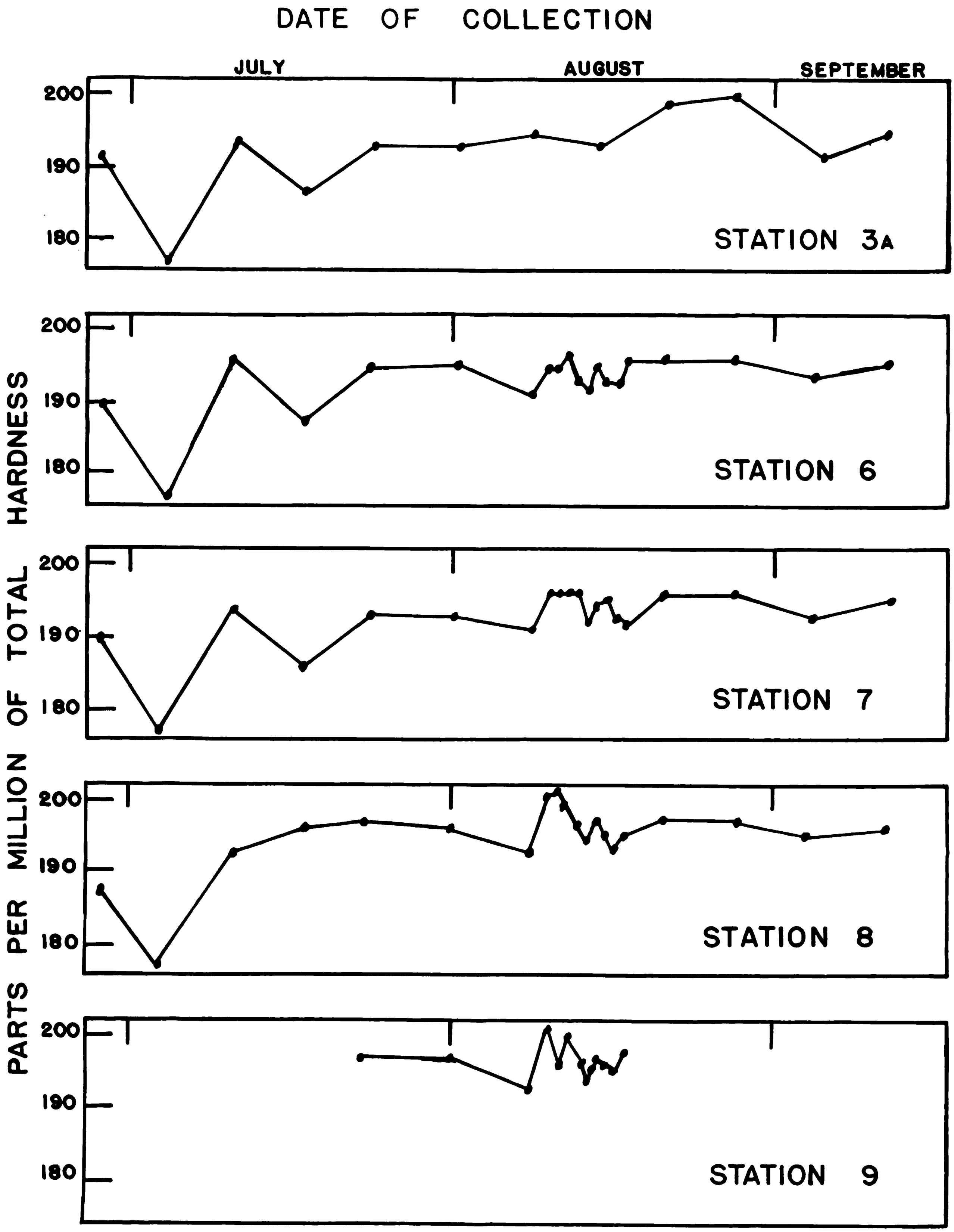
Phosphorus. The West Branch of the Sturgeon River is low in phosphorus. The prefertilized values for total phosphorus ranged from zero to twenty parts per billion (table 6 and Fig. X). The higher values occur during periods of high water. During the stable water periods of late July, the range drops to zero to seven parts per billion. This is extremely low when compared to the total phosphorus content of

Table 3

TOTAL HARDNESS OF THE WEST BRANCH OF THE STURGEON RIVER, 1957, EXPRESSED IN PARTS PER MILLION

Date	Station 3a	Station 6	Station 7	Station 8	Station 9
June 27	192	190	190	188	---
July 4	175	168	170	173	---
" 11	194	196	194	193	---
" 18	187	187	186	196	---
" 25	194	195	193	197	197
Aug. 1	194	195	193	196	197
" 8	196	192	191	193	193
" 10	---	196	196	201	200
" 11	---	196	196	202	196
" 12	---	197	196	199	200
" 13	---	194	196	196	196
" 14	---	193	192	194	195
" 15	194	195	194	197	197
" 16	---	193	195	195	196
" 17	---	193	193	193	195
" 18	---	196	192	195	197
" 23	199	196	196	197	---
" 29	199	196	196	197	---
Sept. 5	192	194	193	195	---
" 11	195	196	195	196	---

Figure VIII. Fluctuations in total hardness of the West Branch of the Sturgeon River, 1957.



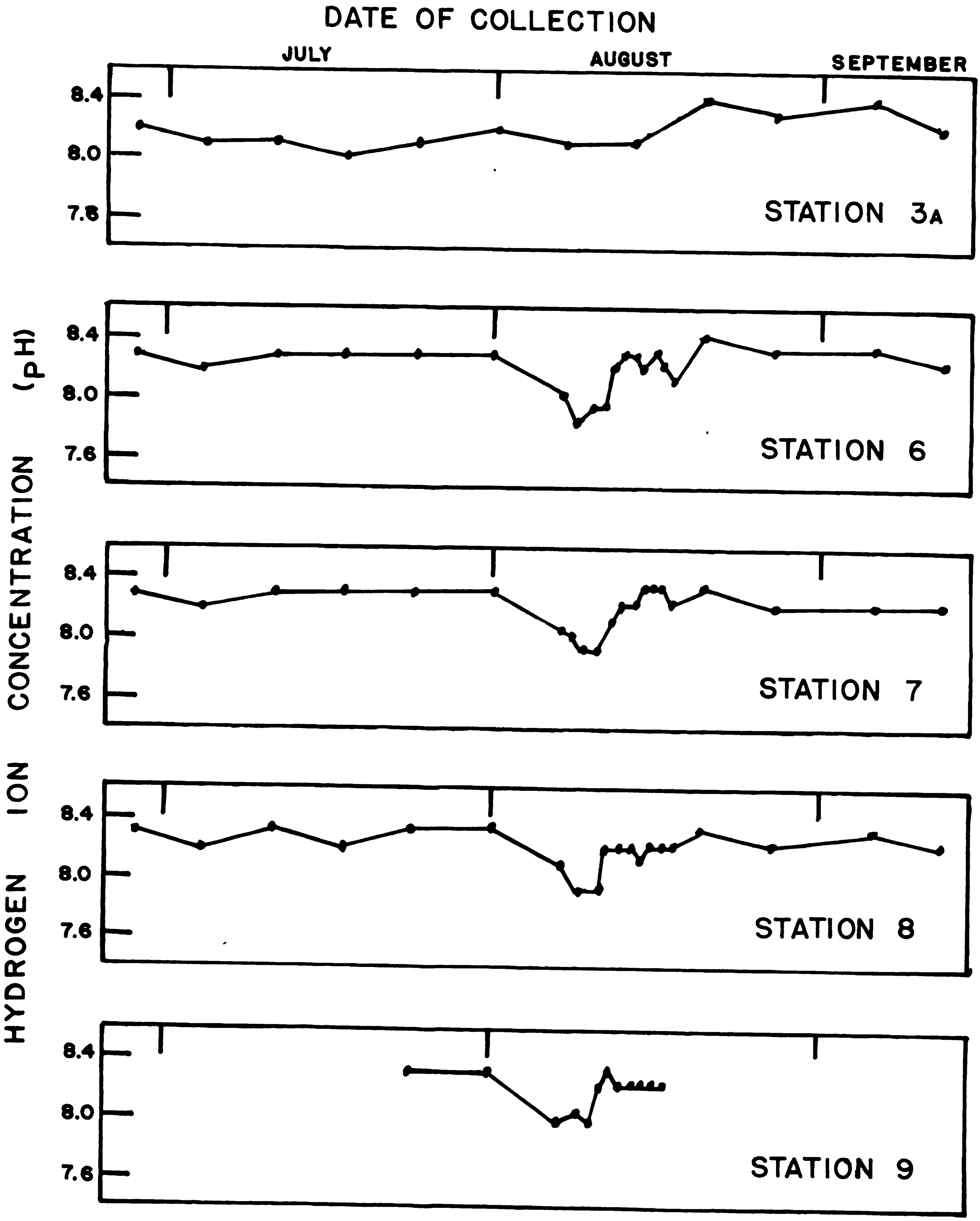
DATE OF COLLECTION
JULY
AUGUST
SEPTEMBER
PARTS PER MILLION OF TOTAL HARDNESS
200
190
180
STATION 3A
STATION 6
STATION 7
STATION 8
STATION 9

Table 4

HYDROGEN-ION CONCENTRATION EXPRESSED IN pH, OF THE WEST BRANCH OF THE STURGEON RIVER, 1957

Date	Station 3a	6	7	8	9
June 27	8.2	8.3	8.3	8.3	---
July 4	8.1	8.2	8.2	8.2	---
" 11	8.1	8.3	8.3	8.3	---
" 18	8.0	8.3	8.3	8.2	---
" 25	8.1	8.3	8.3	8.3	8.3
Aug. 1	8.2	8.3	8.3	8.3	8.3
" 8	8.1	7.9	8.0	8.0	8.0
" 9	---	7.8	8.0	---	---
" 10	---	7.9	7.9	7.9	8.0
" 11	---	7.9	7.9	7.9	7.9
" 12	---	8.2	8.1	8.2	8.2
" 13	---	8.3	8.2	8.2	8.2
" 14	---	8.3	8.2	8.2	8.2
" 15	8.1	8.2	8.3	8.1	8.2
" 16	---	8.3	8.3	8.2	8.2
" 17	---	8.2	8.2	8.2	8.2
" 18	---	8.1	8.2	8.2	8.2
" 23	8.4	8.4	8.3	8.3	---
" 29	8.3	8.3	8.2	8.2	---
Sept. 5	8.4	8.3	8.2	8.3	---
" 12	8.2	8.2	8.2	8.2	---

Figure IX. A graph showing pH values for various stations on the West Branch of the Sturgeon River, 1957.



DATE OF COLLECTION
JULY
AUGUST
SEPTEMBER
HYDROGEN ION CONCENTRATION (pH)
8.4
8.0
7.6
STATION 3A
STATION 6
STATION 7
STATION 8
STATION 9

Minnesota rivers. Nineteen rivers in Minnesota had a total phosphorus content of fifteen to sixty-three parts per billion (Smith and Moyle, 1944).

Welch (1952) says that generally hard-water lakes have a higher productivity than soft-water lakes. In view of the low phosphorus content it was hypothesized that this was the major factor inhibiting the stream's productivity.

The calculated input of phosphorus during fertilization fluctuated (table 5). This fluctuation is due to changes in the hydrostatic pressure of the fertilizing apparatus and mechanical difficulties encountered. There was a slow decline in the phosphorus added as the fertilization apparatus emptied. The lowest addition of fertilizer occurred a short time before the apparatus was recharged with addition fertilizer the next day.

Taking these fluctuations into account, there was a delay in the phosphorus reaching a given station downstream. Checks made with sodium fluorescene dye indicated that the water-mass from Station 6 arrived at Stations 7 and 8 in two and a half and four hours respectively. At station 6, approximately five hundred yards downstream from the point of fertilization, detectable changes in phosphorus didn't occur until after twelve hours. Maximum recorded values didn't occur

Table 5

CALCULATED AMOUNTS OF PHOSPHORUS ADDED TO THE WEST BRANCH OF THE STURGEON RIVER, 1957

Date	Time	Parts Per Billion of Phosphorus Low Value	Parts Per Billion of Phosphorus Recharged Values
August			
8	2:45 pm	—	78
8	2:00 pm	—	78
9	1:20 am	—	78
9	Noon	39	78
10	10:00 am	0	81
11	10:00 am	65	78
12	10:00 am	65	78
13	10:00 am	65	78
14	11:00 am	59	78
15	10:00 am	59	78
15	8:00 pm	59	78
16	9:30 am	59	71
17	estimated time of flow stoppage; 4:00 am.		

Table 6

TOTAL AND ACID-SOLUBLE CONCENTRATIONS OF PHOSPHORUS IN THE WEST BRANCH OF THE STURGEON RIVER, 1957; EXPRESSED IN PARTS PER BILLION

Date	Station 3a		Station 6		Station 7		Station 8		Station 9	
	Total	Sol.	Total	Sol.	Total	Sol.	Total	Sol.	Total	Sol.
June 27	11	--	11	--	20	--	9	--	--	--
July 4	11	--	17	--	13	--	17	--	--	--
" 11	1	--	6	--	5	--	5	--	--	--
" 18	6	--	4	--	4	--	4	--	--	--
" 25	8	--	7	--	5	--	5	--	7	--
Aug. 1	4	--	3	--	2	--	5	--	0	--
" 8*	14	--	12	--	16	--	16	--	9	--
" 8 (PM.)	--	--	12	0	12	7	12	1	12	3
Midnight	--	--	1	4	--	0	10	1	9	0
Aug. 9										
5:35 AM	--	--	21	8	18	13	15	3	--	0
9:00 AM	--	--	23	--	18	13	13	8	7	6
Aug. 10	--	--	19	16	19	15	13	7	--	2
" 11	--	--	30	5	34	24	50	26	27	13
" 12	--	--	71	60	50	32	32	26	37	16
" 13	--	--	71	61	55	42	47	35	32	26
" 14	--	--	68	66	39	32	47	26	39	17
" 15	10	3	50	48	--	35	29	29	25	19
" 16	--	--	37	34	65	66	33	28	27	19
" 17	--	--	9	1	17	2	25	15	26	15
" 18	--	--	5	0	5	0	5	0	10	2
" 23	11	--	14	--	11	--	13	--	--	--
" 29	20	--	12	--	14	--	21	--	--	--
Sept. 5	9	--	10	--	11	--	8	--	--	--
" 12	11	--	12	--	10	--	12	--	--	--

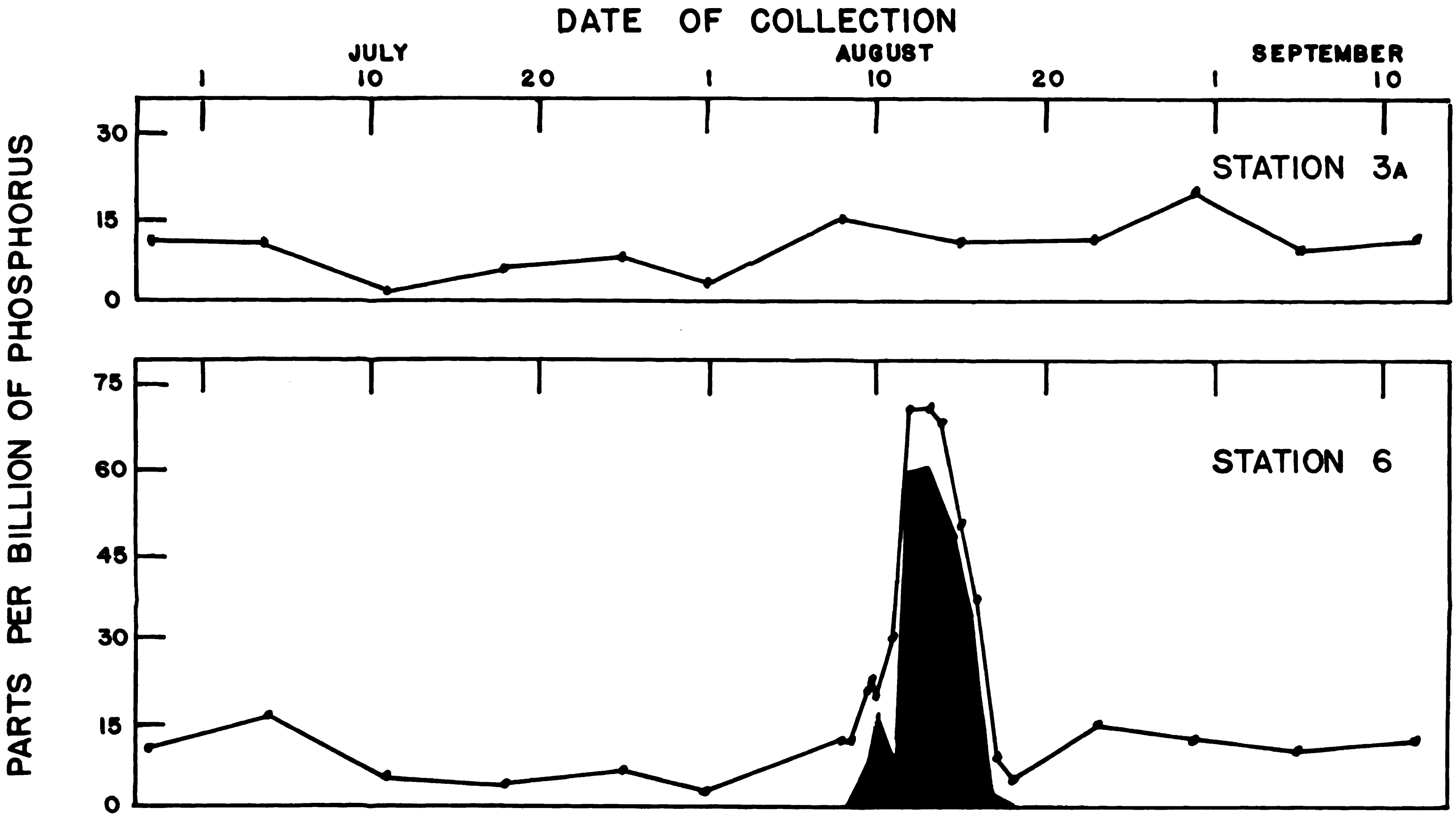
* Values for before fertilization treatment was started on that day.

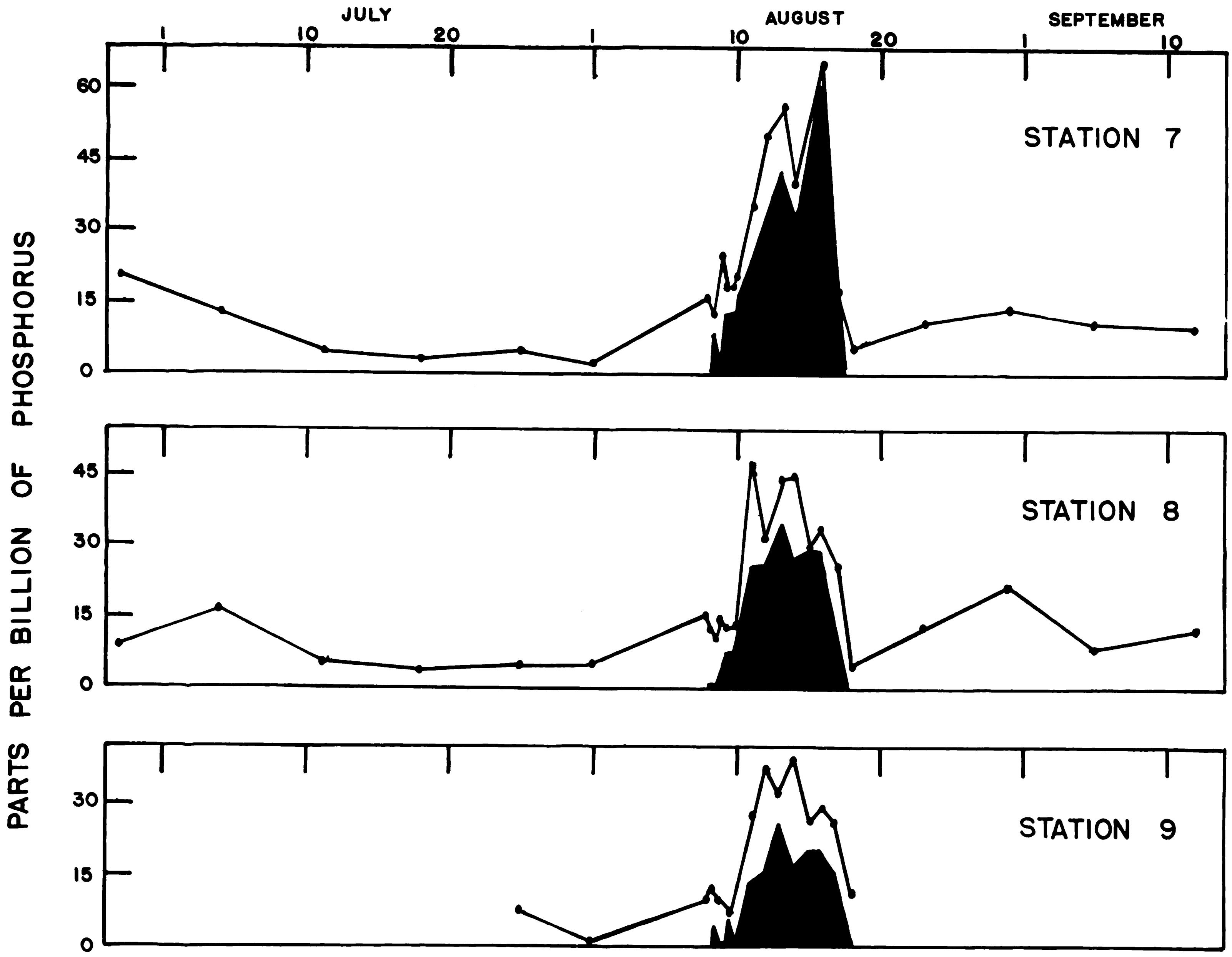
FIGURE X

RESULTS OF PHOSPHORUS ANALYSES

TOTAL PHOSPHORUS — SOLUBLE PHOSPHORUS

FERTILIZER ADDED FROM AUGUST 8 TO AUGUST 17




JULY
AUGUST
SEPTEMBER
1
10
20
1
10
20
1
10
STATION 7
STATION 8
STATION 9
60
45
30
15
0
PARTS PER BILLION OF PHOSPHORUS

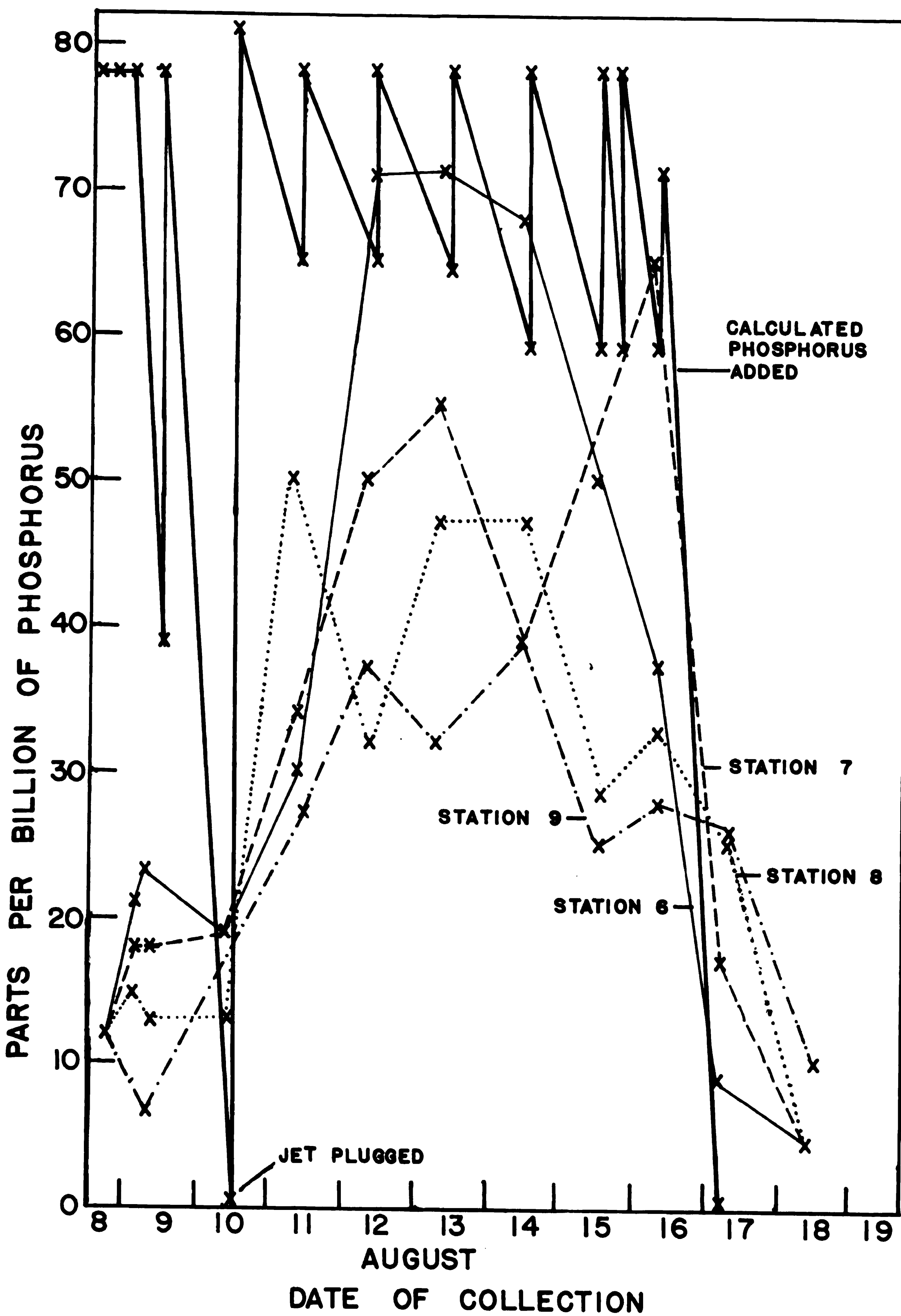
for three and a half days (Fig. XI).

