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MODIFICATION OF TROUT STREAM ECOLOGY BY FERTILIZATION

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by

JOHN F. CARR

AN ABSTRACT

Submitted to the College of Agriculture of Michigan
State University of Agriculture and Applied
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MASTER OF SCIENCE

Department of Fisheries and Wildlife

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ABSTRACT

For the third consecutive summer, inorganic fertilizers were added to a marl lake, which is the source of a trout stream. Immediately following the addition of fertilizer large quantities of fertilizers were detected entering the stream. Three days following fertilization the nutrients entering the stream from the lake had returned to prefertilization levels. No significant increases in the nutrient level could be detected more than one mile below the lake outlet.

During each