Maximum values remained significantly unchanged for two or three days and then began to drop off. This decrease in phosphorus held true for all except Station 7. Once fertilization was stopped the phosphorus content rapidly fell off and within twenty-four hours was back to prefertilization levels.

These fluctuations provide for interesting hypotheses concerning the distribution of phosphorus within the stream. The delay in phosphorus may have been the result of precipitation. Precipitation of phosphorus took place in Hoffman Lake (Plosila, 1958). Alexander (1956) postulated that this was in the form of tricalcium phosphate. This was in the form of a white flocculant material. A similar white floc was observed to appear on a log at the point of fertilization, during periods when the stream of fertilizer didn't enter the stream's main channel. The precipitation of phosphorus may account for the disappearance of a portion of the fertilizer. It is hard to believe that the constant turbulance of the stream would allow a large amount of this floc to settle out to the bottom.

Another possible solution to the problem of phosphorus disappearance may be the binding of phosphate ions or compounds on to the soils of the stream bed. It has been shown by Hepher (1958) that soils, especially those rich in calcium, can readily remove phosphorus from water. Another source for the removal of the phosphorus may be organisms in the stream. The combination of soil and plant uptake may be quite rapid (Hepher, op. cit.; Hutchinson, 1957). The streams volume is rapidly mixed. Within a hundred yards, fluorescene dye indicated that the water was mixed thoroughly throughout the cross-section of the

Figure XI. Fluctuations in quantities of phosphorus added to the river and amounts of phosphorus detected at various stations during the period of fertilization.



PARTS PER BILLION OF PHOSPHORUS
0
10
20
30
40
50
60
70
80
8
9
10
11
12
13
14
15
16
17
18
19
AUGUST
DATE OF COLLECTION
CALCULATED PHOSPHORUS ADDED
STATION 7
STATION 9
STATION 8
STATION 6
JET PLUGGED

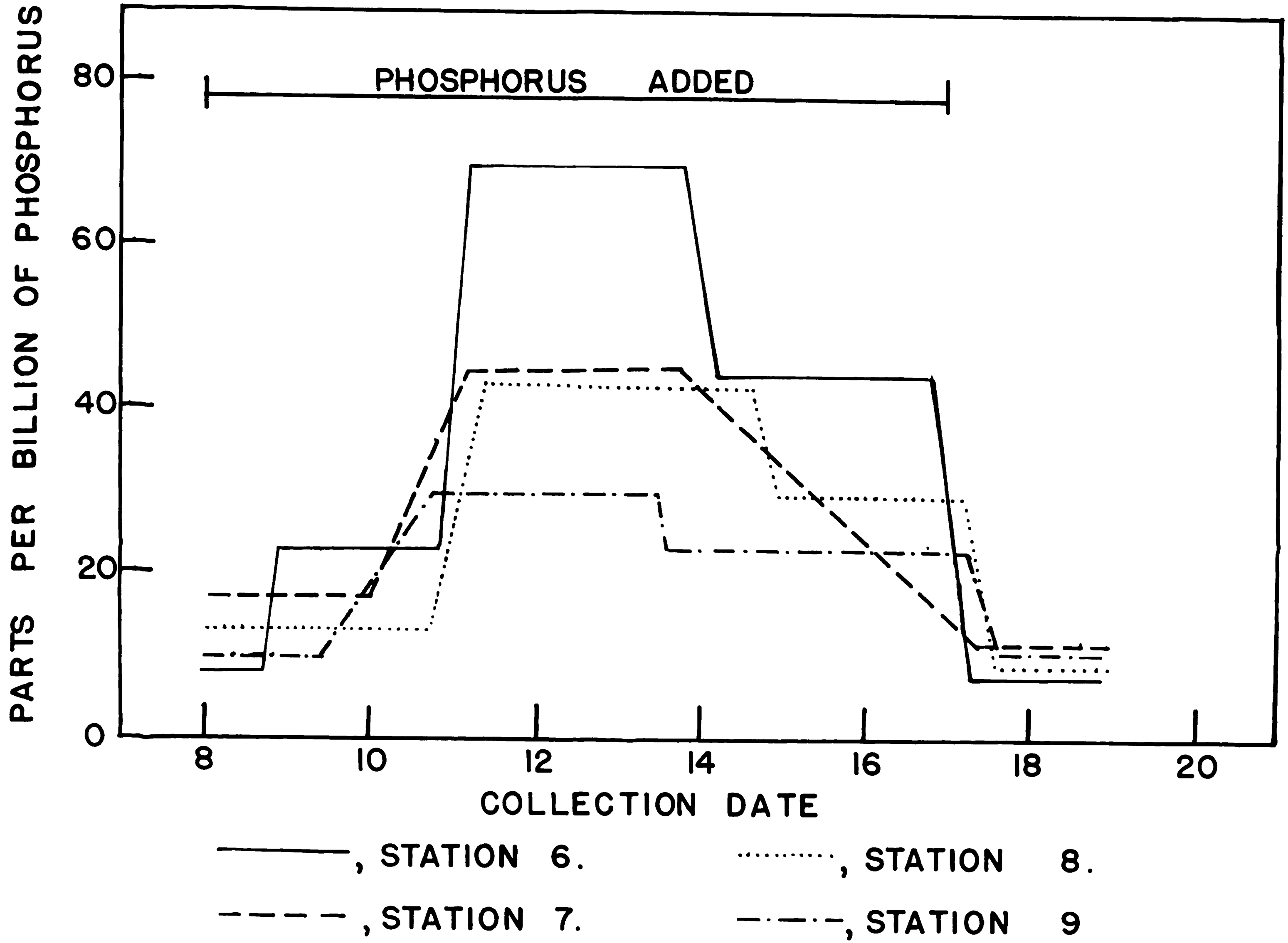
stream. This would assist the phosphorus making contact with the stream's soil and organisms.

After this period of accumulation of phosphorus there was a leveling off of detected phosphorus at the stations. After this period of stability, the phosphorus content began to drop rapidly while the addition of phosphorus remained basically the same (Fig. XII). This could not be very well attributed to the original postulations on slow build-up. Once the stream reached its maximum content or saturation it would appear that the downstream flow would remain relatively constant.

A possible solution to this lies in the periphyton of the stream. Previously obscure species of algae may have been able, with increased nutrients, to overcome competition from the low nutrient favored forms. This population would exhibit the typical sigmoid growth curve of an increasing population; with its characteristic period of lag followed by a period of rapid population increase (Lotka, 1956). Once the period of rapid increase began to take place the population would be able to utilize increasing amounts of phosphorus; thus creating a downward trend in the water's content of phosphorus.

The results of phosphorus determinations indicate that the post-fertilization phosphorus content of the stream was somewhat higher than the pre-fertilization levels (Fig. X). This may be the result of releases of phosphorus previously tied up by an increased standing crop of periphyton or releases from non-organic combinations. Unfortunately higher water levels (Fig. VII), may create this impression. It was observed in early summer that high water created high phosphorus readings. This is probably due to run-off water and increased suspended

Figure XII. Graph of grouped data showing general trends of the phosphorus content at various points downstream from fertilization.


PARTS PER BILLION OF PHOSPHORUS
80
60
40
20
0
PHOSPHORUS ADDED
8
10
12
14
16
18
20
COLLECTION DATE
, STATION 6.
, STATION 7.
, STATION 8.
, STATION 9

organic materials.

Ammonia. Failure of tests to detect ammonia concentrations, indicates that ammonia was considerably lower in the West Branch of the Sturgeon River in 1957 than in previous summers (Grzenda, 1955; Colby, 1957; Carr, M.S.). Results of phosphorus-nitrogen ratio studies on the river in 1957 (Correll, M.S.) showed a 1:10 ratio with no significant changes due to fertilization. Thus it appears that ammonia is only a small portion of the river's nitrogen. The nitrogen utilized in the river's metabolism is probably in the form of a nitrate. Nitrates are readily utilized in plant production.

Biological

Periphyton. In most instances the introduction of additional nutrients will increase the production of an area. One of the primary concerns in this study was to determine whether an ecological system like the West Branch of the Sturgeon River would respond to an increase in phosphorus nutrients. In previous years the responses of plankton in Hoffman Lake varied. Alexander (1956) observed no detectable changes in planktonic organisms in 1954. Similar results occurred in 1955 (Anton, 1957). Plosila (1958), in a study in 1956, observed an increase in organic materials in the lake's water. He contributed this increase to a combination of fertilizer responses, more efficient technique and normal fluctuations.

Periphyton responded significantly in Hoffman Lake in all three years (Plosila, 1958). In the West Branch of the Sturgeon River, Grzenda (1955) found a statistically significant increase in the stream's standing crop of periphyton following fertilization of Hoffman Lake in

1954. The results of 1955 studies are somewhat obscured. Colby (1957) found that bricks used to collect a thirty-day accumulation of periphyton actually showed a decrease in standing crop after fertilization. Shingles which were replaced on a weekly basis responded positively to fertilization. Colby (op. cit.) attributed these differences to various ecological factors, namely, a limitation in growth due to the length of time and amount of organic matter accumulated. Carr (M.S.), in 1956, found a general increase in periphyton samples after fertilization.

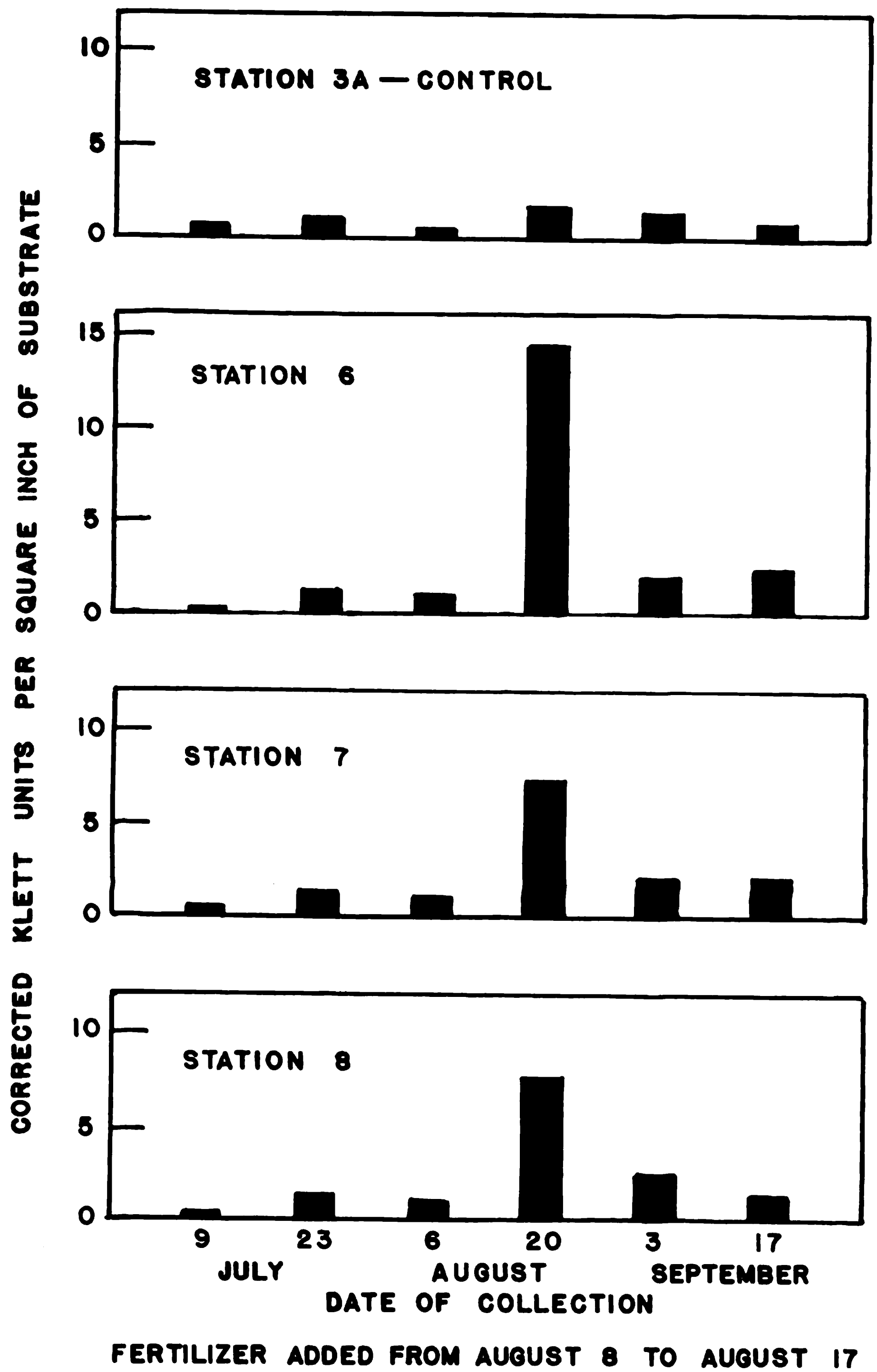
The technique of collecting periphyton from an artificial substrate is not a direct measurement of production. The procedure embodies the collection of an accumulated standing crop over a uniform period of time, which is then used as an index of productivity. The larger the standing crop for a given period of time the greater the rate of production.

In 1957 direct fertilization of the stream produced large increases in the periphyton. Station 7 exhibited approximately an eleven hundred percent increase in periphyton over the two week period prior to fertilization. Stations 7 and 8 showed increases in the order of five hundred and seven hundred percent respectively (Fig. XIII).

There are wide fluctuations in the amount of periphyton per artificial substrate at a given time (see appendix). These fluctuations are probably the result of differences in micro-habitats occupied by each shingle. The shingles have shown these variations with visual observations. Some shingles would exhibit nearly bare surfaces, others would have dense layers of silt and debris, while others would have filaments of algae attached.

Four extra shingles placed in the stream, one each at Stations

Figure XIII. Changes in standing crop of periphyton at various stations.


STATION 3A — CONTROL
STATION 6
STATION 7
STATION 8
CORRECTED KLETT UNITS PER SQUARE INCH OF SUBSTRATE
0
5
10
15
9
23
6
20
3
17
JULY
AUGUST
SEPTEMBER
DATE OF COLLECTION
FERTILIZER ADDED FROM AUGUST 8 TO AUGUST 17

6 and 7, before and during fertilization, were used to collect taxonomic material. This material was checked by Dr. G. W. Prescott and was composed chiefly of diatoms. Two desmids were found but their numbers were relatively low when compared to the diatoms present.

It was necessary to run statistical tests on the pigment extractions to determine if the fertilizer had any long-term influences on the periphyton. The occasional loss of a shingle, making unequal groups, didn't allow normal statistical tests to be used. The data were tested for each station throughout the summer and then for each date of collection throughout the stations. "F" - tests were used to find those groups not significantly different at the five percent level. Groups failing to pass this "F"-test were submitted to the "Multiple Range Test"[5] as outlined by Duncan (1957). This test is a "null-hypothesis" test designed for heteroskedastic means; i.e., means derived from samples with unequal replications. The basic principle of the test is to group together the means that are not significantly different. The results of this test were determined at the five percent level. Chart XIV presents a summary of "F" and "Multiple Range Tests".

The results of these tests removed some doubts as to the stability of Station 3a as a control station. This station exhibited an abrupt rise in periphyton during the period of fertilization of the downstream stations. During this period, filamentous forms of algae, _Spirogyra_ and _Mougeotia_, appeared at Station 3a. An "F"-test indicated that these filamentous growths were not significantly adding to the pigment extractions. After the period of fertilization, _Spirogyra_ and _Mougeotia_ were

---

[5] Set-up, discussions and results of the individual "Multiple Range Tests", are presented in the appendix.

Chart XIV

A SUMMARY OF "F" AND "MULTIPLE RANGE TESTS" SHOWING WHICH MEAN VALUES ARE NOT SIGNIFICANTLY DIFFERENT*

Date of sample Removal ---	July 9	July 23	August 6	September 3	September 17	
Station 3a	52.1*	79.3*	35.5*	141.6*	128.8*	66.3*
Station 6	39.3*	113.3*	109.1*	1197.0**	174.4*	207.5*
Station 7	46.9*	132.4*	110.8*	598.7**	176.7*	173.0*
Station 8	23.1*	136.0*	85.6*&**	626.8***	184.7****	132.9**

* The above chart shows the mean values per shingle in "Corrected Klett-Units" for each station at each time of periphyton sampling. Those values with the same number of asterisks are sampling periods that are not significantly different at the station in question.

Date of sample Removal ---	July 9	July 23	August 6	August 20	September 3	September 17
Station 3a	0.63*	0.96*	0.43*	1.71*	1.55*	0.80*
Station 6	0.47*	1.37*	1.31**	14.42**	2.10*&**	2.50**
Station 7	0.57*	1.60*	1.33**	7.21***	2.13*&**	2.08**&***
Station 8	0.28*	1.64*	1.63**	7.55***	2.23**	1.60***

* The above chart shows the mean value per square inch in "Corrected Klett-Units" for each station at each time of periphyton sampling. Those values with the same number of asterisks are stations not significantly different at the sampling period in question.

seen to appear for about three weeks at Stations 7 and 8.

There was an indication of more pigment from the artificial substrates following fertilization than from the periods before fertilization. This may indicate some residual influences of the fertilizer. The multiple range tests failed to separate Stations 6 and 7 from the prefertilized values after the initial fertilized period. Multiple range tests on data from Station 8 show a significantly lower amount of pigment following the fertilized period. This did not reach a point as low as the prefertilized levels. Thence, Station 8 had an increased standing crop of periphyton for a period following direct fertilization greater than that at Stations 6 and 7. This may be the result of regeneration of phosphorus that was previously bound in an upstream periphyton crop and was released by decomposition.

Summarizing the results of periphyton analyses, one finds a large immediate response to the fertilizer that in all probability exceeds any natural fluctuations. There are indications that the fertilizer may influence periphyton production for some time following fertilization.

Bottom fauna. The dynamics of the bottom fauna is a most complex facet of limnology. Competition, predation, life-cycles, habitat and variety of organisms all add to the complexity of analysis of the population. The fauna of the benthos is one of the important linkages between primary production and fish production. Trout consume very little of the primary production and depend on the invertebrate animals for most of their food. Insects compose most of the macro-invertebrate fauna of the West Branch of the Sturgeon River. Annelids are next in abundance and crayfishes (decapoda) and scuds (amphipoda) are exceptionally low in numbers when compared to other aquatic habitats.

Hoffman lake exhibited increases in numbers of organisms in 1956 (Plosila, 1958). Whether or not this reflects responses to fertilization remains obscured because of changes in technique in removing organisms from the samples. In 1956 the "floatation-method" found more organisms than the previous years "hunt-and-pick" method. The total standing crop biomass showed a decrease in 1956 when compared to 1954-55 results. Plosila (op. cit.) contributes this change to variability in volumetric determinations. Studies were performed on the growth rates of a burrowing mayfly, Ephemera simulans. These studies indicated an increase in growth rate in 1955 over 1954 studies; but 1956 data indicated a rate similar to unfertilized values.

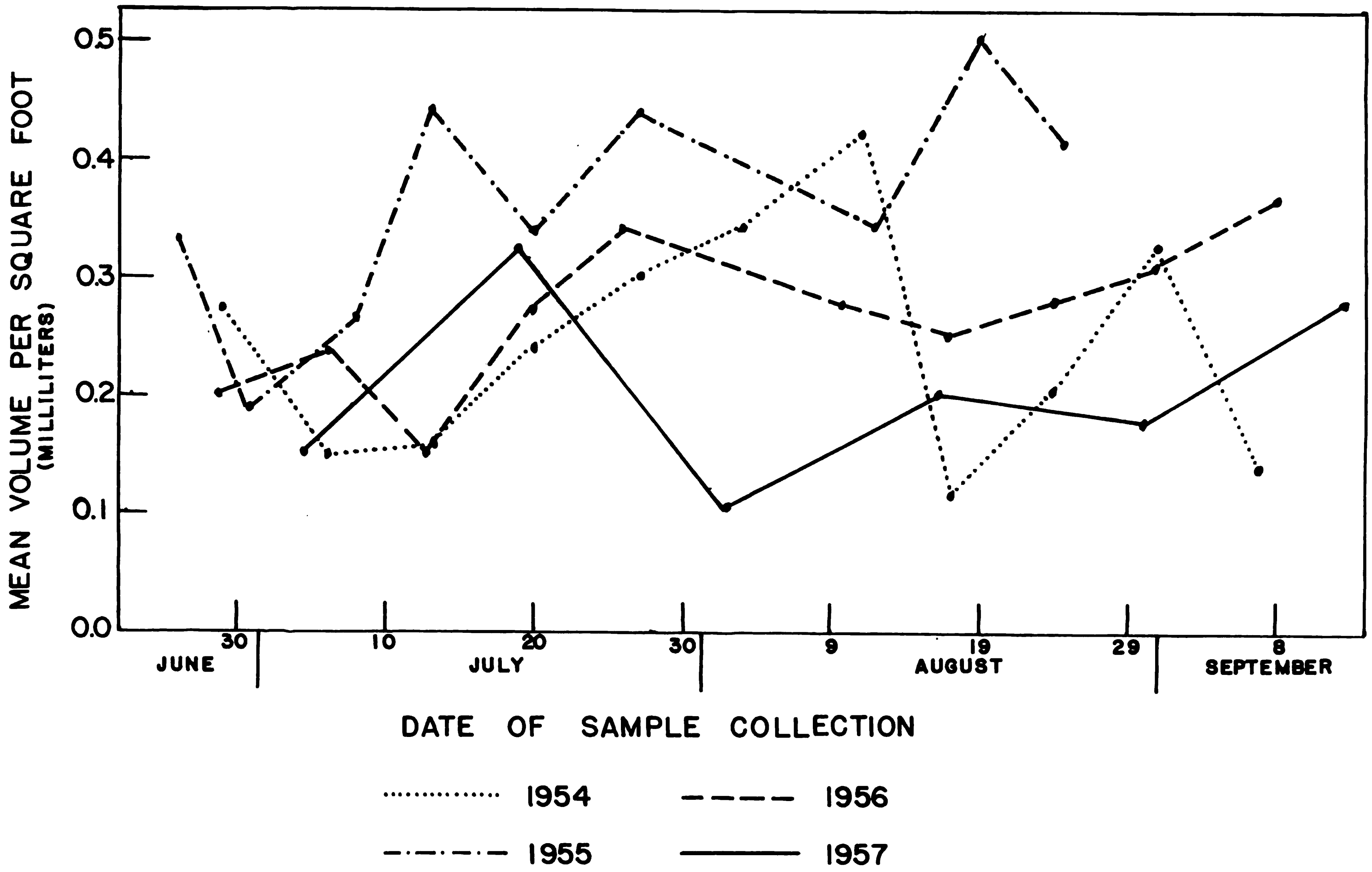
Measurements of volumes of standing crop of macro-invertebrates were used to determine trends in secondary production of the West Branch of the Sturgeon River in 1957. In previous years (1954-56) studies on various taxonomic groups were based primarily on numbers. This procedure produced results that are highly dependent on life-cycles. This is especially evident in those species in which the individuals are small but numerous. A species that is in the adult phase of its life-cycle fails to appear in the samples. Early instars will appear in increasing numbers in the samples as they reach a size large enough to be taken by our sampling methods. Many species have their adult or terrestial phase of the life-cycle in June and July. The immature specimens began to appear in late summer in increasing numbers. This may readily produce an inaccurate estimate, based on numbers, of the insect population response to fertilization. The post-fertilization period is in August and September when sampling obtains increasing numbers of insects.

Total numbers may also distort estimates of total standing crop in another way. The majority of the stream's organisms are small. It takes many small organisms to equal the value of a large organism in terms of food required to produce the organism and food value for the organisms' predators. It was believed that a study based on the biomass of benthic organisms would provide a valid picture of secondary production dynamics. Volumes were taken instead of weights. Ball (1948) found that weights and volume are very similar and may be considered as interchangeable.

Station 8 is the only station used for all four years of study. A review of the total volume of bottom fauna of this station (Fig. XV) indicates wide fluctuations between sampling dates and years. These fluctuations may be attributed to a combination of several factors. In 1954 and 1955 slightly different transects were used. In these two years three transects were used with four evenly spaced samples along them. This distribution of samples, places more sampling weight (50% of the samples) near the bank. Near the bank increased silt and fine particle deposits support the burrowing ephemerids, which add considerable quantities to the volumes. Normal yearly and life-cycle fluctuations account for other variation. Changes in picking of samples may cause still other fluctuations. In the present study the "floatation-method" was used while in previous years the "hunt-and-pick" method was used. General trends show a slight decrease in total volume in 1957 over other years.

The data from the four stations used in 1957 (Stations 3a, 6, 7 and 8) show wide fluctuations between stations. Stations 7 and 8 are

Figure XV. Results of bottom fauna sampling from Station 8 for the years 1954, 1955, 1956 and 1957.



MEAN VOLUME PER SQUARE FOOT
(MILLILITERS)
0.0
0.1
0.2
0.3
0.4
0.5
30
10
20
30
9
19
29
8
JUNE
JULY
AUGUST
SEPTEMBER
DATE OF SAMPLE COLLECTION
1954
1955
1956
1957

relatively stable and generally similar in volume trends (Fig. XVI). Station 6 is stable prior to fertilization. This period of stability is followed by a trend upward for two sampling periods following fertilization and then a return to near prefertilization levels. That this upward trend is a response to the increased periphyton production at Station 6 following fertilization is very questionable.

Station 3a, the control, shows an upward trend also prior to and during this period. Station 3a exhibited a higher standing crop than other stations throughout the season, except for July 19 when the values dropped near those of the other stations. Station 3a exhibited more specimens of the large insects; namely Odonata and _Ephemera simulans_. These large organisms contributed to the increase in volumes.

It may be advantageous to remove the large Odonata from the samples and thereby reduce the means and the variance of the samples to compare more closely with those of the other stations. This does not appear to be ecologically sound. The Odonata are predators on other bottom fauna and thereby have consumed many other organisms to support their own growth. Odonata considered with other organisms in terms of production may reduce estimates of production based on standing crop.

Table 7 shows the results of a two-way analysis of variance performed on the volume measurements. This analysis is based on the method of Snedecor (1956). "F" values for stations were obtained by using the mean square value for "stations" as the numerator and the mean square of the error as the denominator. This is based on the concept that station values are from random points; i.e., any number of possible riffles may have been selected for sampling and an infinite number of points may have been sampled within the riffle. "F" values for season

Figure XVI. The mean total volume of bottom fauna sampled at various stations in 1957.

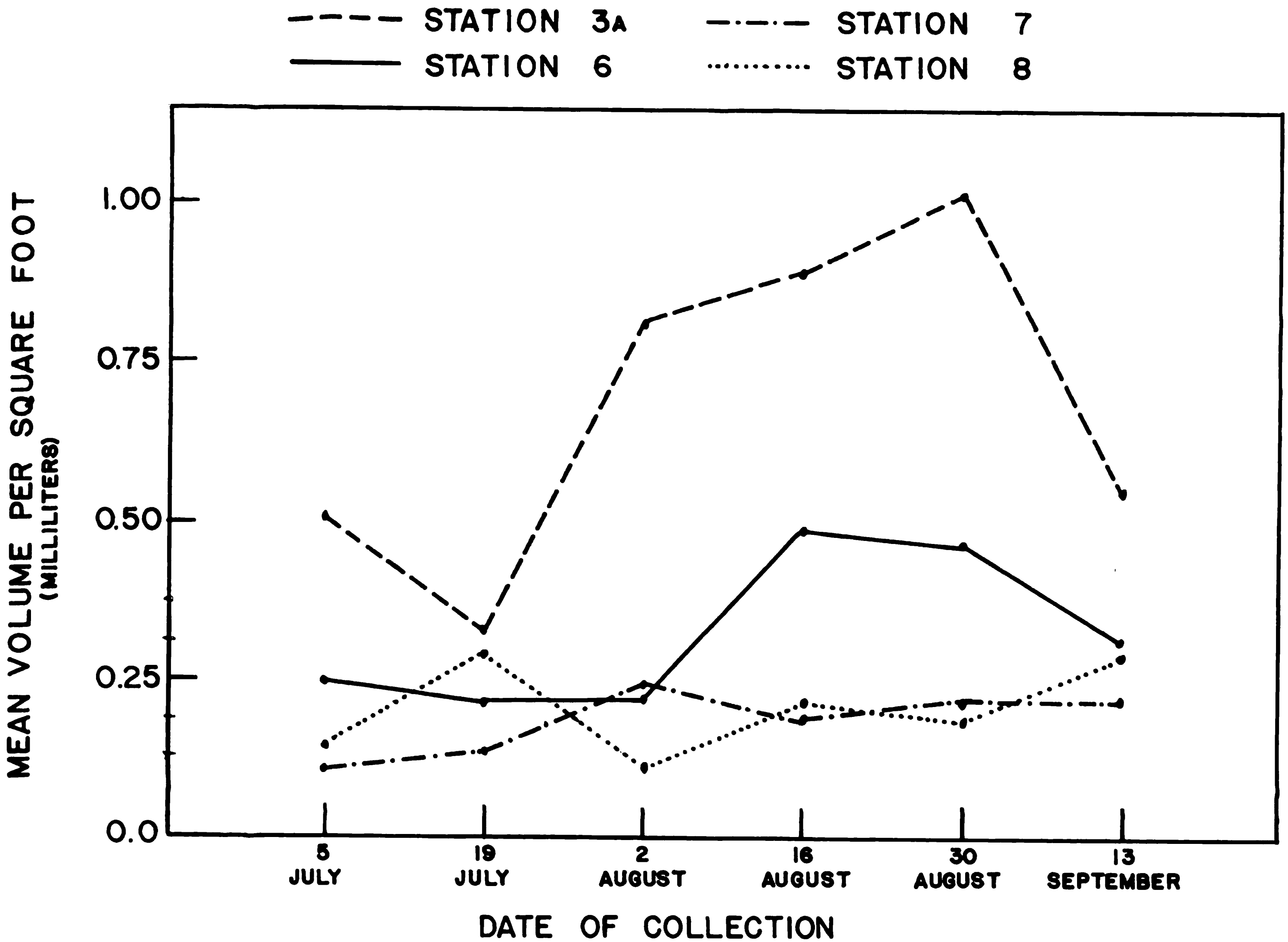

STATION 3A
STATION 6
STATION 7
STATION 8
MEAN VOLUME PER SQUARE FOOT
(MILLILITERS)
1.00
0.75
0.50
0.25
0.0
5 JULY
19 JULY
2 AUGUST
16 AUGUST
30 AUGUST
13 SEPTEMBER
DATE OF COLLECTION

Table 7

TWO-WAY ANALYSIS OF VARIANCE ON BOTTOM FAUNA COLLECTED FROM STATIONS 3a, 6, 7 AND 8

Source of variation	Sum of Squares	Degrees Freedom	Mean Square	"F" value
Total	30.1442	239	0.1430	---
Seasons (row means)	1.4549	5	0.2910	1.29*
Stations (column means)	9.949	3	3.3136	46.57**
Interaction	3.3734	15	0.2249	---
Subtotal (subclass)	14.7773	23	0.6224	---
Within groups (error)	15.3669	216	0.0711	---

* value not significantly different at five percent level.

** value exceeds 3.78, thus the means are significantly different at the one percent level.

changes were determined with mean square values from seasons and interaction as numerator and denominator respectively. In this instance seasons are natural and not influenced by sampling procedures. As a result of this analysis of variance, changes were not detected from one sampling period to the next. Extreme variation was found to lie between the various stations.

Samples were also collected from beds of Chara spp. at Station 7. There was wide variation in the population structure of each sample (table 8). The dominant invertebrate organisms were Pteronarcys pictetti, Odonata, Corydalidae, Diptera, Hexagenia recurvata and various Annelida of which Oligochaeta were most consistently dominant.[6] A total of nine families of Tricoptera were obtained, but their numbers and distribution are inconsistent. In the twenty-four samples taken only one scud, Gammarus spp., was found. Nine families of Diptera were recorded with tendipedids having the greatest (96%) frequency.

Volumetric measurements on these samples were taken when sufficient numbers in the various taxa were accumulated to provide a reasonable accurate measurement. Taxa not providing enough displacement were considered as a trace and disregarded in the final statistics. These small groups contribute very little to the total biomass.

The total biomasses of the samples from beds of Chara, are considerably higher than those from an equal area in a gravel riffle. Table 9 presents comparisons of volume of organisms from equal areas in the riffle and Chara beds at Station 7. The average square foot of Chara was found to support over five times the quantity that a square

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[6]For a complete list of taxa found in sampling beds of Chara, see appendix.

Table 8

BOTTOM FAUNA COLLECTED FROM CHARA-BEDS, WEST BRANCH OF THE STURGEON RIVER, STATION 7, 1957*
(PREFERTILIZATION)

DATE	July 3				July 16 & 17							
SAMPLE NO.	1	2	3	4	1	2	3	4	5	6	7	8
TAXA												
VERTEBRATA												
Entosphenous lamottenii	0/0	0/0	1/48.	1/42.	0/0	0/0	0/0	1/18.	0/0	1/.11	0/0	0/0
Cottus bairdii	2/.06	1/t	3/.10	1/1.10	1/.05	3/.74	0/0	3/.10	0/0	5/.10	3/.08	3/.14
PLECOPTERA												
Pteronarcys pictetii	0/0	3/.16	1/.09	3/.17	7/.79	1/.09	2/.14	5/.35	1/t	2/.14	0/0	6/.15
Miscellaneous	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/t	2/t	0/0	0/0	0/0
ODONATA												
Libelluidae	1/.05	0/0	0/0	2/.08	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Cordulegasteridae	0/0	0/0	0/0	0/0	1/.70	0/0	0/0	0/0	2/1.10	0/0	0/0	0/0
Gomphidae	0/0	0/0	0/0	0/0	0/0	1/.15	0/0	0/0	0/0	0/0	0/0	1/.30
MEGALOPTERA												
Corydalidae	5/.39	5/.44	3/.50	0/0	4/.27	1/.08	0/0	4/.26	1/.09	0/0	2/.11	1/.05
Sialidae	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/.06
TRICOPTERA												
Brachyentridae	2/.06	0/0	1/t	5/.07	2/t	0/0	7/.20	0/0	8/.10	4/.14	6/.15	8/.08
Hydropsychidae	0/0	2/.04	0/0	0/0	0/0	0/0	1/.02	0/0	0/0	0/0	0/0	0/0
Leptoceridae	0/0	0/0	0/0	1/t	0/0	0/0	0/0	0/0	1/t	0/0	0/0	0/0
Psychomyiidae	0/0	0/0	0/0	0/0	1/t	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Phryganeidae	0/0	0/0	0/0	0/0	1/t	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Molannidae	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/t	0/0
Miscellaneous	0/0	0/0	0/0	0/0	0/0	0/0	1/t	0/0	1/t	0/0	0/0	2/t

* number of organisms/volume of organisms in milliliters.

Table 8

BOTTOM FAUNA COLLECTED FROM CHARA-BEDS, WEST BRANCH OF THE STURGEON RIVER, STATION 7, 1957 (continued)*
(PREFERTILIZATION)

DATE	July 3				July 16 & 17							
SAMPLE NO.	1	2	3	4	1	2	3	4	5	6	7	8
TAXA												
DIPTERA												
Tendipedidae	7/t	14/t	4/t	1/t	25/.10	9/t	32/.15	5/t	40/.18	1/t	13/.07	1/5
Rhagionidae	3/.13	1/t	8/t	5/.10	4/t	0/0	5/.08	2/.04	2/.06	0/0	0/0	0/0
Tabanidae	6/.08	1/t	0/0	1/t	0/0	1/t	10/.25	0/0	4/.10	1/t	6/.20	0/0
Anthomyiidae	0/0	1/t	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Tipulidae	0/0	0/0	1/t	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Heleidae	0/0	0/0	0/0	1/t	4/t	0/0	5/t	0/0	0/0	1/t	1/t	0/0
Ptychopteridae	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/.10	0/0	0/0	0/0
EPHEMEROPTERA												
Baetidae	18/.13	5/.07	17/.15	1/5	6/.05	1/t	4/t	0/0	2/t	1/t	2/t	1/t
Hexagenia recurvata	1/t	0/0	0/0	5/.29	2/t	0/0	0/0	1/.07	41/2.3	12/.50	10/.64	4/.24
Ephemera simulians	0/0	0/0	1/t	1/.08	0/0	0/0	0/0	3/.20	0/0	0/0	0/0	5/.19
COLEOPTERA												
Elmidae	1/t	0/0	1/t	1/t	10/.08	1/t	1/t	0/0	0/0	0/0	0/0	0/0
MISCELLANEOUS												
Annelida	3/.32	3/.39	1/t	0/0	1/.11	3/.10	0/0	3/.34	0/0	2/.60	0/0	1/t
Leeches	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	6/.43	1/t	0/0	3/.08
Arachnidae	0/0	0/0	0/0	0/0	1/t	0/0	0/0	0/0	0/0	0/0	0/0	0/0
OLIGOCHAETA	204 .26	83 .18	251 .57	95 .26	81 .09	167 .34	278 .30	171 .27	177 .20	208 .32	189 .50	143 .35
TOTAL **	251 1.42	118 1.28	289 1.31	125 1.05	151 2.19	188 .76	346 1.14	195 1.53	289 4.65	233 1.70	230 1.67	181 1.64

* number of organisms/volume of organisms in milliliters

** exclusive of vertebrata

Table 8

BOTTOM FAUNA COLLECTED FROM CHARA-BEDS, WEST BRANCH OF THE STURGEON RIVER, STATION 7, 1957 *
(POSTFERTILIZATION)

DATE	August 27				September 10 & 11							
SAMPLE NO.	1	2	3	4	1	2	3	4	5	6	7	8
TAXA												
VERTEBRATA												
Entosphenous												
lamottenii	0/0	0/0	0/0	2/1.66	0/0	0/0	0/0	2/.20	0/0	0/0	0/0	0/0
Cottus												
bairdii	1/.04	1/.04	1/.10	3/1.97	2/.39	1/.11	3/.71	8/1.64	4/.68	4/.65	2/.55	0/0
PLECOPTERA												
Pteronarcys												
pictetii	2/.60	1/t	0/0	0/0	2/.05	7/.61	1/.09	0/0	2/.07	0/0	2/.44	5/.41
Miscellaneous	2/t	0/0	2/t	0/0	3/.07	2/t	4/.03	1/t	4/.03	1/t	4/.07	6/.13
ODONATA												
Libelluidae	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Cordulegasteridae	1/.08	1/.61	0/0	0/0	1/.58	0/0	1/.54	1/t	0/0	0/0	0/0	0/0
Gomphidae	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
MEGALOPTERA												
Corydalidae	2/.19	0/0	0/0	0/0	1/.35	1/.43	1/.11	1/.05	0/0	1/.18	0/0	6/.40
Sialidae	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
TRICOPTERA												
Brachycentridae	1/t	2/.05	1/t	0/0	3/.08	2/t	1/t	1/t	0/0	3/t	4/t	0/0
Hydropsychidae	0/0	0/0	1/.08	0/0	0/0	5/.10	0/0	0/0	0/0	0/0	8/.13	3/.05
Leptocaridae	0/0	0/0	0/0	0/0	0/0	0/0	4/.05	0/0	1/t	3/t	0/0	7/.10
Psychomyiidae	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/t	4/t	0/0	0/0
Phryganeidae	0/0	0/0	0/0	0/0	1/t	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Molannidae	3/.06	1/t	0/0	3/.05	1/t	5/.11	2/t	0/0	0/0	2/t	0/0	0/0
Limnephilidae	0/0	1/.14	0/0	2/.04	2/.14	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Rhyacophilidae	0/0	2/.17	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Philopotomidae	0/0	0/0	0/0	0/0	2/t	0/0	0/0	1/t	2/t	0/0	0/0	2/t
Miscellaneous	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0

* number of organisms/volume of organisms in milliliters

Table 8

BOTTOM FAUNA COLLECTED FROM <u>CHARA</u>-BEDS, WEST BRANCH OF THE STURGEON RIVER, STATION 7, 1957 (continued) *
(POSTFERTILIZATION)

DATE	August 27				September 10 & 11							
SAMPLE NO.	1	2	3	4	1	2	3	4	5	6	7	8
TAXA												
DIPTERA												
Tendipedidae	9/t	4/t	2/t	0/0	5/t	15/.07	7/t	2/t	3/t	10/t	4/t	3/t
Rhagionidae	2/t	5/t	1/5	1/t	2/t	12/.10	10/.05	1/t	5/.04	1/t	9/.07	5/.10
Tabanidae	1/t	2/.15	0/0	2/.08	1/04	2/.10	2/.16	0/0	0/0	4/.08	0/0	4/.09
Anthomyiidae	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Tipulidae	2/.40	1/.74	0/0	0/0	2/.07	0/0	0/0	1/t	0/0	0/0	0/0	1/.15
Heleidae	6/t	0/0	1/t	1/t	6/t	16/t	10.t	11/t	0/0	11/t	8/t	3/t
Ptychopteridae	2/.07	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/.06	0/0	0/0	0/0
Stratiomyiidae	1/.15	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Simulidae	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/t	0/0
EPHEMEROPTERA												
Baetidae	1/t	0/0	0/0	0/0	4/t	9/t	1/t	2/t	5/t	7/t	16/.06	10/.10
<u>*Hexagenia recurvata*</u>	9/.75	2/.07	0/0	4/.34	12/.65	7/.43	1/.05	21/1.06	42/2.3	18/.43	0/0	12/.13
<u>*Ephemera simulians*</u>	2/.13	0/0	0/0	1/.07	0/0	0/0	0/0	0/0	1/.04	1/.05	0/0	1/.04
Heptagenidae	0/0	0/0	0/0	0/0	1/t	0/0	0/0	0/0	0/0	0/0	0/0	0/0
COLEOPTERA												
Elmidae	1/t	0/0	1/t	0/0	0/0	3/t	0/0	1/t	1/t	1/t	2/t	0/0
Dytiscidae	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/t	0/0	0/0	0/0
MISCELLANEOUS												
Annelida	0/0	1/.10	0/0	0/0	1/.33	1/.56	0/0	1/.05	0/0	0/0	1/.07	2/.15
Leeches	0/0	0/0	0/0	0/0	1/.04	0/0	0/0	0/0	3/.05	0/0	1/.30	0/0
Arachnidae	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
GAMMARUS	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/t	0/0	0/0	0/0
OLIGOCHAETA	133 .26	201 .38	28 .11	205 .30	219 .40	523 .52	207 .52	165 .50	187 .40	446 1.30	986 1.03	565 .56
TOTAL**	181 2.68	224 2.36	37 .19	219 .88	270 2.80	610 3.03	252 1.60	210 1.66	259 2.95	513 2.04	1046 2.17	636 2.36

* number of organisms/volume of organisms in milliliters ** exclusive of vertebrata

foot of gravel riffle supports.

Statistical analysis on the total biomass of the "Chara-samples" indicated no differences throughout the summer. An "F"-test value of 1.48 indicated that the periods were not significantly different at the five percent level. Gross examination of the data (Fig. XVII) indicates that there was a tendency for an increased standing crop

Table 9

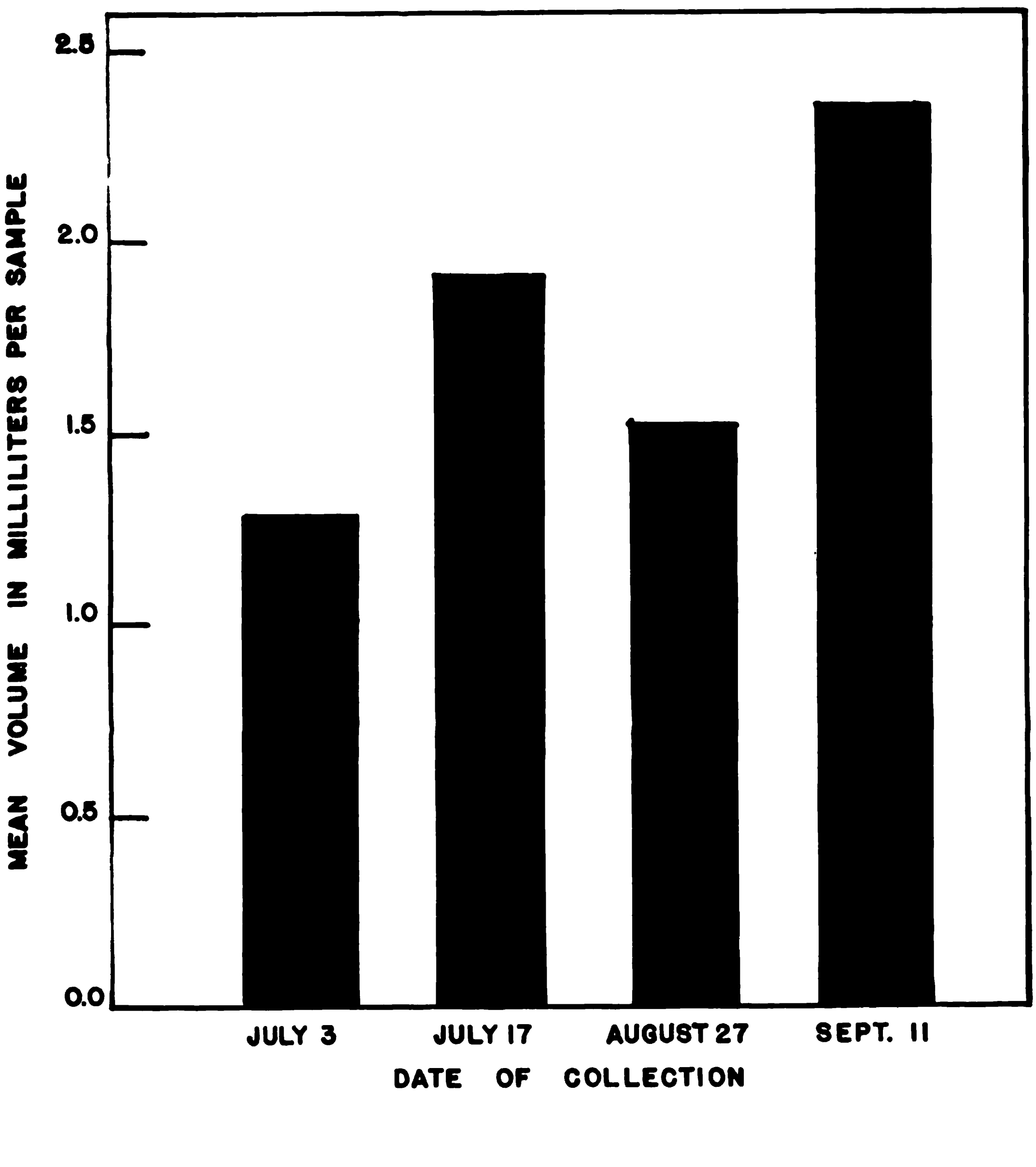
COMPARISONS OF TOTAL VOLUME OF ORGANISMS COLLECTED PER SQUARE FOOT IN A GRAVEL RIFFLE AND FROM BEDS OF CHARA, AT STATION 7.

Collection Period	Mean volume (ml.) gravel riffle	per square foot Chara
July 3-5	0.87	1.60
July 16-19	0.40	2.43
August 27-30	0.21	1.93
September 10-13	0.21	2.96

as the summer progressed. The sampling period means fluctuated around the total sample mean of 1.88 milliliters per sample.

The volume data of the Oligochaeta were submitted to a series of statistical tests. Oligochaetes were found throughout the study and do not exhibit the life-cycle changes of the insects. Their stable life-cycles, when compared to other benthic organisms, will provide for a less complex phase in population dynamics. It was believed that a smaller taxonomic group with a relatively simple life-cycle may indicate fertilization responses that may be obscured in the larger and complex total group. A preliminary "F"-test indicated changes in the standing crop biomass at the five percent level. A "Multiple Range Test" as devised by Duncan (1957) was then performed on the data. This test separates the means into groups that are not significantly different.

Figure XVII. Total volumes of invertebrate organisms sampled from beds of Chara, at Station 7.


2.5
2.0
1.5
1.0
0.5
0.0
MEAN VOLUME IN MILLILITERS PER SAMPLE
JULY 3
JULY 17
AUGUST 27
SEPT. 11
DATE OF COLLECTION

The design of the test is presented in table 10. The results of this test indicated two groups of means for the Oligochaeta volumes. One group group included all sampling period means except the last. The other group included all sampling period means except the first. This results in two over-lapping populations, removing any changes due to fertilization.

The results of bottom fauna analysis failed to indicate population responses to fertilization. There may have been an increase in the bottom fauna's production rate without an increase in the standing crop. This situation may arise with more efficient predation maintaining a similar or reduced standing crop while the production rates were increased (Hayne and Ball, 1956).

Fish. Fish were collected from both Hoffman Lake and the West Branch of the Sturgeon River. Studies on growth and condition of the fishwere of prime concern. Five species of fish were collected in Hoffman Lake; rock bass, common sunfish, largemouth bass, common suckers and yellow perch. Length-weight relationships were calculated from all data collected. Lengths at a given age were determined by back-calculating to the last complete annulus. These lengths were determined for fishes where ages were certain. Fishes whose age determinations were uncertain were rejected.

Fertilizer was applied to Hoffman Lake first in the summer of 1954. Values for the fish studies in 1954 (Alexander, 1956) are for fish that failed to have the possible benefit of increased nutrition. Fish length values are delayed for one year; 1957 mean lengths at the last annulus, were for the end of the 1956 growing season. The condition of the fish is dependent on the year when the fish were collected. Thus, 1957

Table 10

FIVE PERCENT "MULTIPLE RANGE TEST" ON MEANS OF OLIGOCHEATA SAMPLED FROM BEDS OF <u>CHARA</u>.*

a) Analysis of Variance

Source	d.f.	m.s.	$s = \sqrt{m.s}$
between periods	3	0.2332	---------
error	20	0.0492	0.2217

b) Critical values

p	(2)	(3)	(4)
zp	2.95	3.10	3.18
R'p	0.654	0.687	0.705

c) Ranked Period Means and Replication Numbers.**

C	B	A	D
0.2625	0.2963	0.3174	0.6538
(4)	(8)	(4)	(8)

d) Test Sequences

	result***
(D-C)' = .9033 > .7050, (D-B)' = 1.012 .6873.	(BAD)
(A-C)' = 1.098 > .6873.	----
ABC: (A-B)' = .0487 ≯ .6540	(ABC)

* For a detailed explanation of the test, see Appendix.

** The periods of sampling are coded as follows:

A., July 3
B., July 16 & 17
C., August 27
D., September 10 & 11

*** Two means appearing together in parentheses are not significantly different. Two means not together are considered different on the basis of the null-hypothesis.

condition factors are for an unfertilized environment, assuming no latent responses or influences of the fertilizer.

Alexander (1956) believed that the fish population of Hoffman Lake was relatively small. This was based on the general success of trapping in which only yellow perch were readily taken. Recaptures were reportedly quite frequent. Young fish were also unobtainable in 1954. Alexander postulated that this was due to predation by the adult populations. Anton (1957) observed that fishes were also in poor condition, except for largemouth bass, in 1955. Anton also detected a ten percent increase in weights for the yellow perch in 1955 over 1954.

Plosila (1958) observed that the yellow perch maintained their increase in weight in 1956. Plosila also detected what he considered as increases in the condition of the common sucker.

In 1957, the capture of common suckers was difficult compared to previous years. Four weeks of trapping produced 33 specimens. Small fish were not captured. The total lengths at time of capture were a minimum 12 inches and a maximum 16 inches. These fish ranged from three to seven years of age. The scarcity of smaller common suckers may be the result of efficient predation on their population.

The condition of suckers was improved in 1955 and 1956 over 1954. The respective length-weight relationship regression line formulas for the four years being considered are as follows:

1954; nat.log. weight = -0.4388 + 2.3852 nat.log. length
1955; nat.log. weight = -1.6995 + 2.9183 nat.log. length
1956; nat.log. weight = -1.4658 + 2.8318 nat.log. length
1957; nat.log. weight = -0.9352 + 2.5972 nat.log. length

A covariance analysis was performed on the combined data as outlined by Snedecor (1956) (table 11). This test indicated that the differences were in the slopes of the individual regression lines. This indicates that different size-classes gain their respective weights disproportionately. Individual covariance analyses were then performed comparing the lines in groups of two (table 12). The individual lines are depicted in Fig. XVIII.

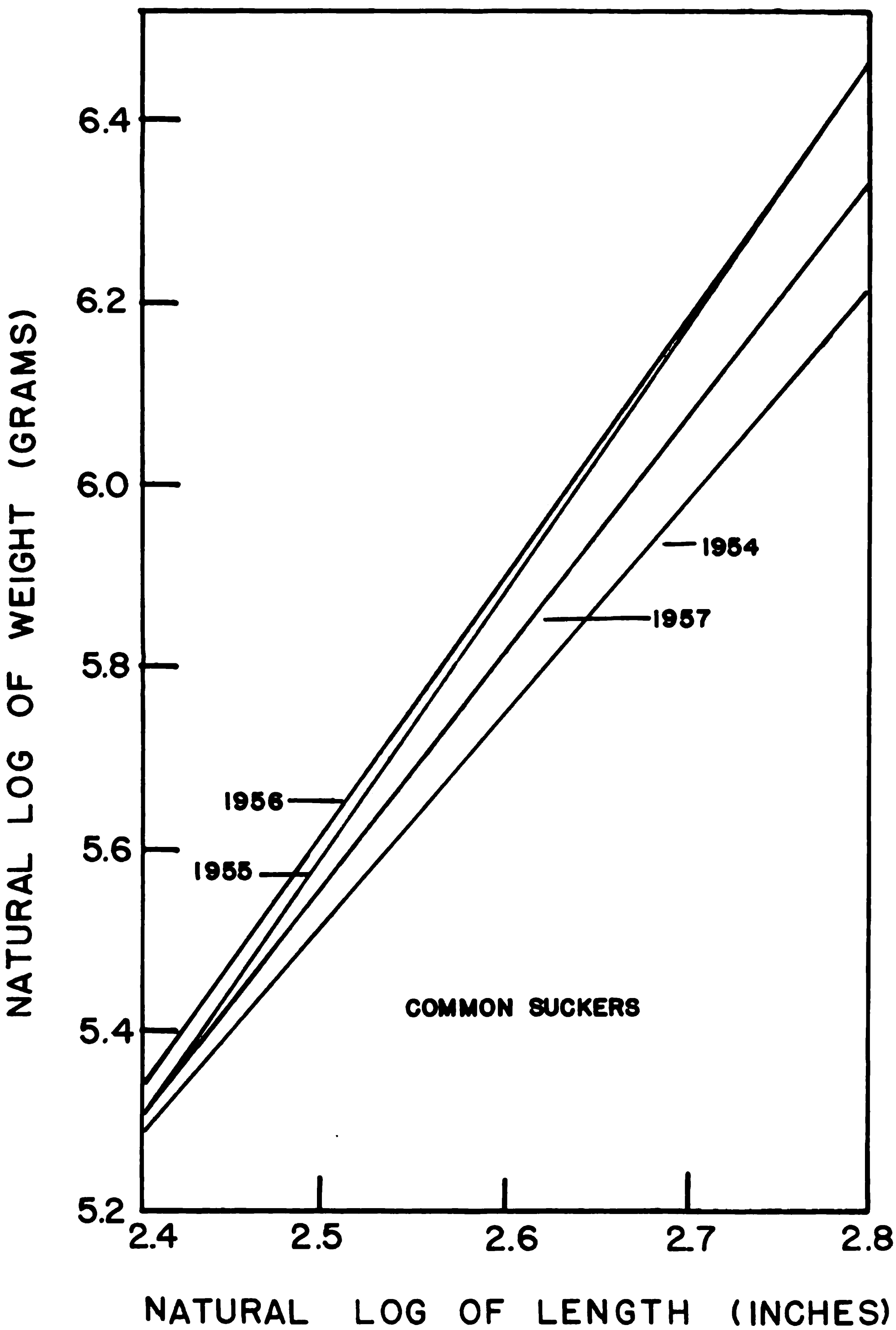
A review of the results of covariance analyses indicates that the suckers increased their weight in 1955 and 1956 over that of the prefertilized period of 1954. The larger fish gained weight more rapidly than the smaller fish. In 1957, a year after fertilization, the suckers didn't gain as much weight as in the two previous fertilized years. This did not drop the length-weight regression line to as low a value as the prefertilized year, 1954 (Fig. XVIII). The 1954 and 1955 lines are not significantly different at the five percent level.

The common suckers exhibited generally slow growth in comparison with other specimens from a similar latitude. (table 14). The scale samples indicated slow growth after the suckers reached a total length of ten inches. Table 14 presents the mean lengths for the Age Classes III through VIII. This table indicates a trend toward slightly increased growth rates in the 1957 samples over the 1956 samples.

The rate of growth of yellow perch in Hoffman Lake is less than in other lakes of the Midwest (table 14). The scales indicated this slow growth rate with their compaction of annuli. The closeness of annuli made age determination difficult and unsure in many specimens. Contestable age determinations were rejected for age and growth studies.

The length-weight regression lines for the four year studies are as follows:

Figure XVIII. Log-log transformations of length-weight relationships of common suckers sampled from Hoffman Lake, 1954, 1955, 1956 and 1957.



NATURAL LOG OF WEIGHT (GRAMS)
6.4
6.2
6.0
5.8
5.6
5.4
5.2
2.4
2.5
2.6
2.7
2.8
NATURAL LOG OF LENGTH (INCHES)
1956
1955
1954
1957
COMMON SUCKERS

Table 11

A COVARIANCE ANALYSIS FOR LENGTH-WEIGHT REGRESSION LINES OF THE COMMON SUCKERS, 1954-57

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	237	24.4352	0.1031
Due to general regression	1	22.5886	22.6886
Deviations from general regression	236	1.7466	0.0074
1. Can one regression line be used for all observations?			
Gain from four separate regressions over general regression	6	0.2714	0.0452
Deviations from separate regressions.	230	1.4752	0.0064
(."F" = 7.056, answer is no)			
2. Can a common slope be used for the separate regression lines?			
Deviations about lines with common slope but fitted through mean of each set of data	233	------	------
Further gains from fitting separate regressions (difference between slopes)	3	0.1363	0.0454
Deviations about separate regressions	230	1.4752	0.0064
("F" = 7.082, answer is no)			

Table 12

THE RESULTS OF COVARIANCE ANALYSES ON ln LENGTH - ln WEIGHT REGRESSION LINES FOR COMMON SUCKERS (based on 5% level)

Years Compared	Differences in the Fish
1954 and 1955*	Weight gains greater in larger size-classes in 1955 than in 1954.
1954 and 1956**	Weight gains greater in larger size-classes in 1956 than in 1954.
1954 and 1957	There were no significant differences in weight gains.
1955 and 1956**	There were no significant differences in weight gains.
1955 and 1957	All fish gained weight less rapidly in 1957 than in 1955.
1956 and 1957	All fish gained weight less rapidly in 1957 than in 1956.

* (Anton, 1957)
** (Plosila, 1958)

Table 13

CALCULATED MEAN WEIGHTS AND LENGTHS OF COMMON SUCKERS FROM HOFFMAN LAKE, 1954, 1955, 1956 and 1957

	1954*			1955**			1956***			1957		
Age Class	Number	Length (inches)	Weight (grams)	Number	Length (inches)	Weight (grams)	Number	Length (inches)	Weight (grams	Number	Length (inches)	Weight (grams)
III	7	9.9	175.7	21	10.1	187.8	17	8.8	109.1	6	10.8	190.0
IV	13	11.0	199.7	25	11.4	225.3	27	10.2	165.8	10	11.2	209.0
V	38	11.8	250.8	21	12.6	295.5	12	11.6	232.9	9	12.4	272.C
VI	8	12.7	307.0	11	13.6	372.3	7	11.0	205.3	2	12.9	301.0
VII	4	13.5	334.0	5	14.5	372.2	3	12.4	288.2	2	13.9	366.0

* (Alexander, 1956)
** (Anton, 1957)
*** (Plosila, 1958)

Table 14

CALCULATED TOTAL LENGTHS OF SEVERAL SPECIES OF FISH FOR HOFFMAN LAKE AND OTHER MIDWESTERN AREAS*

Species and Local	Age Class				
YELLOW PERCH		II	III	IV	V
Hoffman Lake, 1956		3.8	4.3	5.1	---
Hoffman Lake, 1957		3.7	4.5	4.7	5.3
Ohio, general		4.5	6.0	7.3	8.4
Minn., general		4.5	6.0	7.3	8.4
Minn., Red Lake		4.8	6.8	8.4	9.3
COMMON SUCKERS	III	IV	V	VI	VII
Hoffman Lake, 1956	9.2	11.8	12.3	13.2	----
Hoffman Lake, 1957	10.8	11.2	12.4	12.9	13.9
Minn., general	10.2	13.1	14.9	16.7	18.1
Minn., general	11.6	13.9	15.8	16.7	17.2
Ohio, general	12.5	15.1	17.0	18.0	18.5
COMMON SUNFISH		III	IV	V	VI
Hoffman Lake, 1956		4.2	5.2	5.7	6.4
Hoffman Lake, 1957		3.95	5.1	5.6	5.7
Minn., general		4.4	5.5	6.4	7.2
Minn., general		5.1	6.5	7.7	9.6
Mich., general		5.9	6.8	7.5	8.0
ROCKBASS	II	III	IV	V	VI
Hoffman Lake, 1956	2.2	3.6	4.4	5.1	5.8
Hoffman Lake, 1957	2.7	3.4	4.5	5.3	6.3
Ohio, general	2.7	3.7	5.0	6.0	7.0
Minn., general	3.0	4.5	5.9	7.1	8.3
LARGEMOUTH BASS		II	III	IV	
Hoffman Lake, 1956		7.2	9.2	11.8	
Minn., general		9.3	11.5	13.1	
Wisc., North		9.7	11.7	13.2	
Ohio, general		8.0	11.5	13.9	

*Data other than Hoffman Lake from Carlander (1953), 1956 Hoffman Lake data from Plosila (1958).

1954; nat.log. weight = -2.0965 + 3.0855 nat.log. length
1955; nat.log. weight = -1.9729 + 3.0829 nat.log. length
1956; nat.log. weight = -1.4810 + 2.7831 nat.log. length
1957; nat.log. weight = -1.9618 + 2.9257 nat.log. length

A covariance analysis (Snedecor, 1956) was performed on the lines and significant differences observed (table 15). Covariance analyses comparing two regression lines are summarized in table 16. These tests indicate a rise in the condition of yellow perch for two years following fertilization and then a drastic drop to below prefertilization levels in 1957. The mean lengths for the age classes do not drop; but the weights for the individual age classes indicate severe reductions in the condition of the fish (table 17).

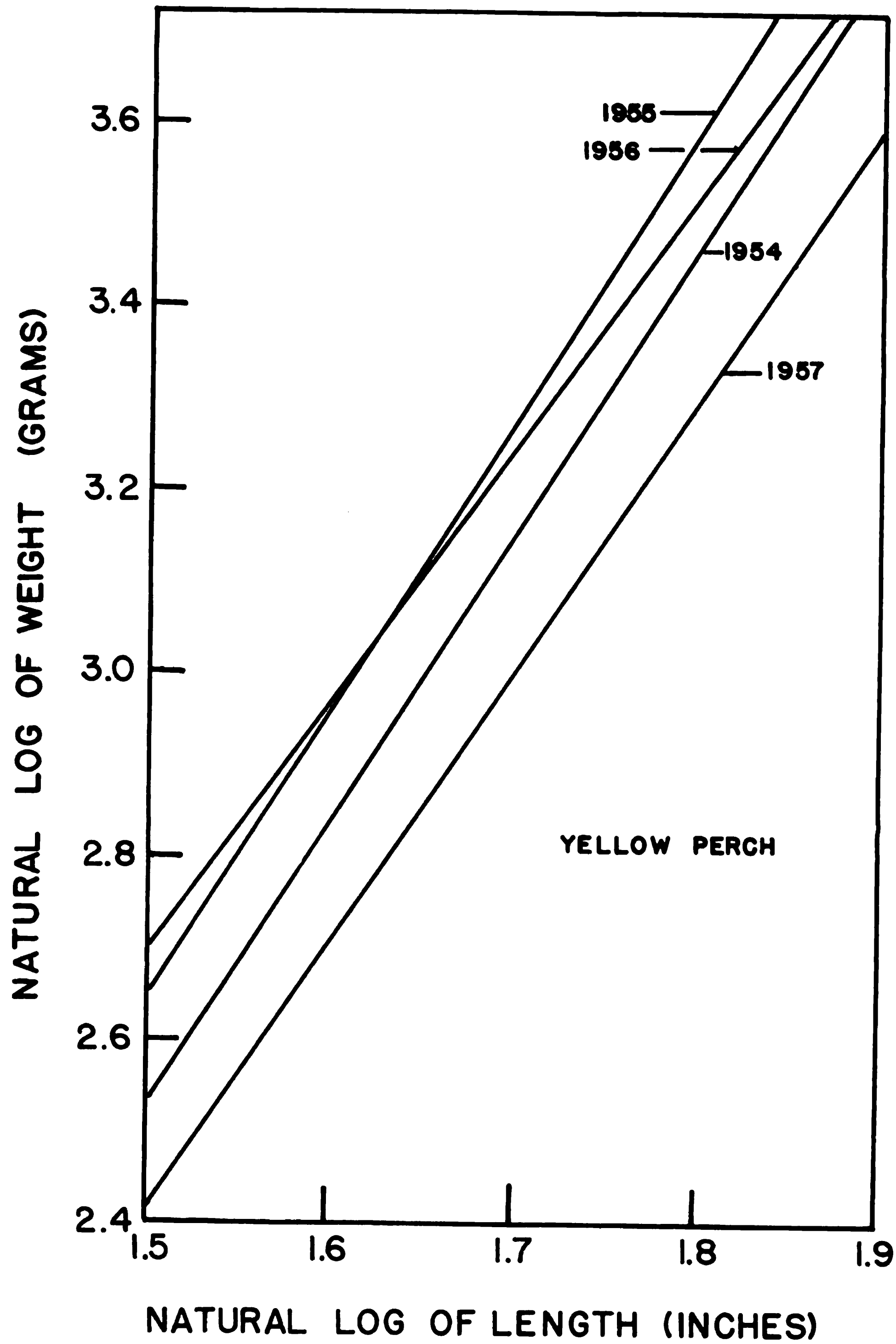
The common sunfish of Hoffman Lake are slower growing than in neighboring habitats (table 14). Length-weight regression line formulae for the various years are as follows:

1954; nat.log. weight = -1.3224 + 3.1370 nat.log. length
1955; nat.log. weight = -1.5133 + 3.2238 nat.log. length
1956; nat.log. weight = -1.2998 + 3.1121 nat.log. length
1957; nat.log. weight = -2.0452 + 3.4908 nat.log. length

Covariance analyses (Snedecor, 1956) were performed on the combined data (table 18). Summaries of individual covariance analyses are presented in table 19. The combined test indicated a slope difference in the ln length-ln weight regression lines; or a difference in weight gains that were not uniformly changed for the different size-classes. The condition factor (relationship of weight to length) was less in 1957 than in 1954.

Age studies of the rock bass indicated little change during the first three years, 1954-56. The covariance analyses on the length-weight regression lines indicated no differences in weight gains from 1954 through 1956. In 1956 the rock bass were not gaining weight as

Figure XIX. Log-log transformations of length-weight relationships of yellow perch sampled from Hoffman Lake, 1954, 1955, 1956 and 1957.



NATURAL LOG OF WEIGHT (GRAMS)
3.6
3.4
3.2
3.0
2.8
2.6
2.4
1955
1956
1954
1957
YELLOW PERCH
1.5
1.6
1.7
1.8
1.9
NATURAL LOG OF LENGTH (INCHES)

Table 15

A COVARIANCE ANALYSIS FOR LENGTH-WEIGHT REGRESSION LINES OF YELLOW PERCH, 1954-57

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	346	108.0839	0.3124
Due to general regression	1	97.9131	97.9131
Deviations from general regression	345	10.1708	0.0295
1. Can one regression line be used for all observations?			
Gain from four separate regressions over general regression	6	3.1942	0.5324
Deviations from separate regressions	339	6.9766	0.0206
("F" = 25.868, answer is no)			
2. Can a common slope be used for the separate regression lines?			
Deviations about lines with common slope but fitted through mean of each set of data	342	6.9942	0.0205
Further gains from fitting separate regressions (difference between slopes)	3	0.0176	0.0059
Deviations about separate regressions	339	6.9766	0.0206
("F" = 0.285, answer is yes)			
3. Can one mean be used for the separate regression lines?			
Gains from lines through each mean, with common slope, compared to general regression	3	3.1766	1.0589
Deviations about lines with common slope	342	6.9942	0.0205
("F" = 51.778, answer is no)			

Table 16

THE RESULTS OF COVARIANCE ANALYSES ON ln LENGTH - ln WEIGHT REGRESSION LINES FOR YELLOW PERCH (based on 5% level)

Years Compared	Differences in the Fish
1954 and 1955*	All fish gained weight less rapidly in 1954 than in 1955.
1954 and 1956**	All fish gained weight less rapidly in 1954 than in 1956.
1954 and 1957	All fish gained weight less rapidly in 1957 than in 1954.
1955 and 1956**	There were no significant differences in weight gains.
1955 and 1957	All gish gained weight less rapidly in 1957 than in 1955.
1956 and 1957	All fish gained weight less rapidly in 1957 than in 1956.

* (Anton, 1957)
** (Plosila, 1958)

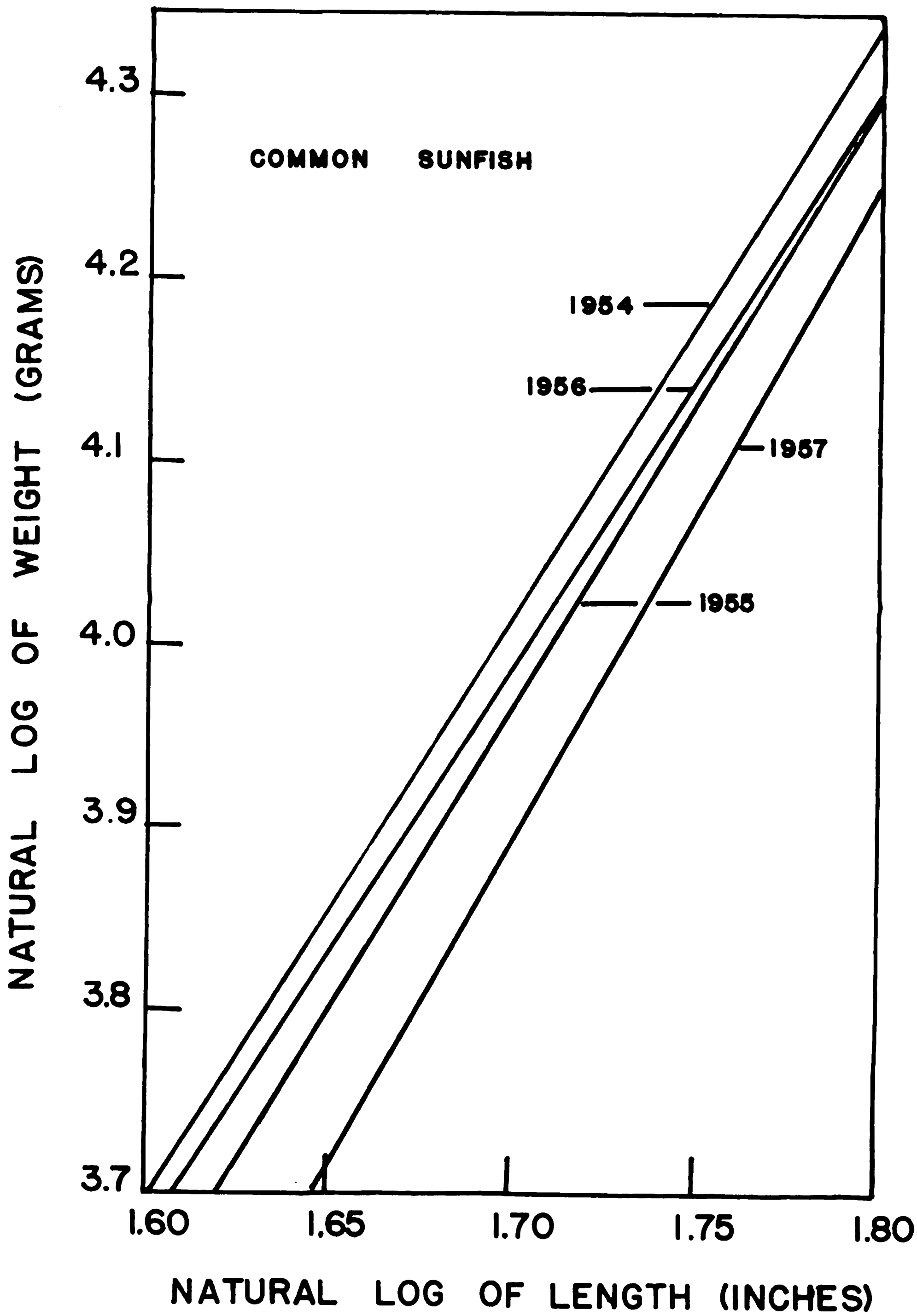
Table 17

CALCULATED MEAN WEIGHTS AND LENGTHS OF YELLOW PERCH FROM HOFFMAN LAKE, 1954, 1955, 1956 and 1957

Age Class	1954*			1955**			1956***			1957		
	Number	Length (inches)	Weight (grams)	Number	Length (inches)	Weight (grams)	Number	Length (inches)	Weight (grams)	Number	Length (inches)	Weight (grams)
I	8	3.8	7.3	--	---	----	7	2.6	6.0	--	---	----
II	46	4.6	13.6	23	4.6	16.5	20	3.8	9.3	9	3.7	6.4
III	28	5.0	20.4	24	5.1	21.2	39	4.3	13.2	9	4.5	12.0
IV	13	5.5	27.9	13	6.0	37.2	13	5.1	21.2	8	4.7	13.0
V	4	8.0	91.0	5	7.8	97.2	--	---	----	6	5.3	18.5

* (Alexander, 1956)
** (Anton, 1957)
*** (Plosila, 1958)

Figure XX. Log-log transformations of length-weight relationships of common sunfish sampled from Hoffman Lake, 1954, 1955, 1956 and 1957.



COMMON SUNFISH
NATURAL LOG OF WEIGHT (GRAMS)
4.3
4.2
4.1
4.0
3.9
3.8
3.7
1954
1956
1957
1955
1.60
1.65
1.70
1.75
1.80
NATURAL LOG OF LENGTH (INCHES)

Table 18

A COVARIANCE ANALYSIS FOR LENGTH-WEIGHT REGRESSION LINES OF COMMON SUNFISH, 1954-57

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	398	98.0740	-----
Due to general regression	1	94.5389	94.5389
Deviations from general regression	397	3.5351	0.0089
1. Can one regression line be used for all observations?			
Gain from four separate regressions over general regression	6	0.7215	0.1203
Deviations from separate regressions	391	2.8136	0.0072
("F" = 16.701, 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	0.2394	0.0798
Deviations about separate regressions	391	2.8136	0.0072
("F" = 11.083, answer is no)			

Table 19

THE RESULTS OF COVARIANCE ANALYSES ON ln LENGTH - ln WEIGHT REGRESSION LINES FOR COMMON SUNFISH (based on 5% level)

Years Compared	Differences in the Fish
1954 and 1955*	All fish gained weight less rapidly in 1955 than in 1954.
1954 and 1956**	There were no significant differences in weight gains.
1954 and 1957	Weight gains greater in smaller size-classes in 1954 than in 1957.
1955 and 1956**	There were no significant differences in weight gains.
1955 and 1957	Weight gains greater in smaller size-classes in 1955 than in 1957.
1956 and 1957	Weight gains greater in smaller size-classes in 1956 than in 1957.

* (Anton, 1957)
** (Plosila, 1958)

Table 20

CALCULATED MEAN WEIGHTS AND LENGTHS OF COMMON SUNFISH FROM HOFFMAN LAKE 1954, 1955, 1956 and 1957

Age Class	1954* Number	Length (inches)	Weight (grams)	1955** Number	Length (inches)	Weight (grams)	1956*** Number	Length (inches)	Weight (grams)	1957 Number	Length (inches)	Weight (grams)
I	--	---	----	--	---	----	3	1.4	0.8	--	---	----
II	--	---	----	8	3.4	12.2	---	---	----	17	3.1	6.7
III	8	4.7	35.1	13	4.5	33.0	3	3.9	18.8	14	4.2	19.4
IV	12	5.6	61.7	13	5.4	55.4	44	5.1	43.4	13	5.7	40.9
V	38	5.8	65.5	29	5.9	64.3	13	5.6	58.1	13	5.7	56.3
VI	37	6.3	85.8	28	6.3	82.9	4	5.7	61.4	2	6.4	84.3
VII	7	6.9	118.3	2	6.8	102.2	--	---	----	5	6.5	89.0
VIII	--	---	----	2	7.5	136.5	--	---	----	1	6.5	89.0

* (Alexander, 1956)
** (Anton, 1957)
*** (Plosila, 1958)

rapidly as in the three previous years. The length-weight regression line formulae for the various years are as follows:

1954; nat.log. weight = -0.5341 + 2.6558 nat.log. weight
1955; nat.log. weight = -0.6367 + 2.7113 nat.log. weight
1956; nat.log. weight = -0.4365 + 2.5694 nat.log. weight
1957; nat.log. weight = -1.2739 + 2.9722 nat.log. weight

Rock bass were found to be plentiful in the small size classes, two to four inches total length, in 1957.

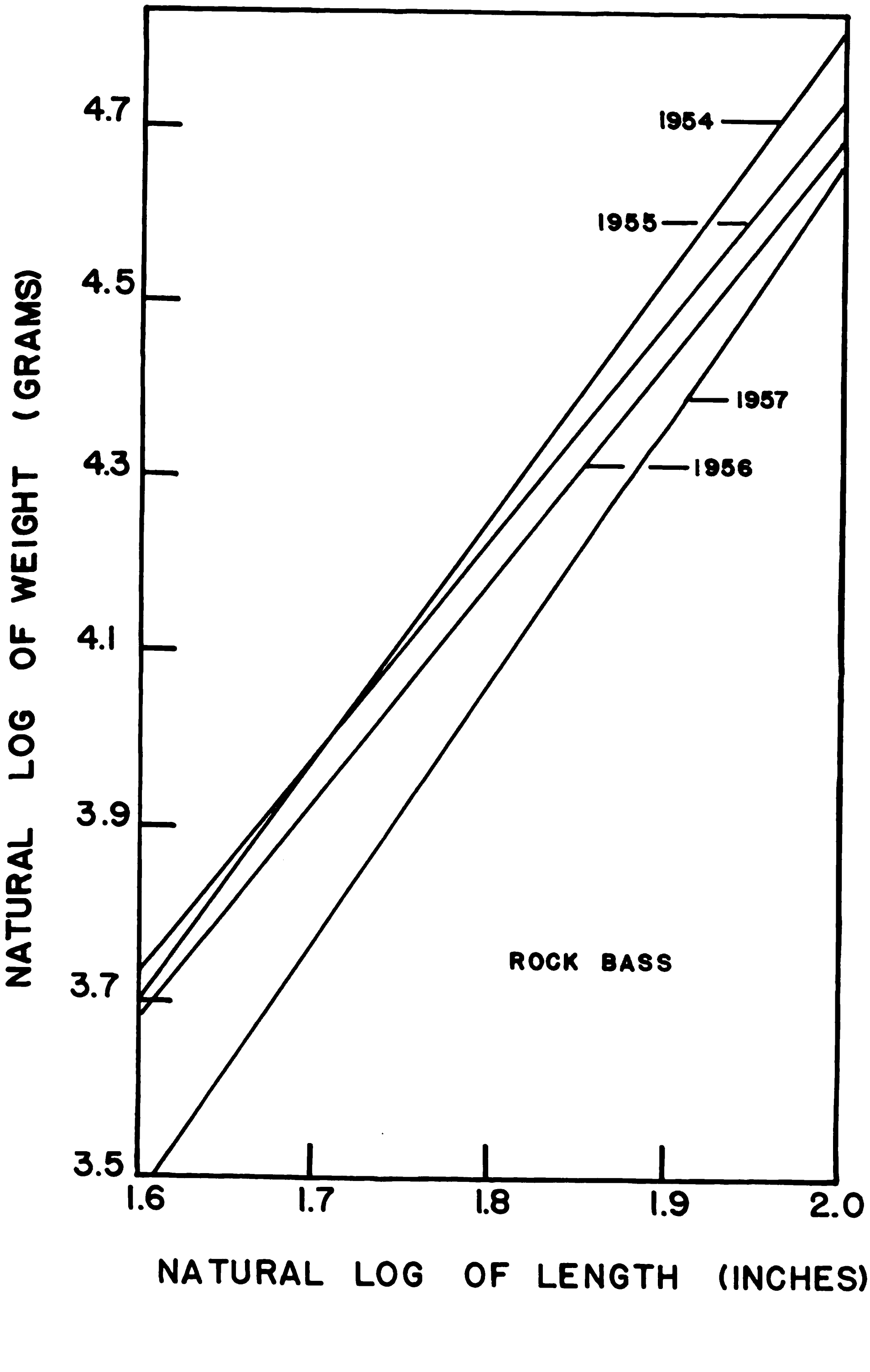
The trapping of largemouth bass in 1957 was unsuccessful compared to previous years. Four weeks of trapping produced only thirteen bass. Whether this is a reflection on a reduced population is doubtful. There is strong evidence that the traps were being molested. Only two speciments were collected above the ten inch legal size, which indicates that possibly the larger specimens were removed. This possible "human" predation" would alter the general population picture when compared to previous years. This along with the small sample size makes general statistics and conclusions unsatisfactory. The regression line formulae for 1954 through 1957 are as follows:

1954; nat.log. weight = -2.0813 + 3.2765 nat.log. length
1955; nat.log. weight = -1.7213 + 3.1020 nat.log. length
1956; nat.log. weight = -1.9679 + 3.2205 nat.log. length
1957; nat.log. weight = -2.5588 + 3.4463 nat.log. length

The general population statistics follow, but 1957 data should be evaluated cautiously.

The data collected for the Hoffman Lake fishes indicate a change. The fish appear to have been in a poorer condition in 1957. Some species, suckers and largemouth bass, increased their condition for two years and then dropped after fertilization ceased, though not below prefertilization values. Rock bass, yellow perch and common sunfish exhibit a reduction in their condition to considerably below prefert-

Figure XXI. Log-log transformations of length-weight relationships of rock bass sampled in Hoffman Lake, 1954, 1955, 1956 and 1957.



NATURAL LOG OF WEIGHT (GRAMS)
4.7
4.5
4.3
4.1
3.9
3.7
3.5
1954
1955
1957
1956
ROCK BASS
1.6
1.7
1.8
1.9
2.0
NATURAL LOG OF LENGTH (INCHES)

Table 21

A COVARIANCE ANALYSIS FOR THE LENGTH-WEIGHT REGRESSION LINES OF ROCK BASS, 1954-57

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	370	118.5502	0.3204
Due to general regression	1	105.2425	105.2425
Deviations from general regression	369	13.3077	0.0036
1. Can one regression line be used for all observations?			
Gain from four separate regression over general regression	6	2.4529	0.4088
Deviations from separate regressions	363	10.8548	0.0299
("F" = 13.6722, answer is no)			
2. Can a common slope be used for the separate regression lines?			
Further gains from fitting separate regressions (differences between the slopes)	3	0.3342	0.1114
Deviations about separate regressions	363	10.8548	0.0299
("F" = 3.726, answer is no)			

Table 22

THE RESULTS OF COVARIANCE ANALYSES ON ln LENGTH - WEIGHT REGRESSION LINES FOR ROCK BASS (based on 5% level)

Years Compared	Differences in the Fish
1954 and 1955*	There were no significant differences in weight gains for the various size-classes.
1954 and 1956**	There were no significant differences in weight gains.
1954 and 1957	Weight gains greater in smaller size-classes in 1954 than in 1957.
1955 and 1956**	There were no significant differences in weight gains.
1955 and 1957	Weight gains greater in smaller size-classes in 1955 than in 1957.
1956 and 1957	Weight gains greater in smaller size-classes in 1956 than in 1957.

* (Anton, 1957)
** (Plosila, 1958)

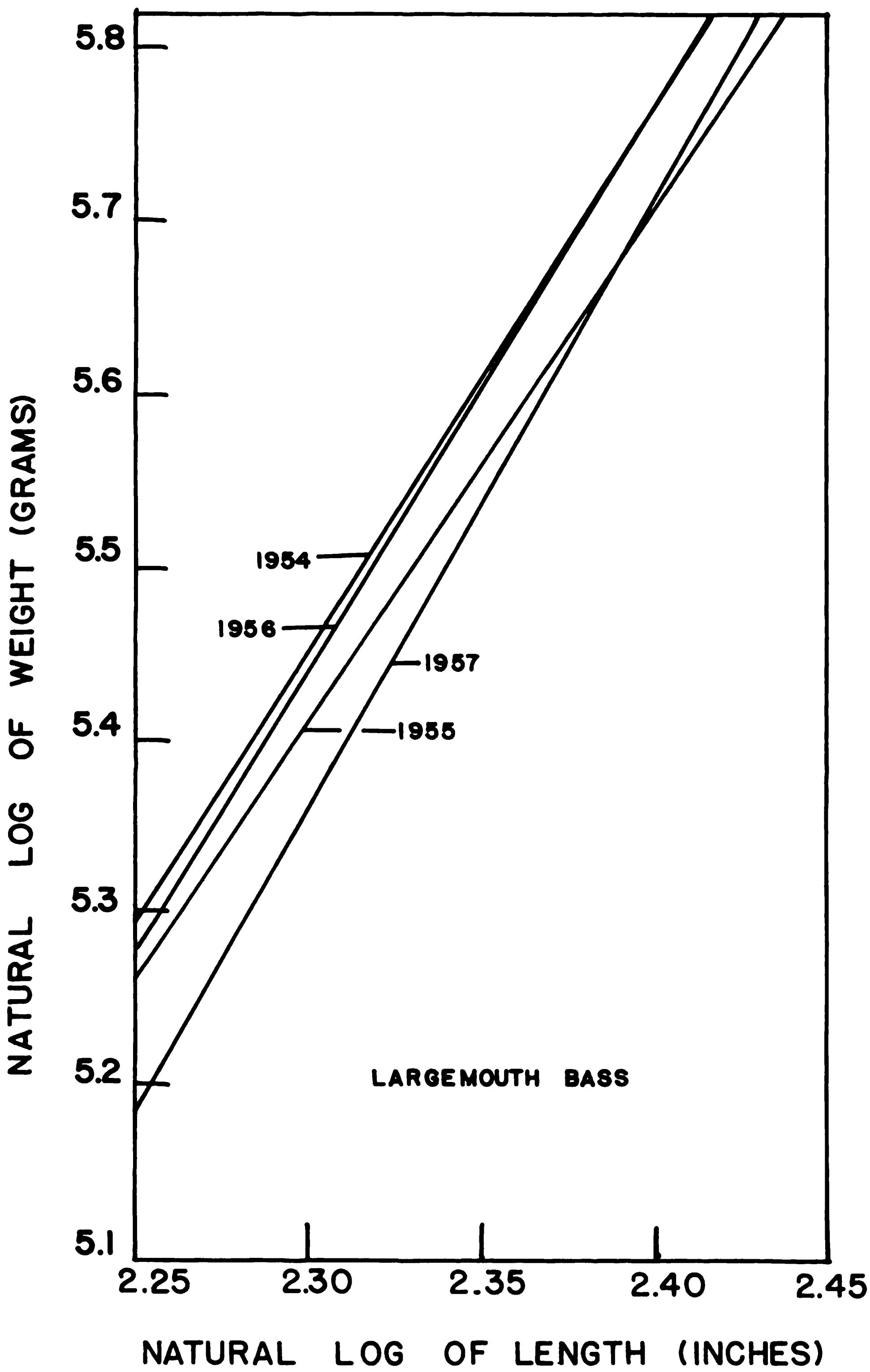
Table 23

CALCULATED MEAN LENGTHS AND WEIGHTS OF ROCKBASS FROM HOFFMAN LAKE
1954, 1955, 1956 and 1957

	1954*			1955**			1956***			1957		
Age Class	Number	Length (inches)	Weight (grams)	Number	Length (inches)	Weight (grams)	Number	Length (inches)	Weight (grams)	Number	Length (inches)	Weight (grams)
II	--	---	----	--	----	----	2	2.2	1.5	2	2.7	1.6
III	--	---	----	--	----	----	4	3.6	4.9	15	3.4	5.3
IV	2	4.7	34.0	4	4.9	40.4	20	4.4	29.4	24	4.5	24.5
V	15	5.4	50.8	10	5.3	49.6	36	5.1	42.5	16	5.3	39.8
VI	32	5.7	60.7	16	5.9	64.2	7	5.8	59.2	5	6.3	66.5
VII	26	6.1	72.8	22	6.3	77.8	21	6.1	67.3	2	6.2	63.4

* (Alexander, 1956)
** (Anton, 1957)
*** (Plosila, 1958)

Figure XXII. Log-log transformations of length-weight relationships of largemouth bass sampled from Hoffman Lake, 1954, 1955, 1956 and 1957.



NATURAL LOG OF WEIGHT (GRAMS)
5.8
5.7
5.6
5.5
5.4
5.3
5.2
5.1
1954
1956
1957
1955
LARGEMOUTH BASS
2.25
2.30
2.35
2.40
2.45
NATURAL LOG OF LENGTH (INCHES)

Table 24

A COVARIANCE ANALYSIS FOR THE LENGTH-WEIGHT REGRESSION LINES OF LARGEMOUTH BASS, 1954-57

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	148	80.635	------
Due to general regression	1	78.6847	68.6847
Deviations from general regression	147	1.9503	0.0133
1. Can one regression line be used for all observations?			
Gain from four separate regression over general regression	6	0.1893	0.0316
Deviations from separate regressions	141	1.7610	0.0125
("F" = 2.526, answer is no)			
2. Can a common slope be used for the separate regression lines?			
Deviations about lines with common slope but fitted through mean of each set of data	144	1.8101	0.0126
Further gains from fitting separate regressions (difference between slopes)	3	0.0491	0.1637
Deviations about separate regressions	141	1.7610	0.0125
("F" = 1.3106, answer is yes)			
3. Can one mean be used for the separate regression lines?			
Gains from lines through each mean, with common slope, compared to general regression	3	0.1402	0.0467
Deviations about lines with common slope	144	1.8101	0.0126
("F" = 3.718, answer is no)			

Table 25

THE RESULTS OF COVARIANCE ANALYSES ON ln LENGTH- ln WEIGHT REGRESSION LINES FOR LARGEMOUTH BASS (based on 5% level)

Years Compared	Differences in the Fish
1954 and 1955*	All fish gained weight less rapidly in 1955 than in 1954.
1954 and 1956**	There were no significant differences in weight gains for the various size-classes.
1954 and 1957	All gish gained weight less rapidly in 1957 than in 1954.
1955 and 1956**	There were no significant differences in weight gains for the various size-classes.
1955 and 1957	There were no significant differences in weight gains for the various size-classes.
1956 and 1957	All fish gained weight less rapidly in 1957 than in 1956.

* (Anton, 1957)
** (Plosila, 1958)

Table 26

CALCULATED MEAN LENGTH AND WEIGHT OF LARGEMOUTH BASS FROM HOFFMAN LAKE
1954, 1955, 1956 and 1957

Age Class	1954* Number	1954* Length (inches)	1954* Weight (grams)	1955** Number	1955** Length (inches)	1955** Weight (grams)	1956*** Number	1956*** Length (inches)	1956*** Weight (grams)	1957 Number	1957 Length (inches)	1957 Weight (grams)
I	--	----	----	--	----	----	2	3.3	6.5	--	----	----
II	23	8.6	151.7	9	8.9	148.2	14	7.2	80.6	3	6.4	46.5
III	15	11.4	380.0	30	10.9	322.2	6	9.2	177.5	9	7.0	63.3
IV	7	13.7	672.5	2	12.5	453.5	2	11.8	395.7	1	9.5	181.0
V	8	14.6	830.8	--	----	----	1	12.3	452.3	--	----	----
VI	2	15.9	1064.0	3	15.3	898.6	1	13.2	567.8	--	----	----

* (Alexander, 1956)
** (Anton, 1957)
*** (Plosila, 1958)

ilization levels once fertilization was stopped.

The lengths of these fish fail to indicate reductions. The reason for this is the last completed year of growth dealt with here is a fertilized year, 1956. The 1957 growth-year was not completed until after sampling operations ceased. Sampling will have to be performed in 1958 to see if growth rates were reduced following fertilization.

A possible cause for this phenomena of poorer condition lies in an increased survival rate for young fish following fertilization. An increase in food for young fish may not increase food for adult fish. A greater survival rate would thence increase the population. This increased population could keep pace with the increased food; providing no more nutrition per fish than before fertilization. Once fertilization ceased and the food supply diminished to normal the fish:food ratio would be reduced, thus creating greater stunting of the population than prior to fertilization.

Juday (1942) observed a decrease in the standing crop of fish following the fertilization of a lake. Weber Lake, Vilas county, Wisconsin, was fertilized several times. Early attempts with inorganic fertilizer failed to produce a response in plant production. Subsequent applications of organic fertilizers, soybean meal and cottonseed meal, produced an approximate fifty percent increase in plankton. After seven years of varied treatment, the animal biomasses failed to respond proportionately to the plant biomasses. The bottom fauna doubled its standing crop but the fish crop was reduced to approximately two-thirds of the prefertilization levels. Juday attributes the poor total animal response, ... "to the decrease in weight of the fish".

Three species of trout were collected from the West Branch of the

Sturgeon River; brown, brook and rainbow. These species exhibited an interesting distribution gradient. Upstream at Station 2 only brook trout were taken. The lack of other species here may be attributed to the silt bottom type or efficient competition from the brook trout. Temperature doesn't appear to be a limiting factor for other species at Station 2. Downstream the brook trout gradually diminish in numbers and the brown trout become dominant. At Station 8 only two brook trout were captured compared to 47 brown trout. Midway in the study area of the stream, Station 6, 37 brown trout and 42 brook trout were captured. Rainbow trout are located from Station 4 downstream. Eleven and nine specimens were captured at Stations 6 and 8 respectively. In previous years rainbow trout occurred more frequently at some stations than in 1957. The only other fish observed were muddlers, *Cottus bairdii*, and American brook lampreys, *Entosphenous lamottenii*. The lampreys were associated with the finer sediments and obtained when electro-fishing and bottom sampling (table 8).

The trout of the West Branch of the Sturgeon River have generally poor growth when compared to other streams. Colby (1957) compared these with data from Cooper (1953) and showed that the mean lengths for Age Classes are below those from what Cooper calls a low productivity stream in Michigan. Previous studies (Colby, 1957; Carr, M.S.) show no significant differences in the growth rates of the trout from 1954 to 1956. Colby found that the larger rainbow trout were in better condition following fertilization and postulated that this may be the result of the rainbow's feeding on the increased filamentous algae. The other species of trout failed to show a growth response to fertilization. A possible reason for failing to detect responses is in the technique of combining data from the various stations. Differences between stations may create variances in combined data that would not test significantly different statistically. Grzenda (personal communication) failed to detect station differences and combined the data from the various stations. Colby (1957) apparently assumed no station differences in 1955 and Carr (personal communication) assumed no changes in 1956. The 1957 data, to be presented subsequently, indicates strong differences between stations. These differences may have occurred in any of the years following 1954. No statistics have been performed comparing various years with 1957.

Scale samples were used to back-calculate total lengths to the last complete annulus. In this technique it is necessary to determine the body-scale length relationship as outlined in the section on "methods". The formulae obtained for the various species and stations are as follows:

Rainbow Trout,
Station 6: fish length = 3.1336 + 0.0263 scale length*
Station 8: fish length = 2.7378 + 0.0283 scale length
Brown Trout,
Station 6: fish length = 1.5810 + 0.0423 scale length
Station 8: fish length = 2.0796 + 0.0325 scale length
Brook Trout,
Station 2: fish length = 2.2267 + 0.0654 scale length
Station 6: fish length = 3.6801 + 0.0297 scale length

* scale length is the anterior scale radius (mm.) times eighty.

The resulting regression lines (Fig. XXIII, XXIV and XXV) exhibit considerable differences between the stations sampled. The regression lines for the rainbow trout (Fig. XXIII) differ least of the three species and a covariance analysis showed the lines not significantly different at the five percent level. The regression lines for brown and brook trout, Fig. XXIV and XXV respectively, exhibit large differences in the body-scale length relationships. Covariance analyses indicate the lines to be highly different in their slopes at five percent level tests, or the scale lengths change different than the body lengths at the stations sampled.

This may indicate that the scale technique is not valid for determining the lengths at the end of the various growing seasons. This is unlikely since studies indicate the technique is valid in neighboring waters. Cooper (1951) determined that the annulus was a valid age criteria in brook trout. Subsequent papers by Cooper (1952 and 1953) discuss the body-scale relationships of brook trout and growth from scale determinations for brook and brown trout in the Pigeon River, approximately twenty miles from the West Branch of the Sturgeon River. The calculated lengths of the various age classes in the West Branch of the Sturgeon River correspond to lengths at time of capture when the seasonal growth pattern of trout is considered (table 27 and 28). Upon completion of the annulus the trout begins a period of rapid growth in late spring and early summer, followed by a slower growth rate until the next annulus formation.

A possible explanation of the differences in body-scale length relationships at the various stations lies in temperature variations between years and stations during the period of scale formation. Hubbs (1922, 1926 and 1941) has presented several papers dealing with variations in the meristic characters of several species. The general theory is that the number of scales, vertebrae, fin-rays, etc. is dependent on the growth rate in the early stages of development. Low temperatures retard growth and development and produce an increased number in the meristic characters.

If the stations varied in temperature for one year during the study the numbers of lateral line scales might vary from the normal for this year class. This difference could be considerable in the fine-scaled salmonids. Eddy and Surber (1947) state the ranges in lateral line scale counts for brown and rainbow trout are 115-150 and 120-140 respectively. Brook trout lateral line scale counts exceed 200 (Eddy and Surber, op. cit.) and the mean number is around 230 (Jordan and Everman, 1902; Leach, 1939). A year class collected at a particular station, with a larger or smaller number of scales, would have a corresponding larger or smaller mean scale length and thence a different body-scale length relationship. This year class combined with other year classes could readily alter the slope of a body-scale length regression line.

The total lengths at time of capture and the calculated lengths indicate differences between the stations (table 27 and 28). These means though are not significantly different. The standard deviations readily indicate that the confidence intervals for various stations will overlap.

The length-weight relationships of the three trout species indicates differences between stations in the condition of the fish. The brook trout at Station 2 are heavier, in the smaller size groups, than the brook trout at Station 6 (Fig. XXVI). As the larger size classes are reached the differences become less until finally the situation is reversed. The two lines differ significantly in their slopes (table 34). This may indicate that younger brook trout at Station 2, closer to Hoffman Lake, were able to respond to increases in production from fertilization.

Brown and rainbow trout indicate a reversal from possible brook trout respond. The upstream Station 6 produced trout in better condition in the larger size classes than downstream Station 8 (Fig. XXVII and XXVIII).

The data indicates the presence of different trout populations in the river, the body-scale relationships vary significantly between stations and growth rates show minor differences from station to station. The condition or length-weight relationships of any one species differs between stations.

Table 27

MEAN LENGTHS AND STANDARD DEVIATION OF THE TROUT SAMPLED FROM THE WEST BRANCH OF THE STURGEON RIVER, 1957

Species and Station	Age Class, Mean and Standard Deviation *							
	0		I		II		III	
	Mean	std. dev.	Mean	std. dev.	Mean	std. dev.	Mean	std. dev.
Brook Trout								
Station 2	2.81	0.34	4.86	0.74	6.97	0.62	9.6	----
Station 6	3.12	0.43	5.24	0.77	7.40	----	----	----
Station 8	2.20	----	6.25	----	----	----	----	----
Brown Trout								
Station 6	2.58	0.19	5.27	0.49	8.18	0.80	10.13	----
Station 8	2.48	0.45	6.03	0.55	9.10	0.43	10.97	----
Rainbow Trout								
Station 6	----	----	5.05	0.62	6.40	----	----	----
Station 8	2.20	----	5.31	0.59	7.05	----	----	----

* standard deviation omitted if mean is derived from less than five specimens.

Table 28

CALCULATED LENGTHS AT THE LAST COMPLETE ANNULUS FOR AGE CLASSES I AND II OF TROUT SAMPLED FROM THE WEST BRANCH OF THE STURGEON RIVER, 1957

	Age Class			
	I		II	
Station and Species	Mean	std. dev.*	Mean	std. dev.
Brook Trout				
Station 2	4.20	0.54	5.48	0.87
Station 6	4.70	0.74	4.90	----
Brown Trout				
Station 6	3.68	0.32	5.30	0.61
Station 8	4.28	0.43	6.2	0.37
Rainbow Trout				
Station 6	4.2	0.18	4.5	----
Station 8	4.3	0.32	5.1	----

* standard deviation omitted if mean is derived from less than five specimens.

Figure XXIII. Body-scale length relationship of rainbow trout in the West Branch of the Sturgeon River.

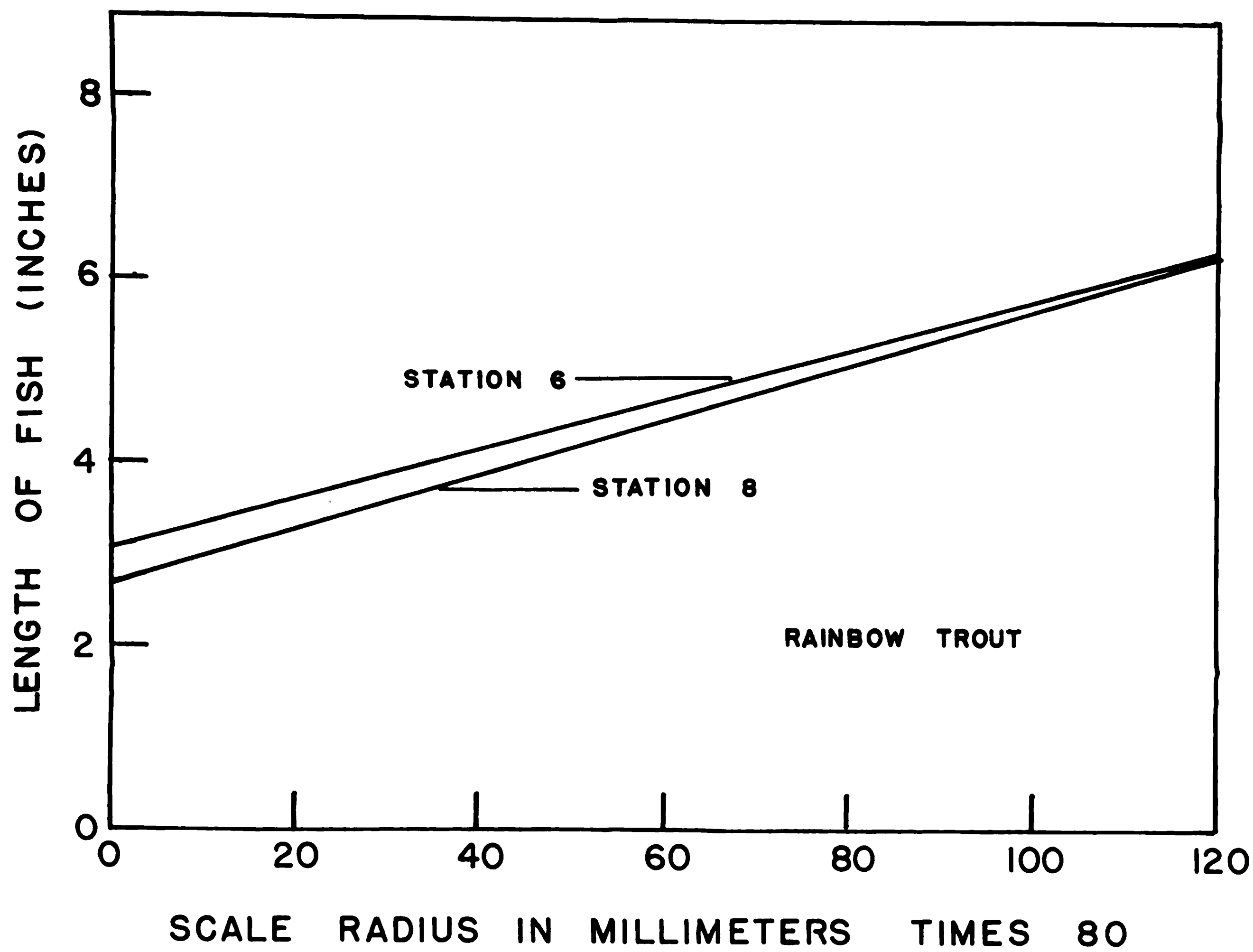

STATION 6
STATION 8
RAINBOW TROUT
LENGTH OF FISH (INCHES)
8
6
4
2
0
0
20
40
60
80
100
120
SCALE RADIUS IN MILLIMETERS TIMES 80

Figure XXIV. Body-scale length relationship of brook trout in the West Branch of the Sturgeon River.

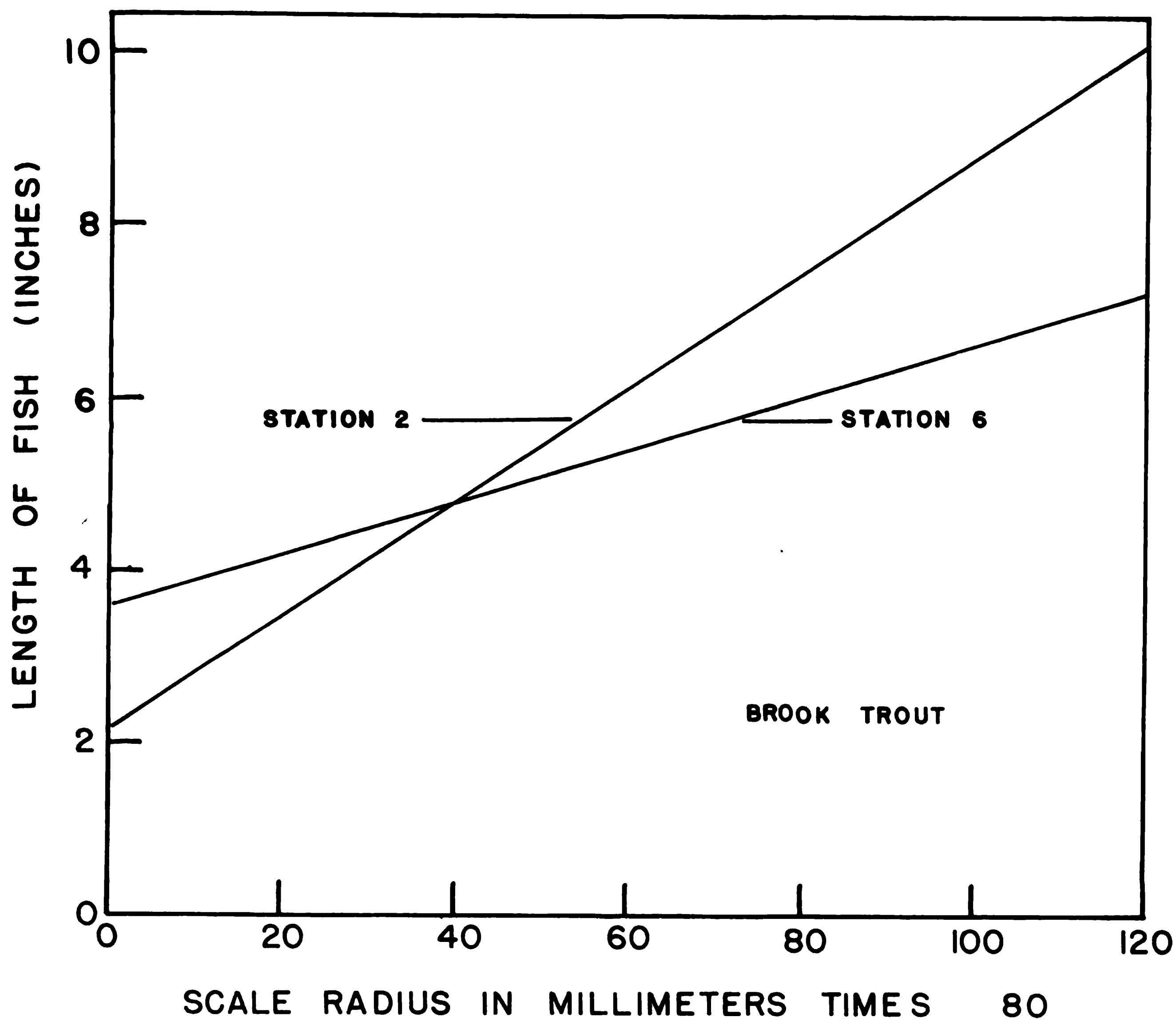
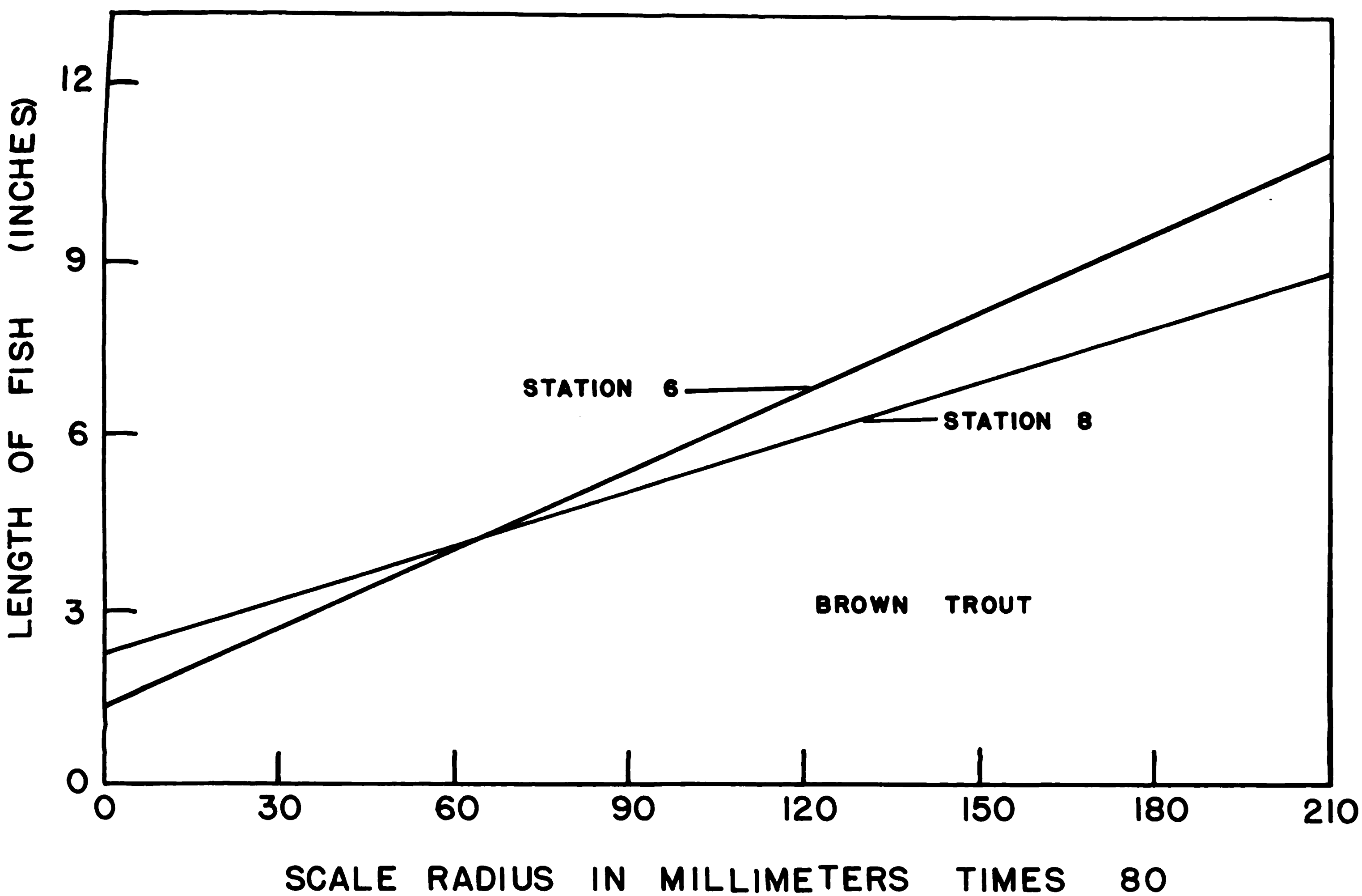
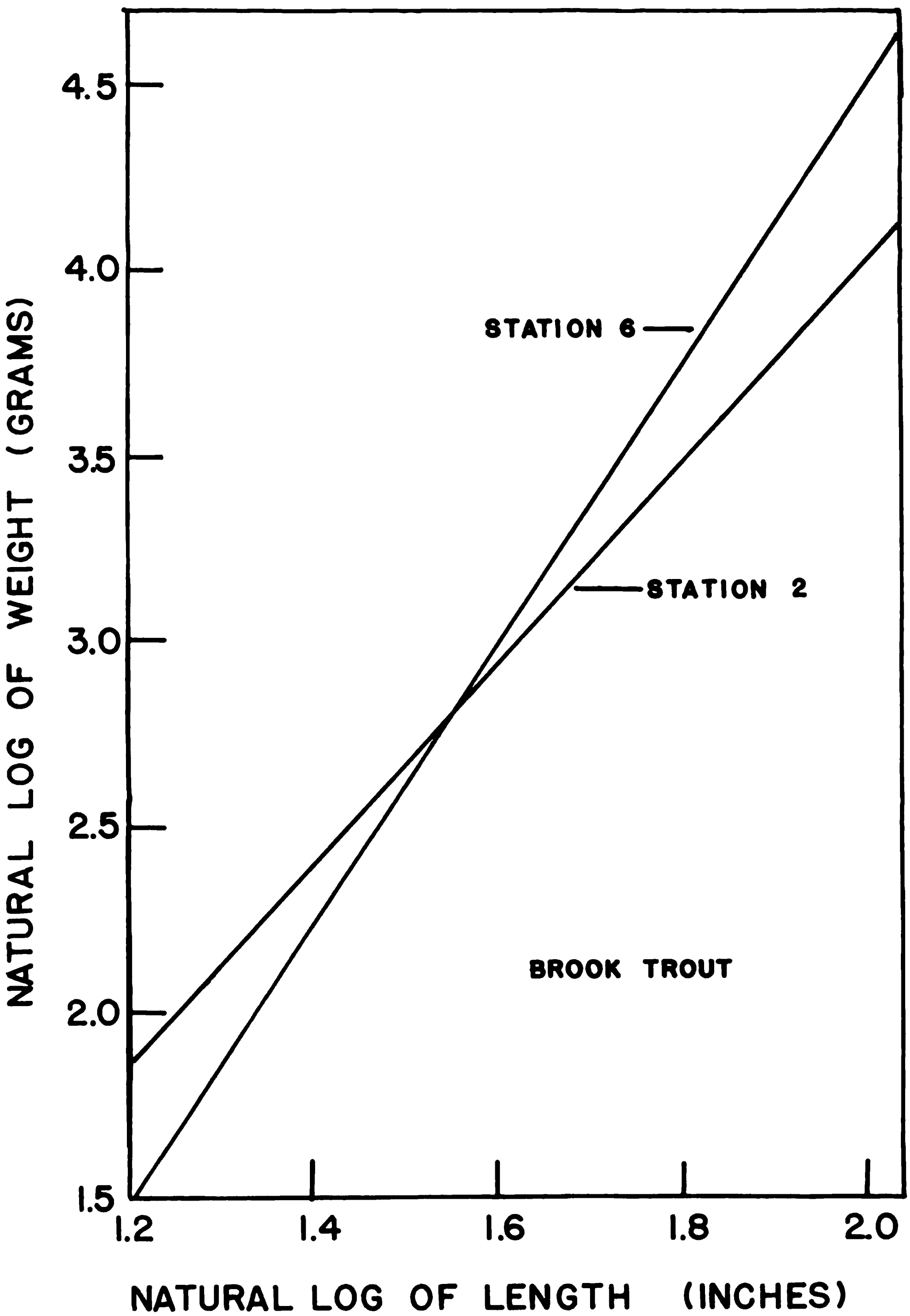

LENGTH OF FISH (INCHES)
10
8
6
4
2
0
STATION 2
STATION 6
BROOK TROUT
0
20
40
60
80
100
120
SCALE RADIUS IN MILLIMETERS TIMES 80

Figure XXV. Body-scale length relationship of brown trout in the West Branch of the Sturgeon River.



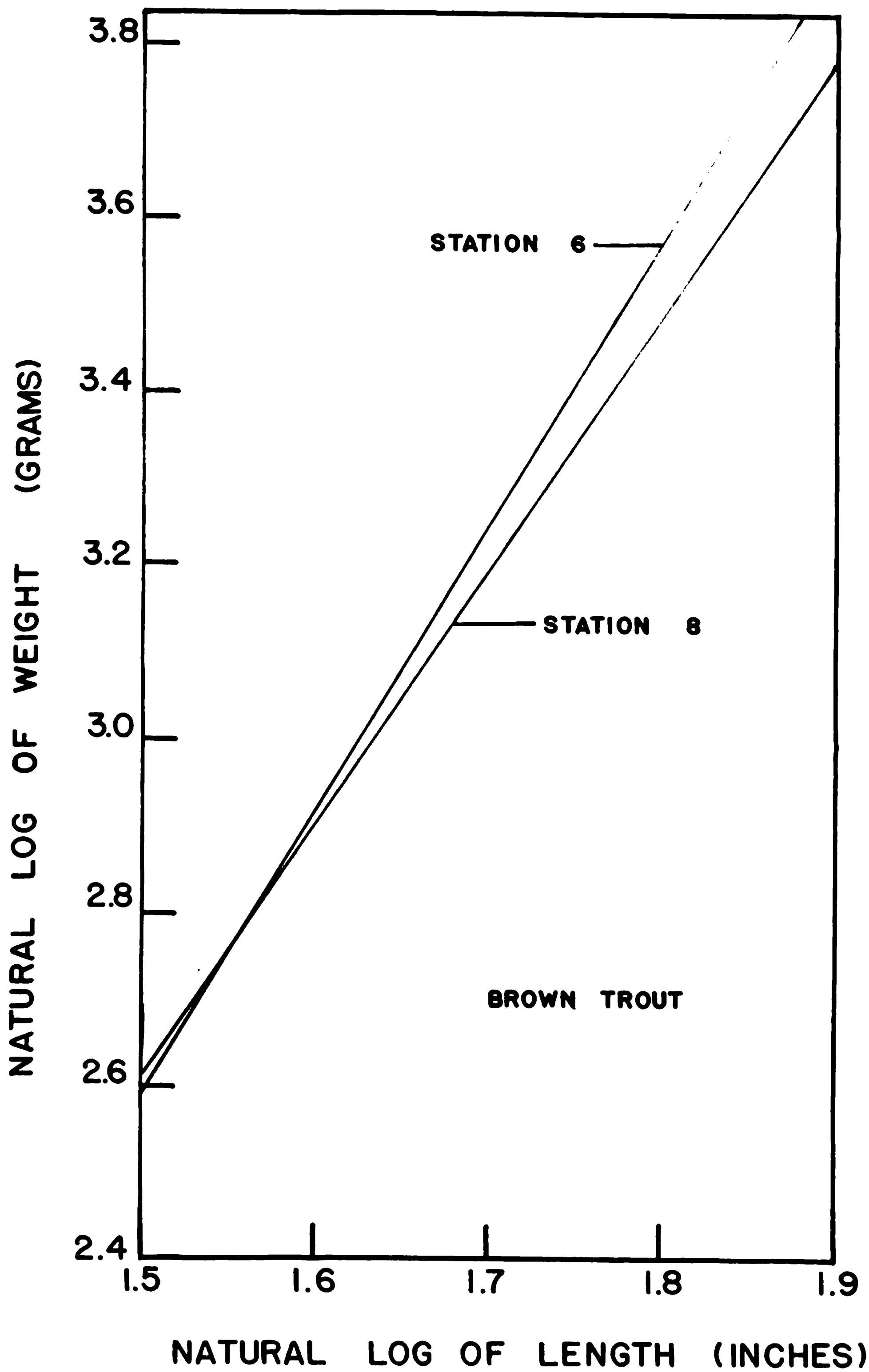
LENGTH OF FISH (INCHES)
12
9
6
3
0
STATION 6
STATION 8
BROWN TROUT
0
30
60
90
120
150
180
210
SCALE RADIUS IN MILLIMETERS TIMES 80

Figure XXVI. Length-weight relationship of the brook trout in the West Branch of the Sturgeon River, 1957.



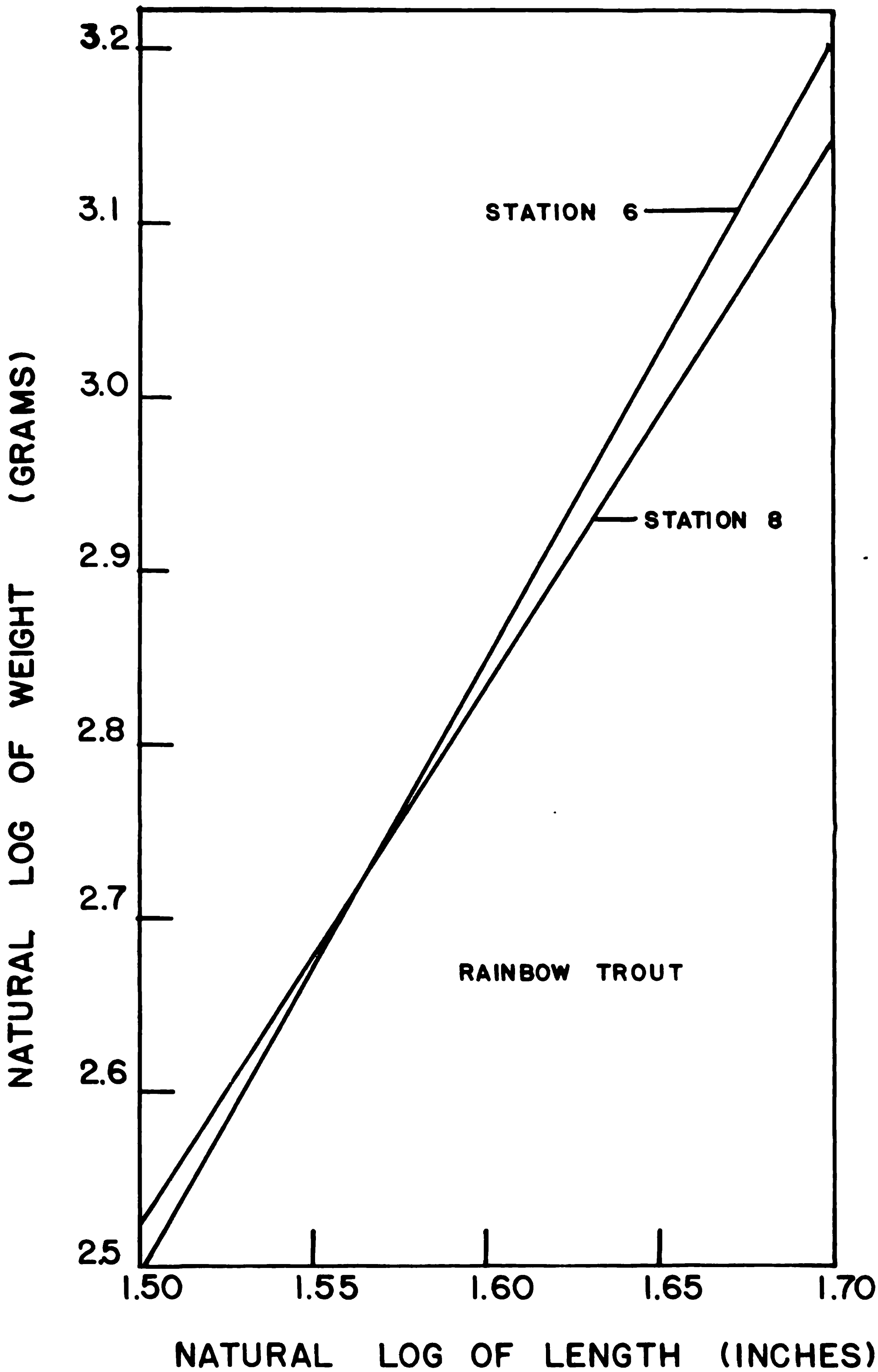
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.2
1.4
1.6
1.8
2.0
NATURAL LOG OF WEIGHT (GRAMS)
NATURAL LOG OF LENGTH (INCHES)
STATION 6
STATION 2
BROOK TROUT

Figure XXVII. Length-weight relationship of the brown trout in the West Branch of the Sturgeon River, 1957.



3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
NATURAL LOG OF WEIGHT (GRAMS)
STATION 6
STATION 8
BROWN TROUT
1.5
1.6
1.7
1.8
1.9
NATURAL LOG OF LENGTH (INCHES)

Figure XXVIII. Length-weight relationship of the rainbow trout in the West Branch of the Sturgeon River, 1957.



3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
NATURAL LOG OF WEIGHT (GRAMS)
STATION 6
STATION 8
RAINBOW TROUT
1.50
1.55
1.60
1.65
1.70
NATURAL LOG OF LENGTH (INCHES)

Table 29

A COVARIANCE ANALYSIS FOR LENGTH-WEIGHT REGRESSION LINES OF BROOK TROUT SAMPLED IN THE WEST BRANCH OF THE STURGEON RIVER, 1957

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	98	42.4600	------
Due to general regression	1	41.5262	41.5262
Deviations from general regression	97	0.9338	0.0096
1. Can one regression line be used for all observations?			
Gain from four separate regressions over general regression	2	0.1734	0.0867
Deviations from separate regressions	95	0.7604	0.0080
("F" = 10.833, answer is no)			
2. Can a common slope be used for the separate regression lines?			
Further gains from fitting separate regressions (difference between slopes)	1	0.0570	0.0570
Deviations about separate regressions	95	0.7604	0.0080
("F" = 7.125, answer is no)			

Table 30

A COVARIANCE ANALYSIS FOR LENGTH-WEIGHT REGRESSION LINES OF BROWN TROUT SAMPLED IN THE WEST BRANCH OF THE STURGEON RIVER, 1957

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	82	52.6560	------
Due to general regression	1	52.0210	52.0210
Deviations from general regression	81	0.6350	0.0078
1. Can one regression line be used for all observations?			
Gain from four separate regressions over general regression	2	0.3468	0.1734
Deviations from separate regressions	79	0.2882	0.0036
("F" = 47.532, answer is no)			
2. Can a common slope be used for the separate regression lines?			
Further gains from fitting separate regressions (difference between slopes)	1	0.0232	0.0232
Deviations about separate regressions	79	0.2882	0.0037
("F" = 6.356, answer is no)			

Table 31

A COVARIANCE ANALYSIS FOR LENGTH-WEIGHT REGRESSION LINES OF RAINBOW TROUT SAMPLED IN THE WEST BRANCH OF THE STURGEON RIVER, 1957

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	19	4.1570	------
Due to general regression	1	4.0479	4.0479
Deviations from general regression	18	0.1091	0.0061
1. Can one regression line be used for all observations?			
Gain from four separate regressions over general regression	2	0.0596	0.0298
Deviations from separate regressions	16	0.0495	0.0031
("F" = 9.64, answer is no)			
2. Can a common slope be used for the separate regression lines?			
Further gains from fitting separate regressions (difference between slopes)	1	0.0484	0.0484
Deviations about separate regressions	16	0.0495	0.0031
("F" = 15.66, answer is no)			

SUMMARY

The biological changes in a stream and lake with the direct addition of inorganic fertilizer are presented. The lake was fertilized in 1954, 1955 and 1956. Primary production of the periphyton was increased after the fertilization. Plankton failed to increase in the lake in 1954 and 1955. The organic content of the lake water increased after fertilization in 1956.

Five species of fish in the lake were studied. A temporary increase in the condition of the fish was observed and this returned to near or below the prefertilization levels after fertilization was stopped.

The West Branch of the Sturgeon River arises from Hoffman Lake and flows through its narrow valley to join the Sturgeon River. Studies on nutrients carried out of the fertilized lake were performed in 1954, 1955 and 1956.

The nutrients were not carried an appreciable distance downstream. The nutrients produced an increase in the standing crop of periphyton near the outlet of Hoffman Lake. Bottom fauna studies indicated no changes that could be attributed to the increased primary production of the upper stream. Fish studies indicated a lack of change in the fish population except for possible increases in the condition of limited size-classes of rainbow trout in 1955.

In 1957, fertilizer was added directly to the stream for eight days. Chemical changes were not noticeable except for the increased phosphorus. The phosphorus did not appear downstream in its estimated amounts or at predetermined times. It was hypothesized that the initial uptake of phosphorus was by the stream's soils and organisms. After approximately

two days of application of phosphorus to the water, during which very little reached the downstream areas, the phosphorus level approached the calculated amounts for approximately three days. The water's phosphorus content then began to drop rapidly until it was near prefertilization levels at the end of fertilizer addition. It was hypothesized that this later uptake of phosphorus was utilized by a rapidly increasing periphyton crop in the stream.

The periphyton crop in the stream showed increases from five to eleven times the prefertilized levels during the fertilized period. The periphyton crop was larger after the fertilization period than before. Following the period of introduction of phosphorus into the stream, the shingles were removed and others put in their place. The shingles at the station furtherest downstream produced the greatest amount of periphyton during the next collection period. It is believed that this may be the result of regeneration of phosphorus by a decomposing periphyton crop.

Studies on the bottom fauna sampled from riffles indicated no changes in the standing crop of organisms that could be attributed to fertilization. Studies on fauna sampled from beds of Chara failed to show a response to the fertilization. The beds of Chara supported a diversified fauna that maintained a much higher standing crop than the gravel riffles.

Studies on the trout of the West Branch of the Sturgeon River indicate changes probably occurred after the fertilization of Hoffman Lake. Evidence has been gathered that the fish populations differed between stations in 1957. This was not observed in 1954. Body-scale length and length-weight relationships were found to be different between the stations studied in 1957. Lengths at time of capture and calculated lengths indicate differences in growth rates between stations.

APPENDIX

TABLE A

A SUMMARY OF AIR AND WATER TEMPERATURES AND DEGREE OF CLOUDINESS

*, sky clear
**, sky semi-cloudy
***, complete overcast
****, raining

Station 3a

Date	time*	air temp.	HOH temp.	sky
June				
26	---	73	67	**
28	---	64	58	****
July				
4	9:15	68	60	**
5	9:15	58	59	**
9	10:30	59	58	**
11	8:15	64	56	***
12	9:30	68	57	*
18	10:30	71	62	*
19	9:15	68	60	*
23	11:30	67	60	**
25	10:00	62	56	***
26	8:45	65	58	***
Aug.				
1	9:10	70	57	*
2	9:40	77	58	**
5	9:25	68	53	*
8	10:00	71	59	***
9	10:30	66	57	****
15	10:40	62	57	***
20	10:15	70	52	*
23	10:05	69	55	***
29	11:20	60	55	***
30	10:15	66	56	**
Sept.				
3	12:30'	76	61	**
5	1:10'	63	59	*
6	10:30	57	51	**
12	11:15	63	57	***
13	10:15	65	56	***
17	10:00	54	49	**
MEAN	10:15	65.9	57.8	

Station 6

Date	time*	air temp.	HOH temp.	sky
June				
27	---	76	60	**
28	---	63	56	****
July				
4	9:55	71	58	**
5	10:50	59	57	**
9	11:45	58	56	**
11	8:45	61	55	**
12	11:10	71	57	**
18	10:00	71	57	*
19	10:50	74	58	*
23	12:45'	68	58	*
25	10:45	66	55	***
26	10:45	66	55	***
Aug.				
1	10:15	76	57	*
2	11:40	83	58	**
5	11:40	70	55	*
8	10:45	68	57	***
8	9:00'	62	57	*
9	1:20'	60	56	***
9	6:25	61	55	****
9	9:45	66	55	****
10	9:20	68	54	*
11	9:45	69	55	**
12	9:50	60	52	**
13	9:45	59	50	***
14	10:40	70	55	**
15	9:05	58	54	***
16	11:30	64	54	**
17	10:20	62	50	*
20	1:45'	71	56	**
23	11:35	68	53	***
29	11:50	59	52	***
Sept.				
3	1:10'	65	56	**
5	1:45'	59	55	*
6	1:00'	61	53	**
12	11:45	61	54	***
13	2:00'	63	55	**
17	2:20	62	53	**
MEAN	11:15	68.2	55.3	

*All items A.M., except for those that are primed.

TABLE A (cont.)

A SUMMARY OF AIR AND WATER TEMPERATURES AND DEGREE OF CLOUDINESS

*, sky clear; **, sky semi-cloudy; ***, complete overcast; ****, raining

Station 7					Station 8				
Date	time†	air temp.	HOH temp.	sky	Date	time*	air temp.	HOH temp.	sky
June					June				
27	----	68	60	**	27	----	65	60	**
29	----	74	59	**	29	----	68	61	**
July					July				
4	10:15	72	58	**	4	10:30	71	58	**
5	2:10'	73	59	**	5	3:30'	64	61	**
9	2:15'	66	57	***	9	2:45'	60	57	***
11	9:15	64	55	**	11	9:30'	66	55	**
12	1:40'	64	58	**	12	2:50'	66	59	**
18	9:40	72	55	*	18	9:30	73	55	*
19	2:50'	84	65	*	19	3:45'	82	65	*
23	3:00'	70	62	*	23	3:45'	62	61	*
25	10:55	69	54	***	25	11:05	65	54	***
26	12:15'	71	56	***	26	2:50'	73	58	***
Aug.					Aug.				
1	10:40	76	57	*	1	11:00	75	57	*
2	3:35'	83	64	**	2	4:50'	86	65	*
5	2:10'	75	60	*	5	3:35	74	61	*
8	3:20'	66	58	***	8	4:06'	70	57	***
8	8:45'	60	57	*	8	8:30'	62	57	*
9	12:55	62	56	***	9	12:35	62	56	***
9	6:10	60	55	****	9	5:50	63	55	****
9	9:00	67	55	****	9	9:00	67	55	****
10	9:10	68	54	*	10	9:50	67	54	*
11	9:35	70	54	**	11	9:25	70	54	**
12	9:40	60	51	**	12	9:35	60	52	**
13	9:30	60	50	***	13	9:20	60	50	***
14	10:20	72	54	**	14	10:10	70	54	**
15	8:50	59	54	***	15	8:40	59	54	***
16	11:50	64	55	**	16	11:20	67	53	**
17	10:00	64	49	*	17	9:20	62	49	*
18	10:45	69	51	----	18	10:35	68	51	----
20	3:10'	69	56	***	20	3:50'	64	57	****
23	2:15'	63	54	****	23	3:10'	63	54	****
29	noon	60	52	***	29	12:10	60	52	***
30	2:30'	69	57	**	30	3:30'	72	58	**
Sept.					Sept.				
3	4:15'	64	59	****	3	5:00'	64	59	****
5	2:00'	62	55	*	5	4:30'	63	58	*
6	2:15'	62	55	**	6	2:45'	64	54	**
12	noon	62	54	***	12	12:15'	63	54	***
13	3:20'	64	57	***	13	4:00'	63	57	***
17	2:40'	66	54	**	17	4:00'	65	55	*
MEAN	12:15'	67.4	56.1		MEAN	12:45'	66.6	56.3	

† All times A.M. except for those primed.

TABLE A (cont.)

A SUMMARY OF AIR AND WATER TEMPERATURE AND DEGREE OF CLOUDINESS

*, sky clear; **, sky semi-cloudy; ***, complete overcast, ****, raining

Station 9

Date	time*	air temp.	HOH temp.	Sky
July				
25	11:15	71	54	***
Aug.				
1	11:10	77	59	*
8	4:35'	72	57	***
8	8:10'	61	58	*
9	12:10	60	56	****
9	5:35	62	55	****
9	8:45	65	55	****
10	8:50	67	54	*
11	9:10	69	54	**
12	9:15	60	52	**
13	9:10	60	52	**
14	9:50	68	54	**
15	8:25	60	54	***
16	11:10	66	54	**
17	9:10	62	49	*
18	10:25	67	52	----
MEAN	10:45	65.4	54.1	

*All times A.M. except for those primed.

TABLE B

DENSITY OF EXTRACTED PHYTOPIGMENTS FROM BIWEEKLY SHINGLES

Station 3a

	July 9			July 23			August 6		
No.	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts
1	21	3.6	21	----	----	-----	16	2.8	16
2	20	3.4	20	59	10.2	59	14	2.5	14
3	7	1.2	7	116	20.1	118	31	5.4	31
4	39	6.7	39	52	9.0	52	30	5.2	30
5	55	9.5	55	83	14.3	83	80	13.8	80
6	160	27.6	180	99	17.1	99	51	8.8	51
7	80	13.8	80	54	9.3	54	20	3.5	20
8	19	3.2	19	63	10.9	63	15	2.7	15
9	64	11.0	64	123	21.3	130	58	10.0	58
10	36	6.5	36	56	9.7	56	40	6.9	40
SUM		86.5	521		121.9	714		61.6	355
MEAN		8.65	52.1		13.56	79.3		6.16	35.5

	August 20			Sept. 3			Sept. 17		
No.	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts
1	126	21.8	134	83	14.3	83	51	8.8	51
2	161	27.8	180	167	28.8	193	71	12.3	71
3	148	25.2	160	103	17.8	103	68	11.8	68
4	178	30.8	212	114	19.7	120	70	12.1	70
5	178	30.8	212	124	21.5	130	94	16.2	94
6	86	15.9	86	156	27.0	175	90	15.6	90
7	156	27.0	170	97	16.8	97	54	9.3	54
8	114	15.7	120	122	21.1	125	24	4.2	24
9	59	10.2	59	110	19.0	112	66	11.4	66
10	83	14.3	83	132	22.9	150	75	13.0	75
SUM		219.5	1416		198.8	1288		114.7	663
MEAN		21.95	141.6		19.88	128.8		11.47	66.3

TABLE B (cont.)

DENSITY OF EXTRACTED PHYTOPIGMENTS FROM BIWEEKLY SHINGLES

Station 6

	July 9			July 23			August 6		
No.	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts
1	36	6.1	36	87	15.0	87	90	15.6	90
2	56	9.6	56	110	19.0	112	---	----	----
3	30	5.1	30	105	18.2	105	96	16.6	96
4	16	2.7	16	141	24.4	152	---	----	----
5	7	1.2	7	108	18.6	110	97	16.8	97
6	25	4.3	25	152	26.3	168	138	23.9	150
7	33	5.6	33	82	14.2	82	115	19.9	120
8	66	11.4	66	66	11.4	66	94	16.3	94
9	68	11.7	68	139	24.1	150	125	21.6	132
10	56	9.6	56	101	17.5	101	94	16.2	94
SUM		67.3	393		188.7	1133		146.9	873
MEAN		6.73	39.3		18.87	113.3		18.36	109.1

	August 20			Sept. 3			Sept. 17		
No.	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts
1	398	65.3	1720	51	8.8	51	182	31.4	220
2	362	62.6	1225	204	35.2	265	136	23.6	252
3	381	65.9	1500	189	32.6	230	137	23.8	148
4	328	56.7	860	117	20.2	122	107	18.5	107
5	311	53.8	720	138	23.9	150	115	19.9	117
6	302	52.2	690	146	25.2	262	158	27.4	277
7	370	64.0	1425	176	30.4	206	161	27.9	280
8	393	67.9	1600	155	26.8	170	145	25.1	258
9	398	68.8	1720	131	22.7	138	149	25.8	265
10	269	46.5	510	138	23.9	150	141	24.4	151
SUM		603.3	11970		249.7	1744		247.8	2075
MEAN		60.33	1197.0		24.97	174.4		24.78	207.5

TABLE B (cont.)

DENSITY OF EXTRACTED PHYTOPIGMENTS FROM BIWEEKLY SHINGLES

Station 7

	July 9			July 23			August 6		
No.	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts
1	67	11.6	67	94	16.3	94	75	12.9	75
2	19	3.2	19	112	19.4	114	162	28.0	180
3	46	7.9	46	93	16.1	93	139	24.1	152
4	55	9.5	55	120	20.8	126	139	24.1	152
5	8	1.4	8	47	8.2	47	70	12.1	70
6	64	11.0	64	137	23.7	148	70	12.1	70
7	30	5.1	30	159	27.5	177	88	15.2	88
8	92	15.9	92	150	26.0	165	102	17.6	102
9	33	5.6	33	131	22.7	148	61	10.5	61
10	55	9.5	55	178	30.4	212	145	25.1	158
SUM		80.7	469		211.1	1324		187.7	1108
MEAN		8.07	46.9		21.11	132.4		18.77	110.8

	August 20			Sept. 3			Sept. 17		
No.	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts
1	270	46.7	510	138	23.9	150	167	28.9	195
2	205	35.5	265	115	19.9	120	85	14.7	85
3	271	46.9	510	172	29.7	200	156	27.0	175
4	259	44.8	460	191	33.0	240	105	18.2	105
5	306	52.9	720	167	28.8	195	149	25.8	162
6	109	18.8	112	80	13.8	80	103	17.8	103
7	305	52.8	710	102	17.7	102	145	25.1	158
8	342	59.2	1110	216	37.2	300	207	35.7	270
9	264	45.7	470	120	20.8	125	118	20.4	222
10	352	60.9	1120	198	34.2	255	198	34.2	255
SUM		464.2	5987		259.0	1767		247.8	1730
MEAN		46.42	498.7		25.90	176.7		24.78	173.0

TABLE B (cont.)

DENSITY OF EXTRACTED PHYTOPIGMENTS FROM BIWEEKLY SHINGLES

Station 8

	July 9			July 23			August 6		
No.	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts
1	38	6.5	38	186	32.1	220	82	14.2	82
2	21	3.5	21	146	23.2	160	76	13.2	76
3	13	2.2	13	67	11.5	67	145	25.1	158
4	0	0.0	0	63	10.8	63	58	10.0	58
5	9	1.5	9	74	12.8	74	132	22.9	140
6	57	9.8	57	142	24.6	155	87	15.0	87
7	45	7.7	45	225	38.8	315	48	8.3	48
8	7	1.2	7	105	18.2	105	39	6.8	39
9	11	1.9	11	71	12.3	71	101	17.5	101
10	30	5.1	30	127	22.0	130	67	11.6	67
SUM		39.4	231		206.3	1360		144.6	856
MEAN		3.94	23.1		20.63	136.0		14.46	85.6

	August 20			Sept. 3			Sept. 17		
No.	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts	Klett Units	Harvey Units	Correct Kletts
1	---	----	---	133	23.0	147	151	26.1	165
2	288	49.8	605	121	20.9	125	122	21.1	125
3	317	54.8	790	138	23.9	150	120	20.8	124
4	276	47.8	540	112	17.3	113	93	16.1	93
5	317	54.8	790	210	36.2	280	164	28.4	180
6	337	58.3	990	217	37.4	305	112	17.4	113
7	308	53.3	720	152	26.3	168	107	18.5	107
8	181	31.3	220	119	20.6	222	145	25.1	158
9	311	53.8	760	142	24.6	152	99	15.1	99
10	185	32.0	226	---	----	---	150	26.0	165
SUM		436.1	5641		230.9	1662		214.6	1329
MEAN		48.5	626.8		25.7	184.7		21.46	132.9

TABLE C

ENUMERATION OF BOTTOM FAUNA COLLECTED PER SQUARE FOOT SURBER SAMPLE

Station 3a

Volume in Milliliters

Sample	July 5		July 19		August 2	
Number	Number	Volume	Number	Volume	Number	Volume
1	72	.25	72	.32	187	.17
2	77	1.10	104	.31	228	1.28
3	119	.18	72	.26	226	1.01
4	197	.26	109	.40	256	.76
5	141	.28	119	.23	257	1.41
6	175	1.53	147	.22	199	.37
7	42	.15	85	.12	217	.23
8	49	.14	69	.14	219	1.45
9	112	.21	163	.33	255	.57
10	111	.94	261	1.18	271	.99
Total	1095	8.74	1201	10.20	2315	5.41

Sample	August 16		August 30		September 13	
number	Number	Volume	Number	Volume	Number	Volume
1	314	.66	351	.89	129	.74
2	431	.70	258	.40	172	.85
3	398	1.33	202	.58	110	.82
4	313	.58	253	.88	101	.43
5	350	.48	201	1.68	212	.37
6	203	.42	316	.67	65	.15
7	238	1.37	444	2.97	65	.64
8	250	.33	253	.55	93	.36
9	338	1.28	166	.62	214	.27
10	285	1.59	192	.96	127	.78
Total	3120	5.14	2636	3.51	1288	8.24

TABLE C (cont.)

ENUMERATION OF BOTTOM FAUNA COLLECTED PER SQUARE FOOT SURBER SAMPLE

Station 6

Volume in Milliliters

Sample Number	July 5 Number	July 5 Volume	July 19 Number	July 19 Volume	August 2 Number	August 2 Volume
1	59	.09	252	.14	186	.36
2	246	.64	123	.10	139	.29
3	96	.10	238	.08	53	.24
4	46	.06	505	.22	97	.13
5	141	.14	405	.17	65	.13
6	103	.25	108	.07	58	.15
7	312	.33	266	.24	72	.34
8	224	.20	311	.28	62	.24
9	289	.64	459	.69	43	.14
10	39	.04	107	.15	39	.11
Total	1555	4.74	2774	4.03	814	3.20

Sample Number	August 16 Number	August 16 Volume	August 30 Number	August 30 Volume	September 13 Number	September 13 Volume
1	387	.42	227	1.12	143	.37
2	339	.75	360	.49	185	.48
3	321	.40	327	.13	108	.44
4	192	.40	214	.35	152	.39
5	773	.65	83	.30	103	.23
6	138	.45	267	.57	74	.19
7	116	.39	127	.24	121	.29
8	106	.39	198	.35	70	.24
9	150	.44	85	.23	95	.32
10	165	.51	239	.25	75	.25
Total	2687	2.49	2127	2.14	1126	2.13

TABLE C (cont.)

ENUMERATION OF BOTTOM FAUNA COLLECTED PER SQUARE FOOT SURBER SAMPLE

Station 7

Volume in Milliliters

Sample	July 5		July 19		August 2	
Number	Number	Volume	Number	Volume	Number	Volume
1	15	.11	53	.08	50	.33
2	17	.15	45	.05	58	.22
3	13	.08	31	.04	37	.39
4	8	.05	45	.06	45	.24
5	12	.11	23	.02	58	.36
6	15	.13	64	.20	44	.13
7	6	.10	44	.19	55	.19
8	18	.11	27	.14	78	.17
9	27	.15	66	.37	60	.20
10	23	.14	48	.22	65	.23
Total	154	1.70	446	2.19	550	2.11

Sample	August 16		August 30		September 13	
Number	Number	Volume	Number	Volume	Number	Volume
1	82	.28	102	.25	288	.47
2	89	.18	107	.14	248	.21
3	85	.17	107	.17	220	.15
4	30	.07	299	.20	8	.04
5	32	.08	115	.26	173	.14
6	65	.10	94	.11	153	.20
7	36	.15	91	.22	94	.12
8	95	.15	91	.07	114	.22
9	84	.23	350	.60	276	.21
10	88	.29	175	.17	196	.35
Total	686	1.13	1531	1.37	1770	2.48

TABLE C (cont.)

ENUMERATION OF BOTTOM FAUNA COLLECTED PER SQUARE FOOT SURBER SAMPLE

Station 8

Volume in Milliliters

Sample Number	July 5 Number	July 5 Volume	July 19 Number	July 19 Volume	August 2 Number	August 2 Volume
1	37	.11	375	.76	91	.10
2	86	.10	137	.42	60	.04
3	99	.22	92	.26	77	.16
4	67	.18	79	.46	41	.11
5	65	.16	92	.31	65	.10
6	66	.13	102	.17	24	.11
7	20	.05	63	.14	24	.08
8	37	.15	58	.07	48	.08
9	40	.18	77	.15	28	.14
10	50	.21	75	.12	32	.20
Total	567	2.03	450	1.68	490	2.79

Sample Number	August 16 Number	August 16 Volume	August 30 Number	August 30 Volume	September 13 Number	September 13 Volume
1	148	.23	301	.17	156	.30
2	135	.42	99	.14	95	.15
3	137	.15	190	.26	153	.30
4	95	.11	147	.14	118	.23
5	112	.25	5	.01	199	.25
6	41	.09	152	.16	153	.35
7	73	.16	192	.28	171	.38
8	61	.18	121	.13	223	.37
9	43	.14	205	.25	190	.20
10	144	.30	110	.14	123	.26
Total	989	1.49	1522	2.86	1581	1.12

TABLE D

A LIST OF ORGANISMS FOUND IN BEDS OF CHARA SPP. IN THE WEST BRANCH OF THE STURGEON RIVER, 1957

This list is based on the taxonomic keys presented by Pennak (1953), Needham and Westfall (1955), Frison (1935), Ross (1944) and Burke (1953). The organisms have been identified as far as possible or practical in the limited time available.

VERTEBRATA
- *Cottus bairdii*
- *Entosphenous lamottenii*

DIPTERA
- Tabanidae
  - *Chrysops* spp.
- Rhagionidae
  - *Atherix variegata*
- Simulidae
- Anthomyiidae
- Heleidae
  - *Palyomyia* spp.
- Ptychopteridae
  - *Ptychoptera rufocincta*
- Stratiomyiidae
  - *Stratiomyia* spp.
- Tipulidae
  - *Tipula* spp.
  - Misc.

ODONATA
- Libellulidae
  - *Somatochlora hudsonica*
  - *Somatochlora* spp.
- Cordulegasteridae
  - *Cordulegaster obliquus*
  - *Cordulegaster maculatus*
  - *Cordulegaster* spp.
- Gomphidae
  - *Ophiogomphus mainensis*
  - *Ophiogomphus asperus*

MEGALOPTERA
- Corydalidae
  - *Chauliodes* spp.
- Sialidae
  - *Sialis* spp.

PLECOPTERA
- Pteronarcidae
  - *Pteronarcys pictetii* (= nobilis)
- Chloroperlidae

TRICHOPTERA
- Rhycophilidae
  - *Rhyacophila vibox*
- Philipotomidae
  - *Dolophilus moestus*
- Psychomyiidae
  - Genus B (?)
- Hydropsychidae
- Phryganeidae
  - *Ptilostomus* spp.
- Limnephilidae
  - *Astenophylax argus*
  - *Pycnopsyche* spp.
- Molannidae
  - *Mollana* spp.
- Leptoceridae
  - *Leptocella albida*
  - *Athripsodes* spp.
  - *Triaenodes marginata* (?)
  - Misc.
- Brachycentridae
  - *Micrasema rusticum*
  - *Brachycentrus lateralis*
  - *Brachycentrus americanus*

EPHEMEROPTERA
- Baetidae
  - *Ephemerella* spp.
  - *Siphonlurus* spp.
  - *Blasturus* spp.
  - *Caenis* spp.
- Ephemeridae
  - *Hexagenia recurvata*
  - *Ephemera simulans*

MISCELLANEOUS INVERTEBRATES
- Annelidae
  - Oligochaeta - Tubificidae and others.
  - Hirudinea
- Amphipoda
  - *Gammarus* spp.
- Gastropoda
  - *Gyralus* spp.
  - *Aplexa hypnorum*
- Pelecypoda
  - *Sphaerium* spp.
  - *Pisidium* spp.

Multiple Range Tests

Statistical analyses were performed on the periphyton data to find which pairs of means were statistically different. The data were tested two ways. First, the data were tested by stations to find groups of means at the different sampling dates that were not significantly different at the date of sampling.

The data were first submitted to "F" tests. It was found by the "F" tests that station 3a didn't vary significantly through the sampling dates and that the sampling dates, July 9 and July 23 didn't vary between stations. The remainder of the sampling dates and stations were then submitted to a "Multiple Range Test" (Duncan, 1957). This test groups means that are not significantly different and is designed for means that are derived from an unequal number of samples.

The general procedure of the test is as follows:

Section A, involves an analysis of variance to determine the error standard deviation, "s".

Section B, involves the computing of a critical value, R'p. The R'p value is obtained by multiplying the "s" value (section A) by the Zp value which is obtained from a table of values by Duncan (1955).

Section C. The letter is the coded station or date for which the respective mean is presented beneath the letter. The number in parenthesis indicates the number of samples the mean is derived from.

Section D. This section is the test sequence. The lowest mean value is subtracted from the highest mean value. The difference is then altered to a prime value by multiplying it by the value Aij. The value Aij is derived as follows:

$$Aij = \sqrt{2RiRj/(Ri + Rj)}$$

Where:

Ri equals the replication number of the lower mean.

Rj equals the replication number of the higher mean.

The primed value is then compared to the critical value, Zp, at the p value (section B) for two plus the number of means lying between the ranked means being tested. If the primed value doesn't exceed the Zp value the means and the intermediate means are not significantly different. If the prime value exceeds the Zp value the procedure is continued until the primed value doesn't exceed the Zp value using the largest mean and the next smallest mean. The procedure is brought to a close if the replication numbers of intermediate means is not greater than those for the means involved. If a larger replication number is present the test must be continued until the mean is utilized to see if the mean will be excluded from the tentatively grouped means. If all the means do not group on the first test sequence, further sequences must be run, starting with the second highest mean with the lower means. This procedure is continued until all possible none different mean groups are obtained.

The following pages cover the analyses performed on the periphyton data. The values mentioned in the text may be observed here.

"Multiple Range Test" to Determine the Stations Not Significantly Different in Periphyton on August 6, 1957

a) Analysis of Variance

Source	d.f.	m.s	s = $\sqrt{m.s.}$
between stations	3	11593.5	--------
error	34	1179.2	34.3366

b) Critical Values

p	(2)	(3)	(4)
Zp	2.88	3.03	3.11
R'p	98.89	104.04	106.79

c) Ranked Period Means and Replication Numbers.*

A	D	B	C
35.5	85.6	109.1	110.8
(10)	(10)	(8)	(10)

d) Test Sequence

(C-A)' = 238 > 106.787	result**
(C-D)' = 79 ≯ 104.039	
(B-A)' = 646 > 104.039	(CBD)
(B-D)' = 70 ≯ 98.889	------
(D-A)' = 158 > 98.889	(A)

* The stations are coded as follows:
A, Station 3a
B, Station 6
C, Station 7
D, Station 8

** Two means appearing together in parentheses are not significantly different.

"Multiple Range Test" to Determine the Stations Not Significantly Different in Periphyton on August 20, 1957

a) Analysis of Variance

Source	d.f.	m.s.	s = $\sqrt{m.s}$
between stations	3	1,868,357.	--------
error	35	98,753.	314.24

b) Critical Values

p	(2)	(3)	(4)
Zp	2.88	3.03	3.11
R'p	905	952	977

c) Ranked Treatment Means and Replication Numbers*

A	C	D	B
141.6	598.7	626.8	1197.0
(10)	(10)	(9)	(10)

d) Test Sequence

	result**
(B-A)' = 337.49 > 977	
(B-C)' = 1892.00 > 952	
(B-D)' = 5401.85 > 905	(B)
(D-A)' = 4596.60 > 952	
(D-C)' = 266.21 ≯ 905	(DC)
(C-A)' = 1445.49 > 905	(A)

* The stations are coded as follows:
A, Station 3a
B, Station 6
C, Station 7
D, Station 8

** Two means significantly together in parentheses are not significantly different

"Multiple Range Test" to Determine the Stations Not Significantly Different in Periphyton on September 3, 1957

a) Analysis of Variance

Source	d.f.	m.s.	s = $\sqrt{m.s.}$
between stations	3	16,240.2	--------
error	35	3,906.0	62.498

b) Critical Values

p	(2)	(3)	(4)
Zp	2.88	3.03	3.11
R'p	179.99	189.36	194.37

c) Ranked Treatment Means and Replication Numbers*

A	B	C	D
128.8	174.4	176.7	184.7
(10)	(10)	(10)	(9)

d) Test Sequence

	result*
(D-A)' = 529.57 > 194.37	
(D-B)' = 97.58 ≯ 189.36	(DCB)
(C-A)' = 151.47 ≯ 194.37	(ABC)

* The stations are coded as follows
A, Station 3a
B, Station 6
C, Station 7
D, Station 8

** Two means appearing together in parentheses are not significantly different.

"Multiple Range Test" to Determine the Stations Not Significantly Different in Periphyton on September 17, 1957

a) Analysis of Variance

Source	d.f.	m.s.	$s = \sqrt{m.s.}$
between stations	3	36,767.7	--------
error	36	2,561.6	50.6162

b) Critical Values

p	(2)	(3)	(4)
Zp	2.88	3.03	3.11
R'p	145.77	153.37	157.42

c) Ranked Treatment Means and Replication Numbers*

A	D	C	B
66.3	132.9	173.0	207.5
(10)	(10)	(10)	(10)

d) Test Sequence

	result**
(B-A)' = 446.0 > 157.42	
(B-D)' = 235.0 > 153.37	
(B-C)' = 109.0 ≯ 145.77	(BC)
(C-A)' = 337.4 > 153.37	
(C-D)' = 126.0 ≯ 145.77	(CD)
(D-A)' = 210.0 > 145.77	(A)

* The stations are coded as follows:
A, Station 3a
B, Station 6
C, Station 7
D, Station 8

** Two means appearing together in parentheses are not significantly different.

"Multiple Range Test", to Determine the Sampling Periods Not Significantly Different in Periphyton at Station 6

a) Analysis of Variance

Source	d.f.	m.s.	s = $\sqrt{m.s.}$
between periods	5	1,919,476	--------
error	52	389,653	624.3

b) Critical Values

p	(2)	(3)	(4)	(5)	(6)
Zp	2.84	2.99	3.09	3.15	3.21
R'p	1773.0	1866.7	1929.1	1966.5	2004.0

c) Ranked Treatment Means and Replication Numbers*

A	C	B	E	F	D
39.3	109.1	113.3	174.4	207.5	1197.0
(10)	(8)	(10)	(10)	(10)	(10)

d) Test Sequence.

	result*
(D-A)' = 3660.99 > 2004.0	
(D-C)' = 9670.12 > 1966.5	
(D-B)' = 3426.98 > 1929.1	
(D-E)' = 3233.76 > 1866.7	
(D-F)' = 3129.09 > 1173.0	(D)
(F-A)' = 531.89 ≯ 1966.5	
CBEFA: (F-C)' = 874.65 ≯ 1929.1	(CBEFA)

* The sampling dates are coded as follows:
- A, July 9
- B, July 23
- C, August 6
- D, August 20
- E, September 3
- F, September 17

** Two Means appearing together in parentheses are not significantly different.

"Multiple Range Test" to Determine the Sampling Periods Not Significantly Different in Periphyton at Station 7

a) Analysis of Variance

Source	d.f.	m.s.	$s = \sqrt{m.s.}$
between periods	5	391,905	
error	54	20,162	141.99

b) Critical Values

p	(2)	(3)	(4)	(5)	(6)
Zp	2.84	2.99	3.09	3.15	3.21
R'p	403.25	424.55	438.75	447.27	455.79

c) Ranked Treatment Means and Replication Numbers*

A	C	B	F	E	D
46.9	110.8	132.4	173.0	176.7	598.7
(10)	(10)	(10)	(10)	(10)	(10)

d) Test Sequence

	result**
(D-A)' = 1744.96 > 455.79	
(D-C)' = 1542.89 > 447.29	
(D-B)' = 1474.58 > 438.75	
(D-F)' = 1346.19 > 424.55	
(D-E)' = 1334.49 > 403.25	(D)
(E-A)' = 410.47 ≯ 447.27	(ACBFE)

* The sampling dates are coded as follows:
- A, July 9
- B, July 23
- C, August 6
- D, August 20
- E, September 3
- F, September 17

**Two means appearing together in parentheses are not significantly different.

"Multiple Range Test" to Determine the Sampling Periods Not Significantly Different in Periphyton at Station 8

a) Analysis of Variance

Source	d.f.	m.s.	$s = \sqrt{m.s.}$
between periods	5	440,470.	-------
error	52	12,842	113.323

b) Critical Values

p	(2)	(3)	(4)	(5)	(6)
Zp	2.84	2.99	3.09	3.15	3.21
R'p	321.84	338.84	350.17	356.97	363.77

c) Ranked Treatment Means and Replication Numbers*

(A)	(C)	(F)	(B)	(E)	(D)
23.1	85.6	132.9	136.0	184.7	626.8
(10)	(10)	(10)	(10)	(9)	(9)

d) Test Sequence

Test	result**
(D-A)' = 5719.2 > 363.77	
(D-C)' = 5127.1 > 356.97	
(D-F)' = 4679.0 > 350.17	
(D-B)' = 4649.6 > 338.84	
(D-E)' = 3987.9 > 321.84	(D)
(E-A)' = 1530.9 > 356.97	
(E-C)' = 938.8 > 350.17	
(E-F)' = 490.7 > 338.84	
(E-B)' = 461.4 > 321.84	(E)
(B-A)' = 357.0 > 350.17	
(B-C)' = 159.4 ≯ 338.84	(CFB)
(F-A)' = 347.2 > 338.84	
(F-C)' = 149.6 ≯ 321.84	----
(C-A)' = 197.6 ≯ 321.84	(AC)

* The sampling dates are coded as follows:

A, July 9	D, August 20
B, July 23	E, September 3
C, August 6	F, September 17

** Two means appearing together in parentheses are not significantly different.

LITERATURE CITED

Alexander, Gaylord Ray

1956. The fertilization of a marl lake. Master's thesis, Michigan State University.

American Public Health Association

1955. Standard Methods. 10th ed., N.Y., 522 pp.

Anton, Nickolas

1957. Biological, chemical and physical changes resulting from fertilization of a marl lake, Master's thesis, Michigan State University.

Ball, Robert C.

1948. The relationship between available fish food, feeding habits of fish and total production in a Michigan Lake. Mich. State Coll., Ag. Exp. Sta., Tech. Bull. 206, 59 pp.

1950. Fertilization of natural lakes in Michigan. Trans. Am. Fish. Soc., 1948, 78:145-155.

Ball, Robert C. and Howard D. Tait

1952. Production of bass and bluegills in Michigan ponds. Mich. State Coll., Ag. Exp. Sta., Tech. Bull. 231, 24 pp.

Ball, Robert C. and Howard Tanner

1951. The biological effects of fertilizer on a warm-water lake. Mich. State Coll., Ag. Exp. Sta., Tech. Bull. 210, 28 pp.

Brehmer, Morris L.

1958. A study of nutrient accrual, uptake and regeneration as related to primary production in a warm water stream. Ph. D. thesis, Michigan State University.

Burks, B. D.

1953. The mayflies, or Ephemeroptera, of Illinois. Ill. Nat. Hist. Survey Bull. Vol. 26, Art. 1, pp 1-216.

Carlander, Kenneth D.

1953. Handbook of freshwater fishery biology with the first supplement. Wm. C. Brown Co., Dubuque, Iowa, 429 pp.

Coker, Robert E.

1954. Streams Lakes Ponds. Univ. N. Carolina Press, Chapel Hill, 327 pp.

Colby, Peter James

1957. Limnological effects of headwater fertilization on the West Branch of the Sturgeon River, Michigan. Master's Thesis, Michigan State University.

Cooper, Edwin L.

1951. Validation of the use of scales of brook trout, Salvelinus fontinalis, for age determination. Copeia, 1951, No. 2. pp. 141-148.

1952. Body-scale relationship of brook trout, Salvelinus fontinalis, in Michigan. Copeia, 1952, No. 1, pp. 1-4.

1953. Growth of brook trout (Salvelinus fontinalis) and brown trout (Salmo trutta) in the Pigeon River, Otsego County, Michigan. Trans. Mich. Acad. Sci., Vol. 38, pp. 151-162.

Dobie, John and John Moyle

1956. Methods used for investigating productivity of fish-rearing ponds in Minnesota. Minn. Dept. of Cons., Fish. Res. Unit, Spec. Pub. No. 5, 54 pp.

Duncan, David B.

1955. Multiple range and multiple F tests. Biometrics, 11(1):1-42.

1957. Multiple range tests for correlated and heteroscedastic means. Biometrics, 13(2):164-176.

Eddy, Samuel and Thaddeus Surber

1947. Northern fishes. Univ. of Minn. Press. 276 pp.

Ellis, M. M., B.A. Westfall and M.B. Ellis

1948. Determination of water quality. U.S. Dept. Interior, Fish and Wild. Ser., Res. Rept. No. 9, 119 pp.

Frison, Theodore H.

1935. The stoneflies, or Plecoptera, of Illinois. Ill. Nat. Hist. Survey Bull. Vol. 20, Art. 4, pp 281-471.

Grzenda, Alfred Richard

1955. The biological response of a trout stream to headwater fertilization. Master's thesis, Michigan State University.

Gumtow, Ronald B.

1955. An investigation of the periphyton in a riffle of the West Gallatin River, Montana. Trans. Am. Micros. Soc., 74(3): 278-292.

Harvey, H. W.

1934. Measurement of phytoplankton population. Jour. Mar. Bio. Assoc., 19:761-773.

Hayne, Don W. and Robert C. Ball

1956. Benthic productivity as influenced by fish predation. Limnology and Oceanography, 1(3):162-175.

Hepher, B.

1958. On the dynamics of phosphorus added to fishponds in Israel. Limnology and Oceanography, 3(1):84-100.

Hubbs, Carl L.

1922. Variations in the number of vertebrae and other meristic characteristics of fishes correlated with the temperature of water during development. Am. Nat., 56:360-372.

1926. The structural consequences of modifications of the development rate of fishes, considered in reference to certain problems of evolution. Am. Nat., 60:57-88.

1941. Increased number and delayed development of scales in abnormal suckers. Mich. Acad. Sc., 1940, 26:229-237.

Huntsman, A. G.

1948. Fertility and fertilization of streams. Jour. Fish. Res. Bd. Canada, 7(5):248-253.

Hutchinson, G. Evelyn

1957. A treatise on limnology, Vol. 1, Geography, physics, and chemistry. John Wiley, N.Y., 1015 pp.

Jordan, David Starr and Barton Warren Evermann

1902. American food and game fishes. Doubleday, Page and Co., N.Y., 572 pp.

Juday, Chancey

1942. The summer standing crop of plants and animals in four Wisconsin lakes. Trans. Wis. Acad. Sci., 34:103-135.

Lagler, Karl F.

1952. Freshwater fishery biology, Wm. C. Brown Co., Dubuque, Iowa, 360 pp.

Leach, Glen C.

1939. Artificial propagation of brook trout and rainbow trout, with notes on three other species. U.S. Dept. Interior, Bur. of Fish., Fish. Doc. No. 955. 74 pp.

Lotka, Alfred J.

1956. Elements of mathematical biology. Dover, N.Y., 465 pp.

Maciolek, J. A.

1954. Artificial fertilization of lakes and ponds, a review of the literature. U.S. Fish and Wild. Ser., Spec. Sci. Rept.-Fish., No. 113, 41 pp.

Manning, Winston M., and Richard E. Juday

1941. The chlorophyll content and productivity of some lakes in Northeastern Wisconsin. Trans. Wis. Acad. Sci., 33:369-379.

Needham, James G. and Minter J. Westfall, Jr.

1955. A manual of the dragonflies of North America (Anisoptera). Univ. of Calif. Press, Berkeley, 628 pp.

Nelson, Philip R. and W.T. Edmondson

1955. Limnological effects of fertilizing Bare Lake, Alaska. Fish. Bull. 102, Fish and Wild. Ser., Vol. 56

Newcombe, Curtis L.

1950. A quantitative investigation of attachment materials in Sodon Lake, Michigan. Ecology, 31(2):204-210.

Patrick, Ruth E.

1949. A proposed biological measure of stream conditions based on a survey of Conestoga Basin, Lancaster County, Pennsylvania. Proc. Acad. Nat. Sci. Philadelphia. 101:277-347.

Pennak, Robert W.

1953. Fresh-water invertebrates of the United States. Ronald, N.Y., 769 pp.

Plosila, Daniel S.

1958. An evaluation of lake production following artificial enrichment. Master's thesis, Michigan State University.

Prescott, Gerald W.

1951. Algae of the Western Great Lakes Area. Cranbrook Institute of Science, Bull. No. 31, 946 pp.

Roelofs, Eugene W.

1941. Fisheries survey of Hoffman Lake, Charlevoix County, Michigan. Report No. 698. Institute for Fisheries Research, Mich. Dept. Cons. Mimeograph report.

Ross, Herbert W.

1944. The caddis flies, or Trichoptera, of Illinois. Ill. Nat. Hist. Survey Bull., Vol. 23, Art. 1, pp. 1-326.

Rounsefell, George A. and W.H. Everhart

1953. Fishery science: its methods and applications. John Wiley and Sons, New York, 444 pp.

Ruttner, Franz

1953. Fundamentals of limnology. (Translated by D.G. Frey and F. E. Fry) Univ. of Toronto Press, 242 pp.

Snedecor, George W.

1956. Statistical Methods. The Iowa State College Press, Ames, Iowa, 534 pp.

Smith, Lloyd L. and John B. Moyle

1944. A biological survey and fishery management plan for the streams of the Lake Superior North Shore Watershed. Minn. Dept. Cons., Tech. Bull. No. 1, 228 pp.

Smith, M.W.

1948. Fertilization of a lake to improve trout angling. Note No. 105, Prog. Rept. Atl. Biol. Sta., Fish. Res. Bd. Canada, 48:3-6.

Smith, Stanford H.

1954. Method of producing plastic impressions of fish scales without using heat. Prog. Fish. Cult., 16(2):75-78.

Snieszko, Stanislas

1941. Pond fish farming in Poland, pp. 227-240 in Symposium on Hydrobiology. Univ. of Wis. Press, Madison.

Strickland, J.D.H.

1958. Solar radiation penetrating the ocean. Jour. Fish. Res. Bd. Canada, 15(3):453-493.

Swingle, H.S.

1947. Experiments on pond fertilization. Alabama Ag. Exp. Sta. Bull. 264, 34 pp.

Swingle, H.S. and E.V. Smith

1939. Fertilizers for increasing the natural food of fish in ponds. Trans. Am. Fish. Soc., 1938, 68:126-134.

Tucker, Allen

1949. Pigment extraction as a method of quantitative analysis of phytoplankton. Trans. Am. Micros. Soc., 68(1):21-33.

Welch, Paul S.

1948. Limnological methods. Blakiston Co., Philadelphia, 381 pp.

1952. Limnology, McGraw-Hill, N.Y., 538 pp.

Whiteside, E. P., I. F. Schneider and R. L. Cook

1956. Soils of Michigan. Michigan State Univ., Ag. Exp. Sta., Spec. Bull. 402, 52 pp.

Young, O. W.

1945. A limnological investigation of the periphyton in Douglas Lake, Michigan. Trans. Am. Micros. Soc., 64(1):1-20.

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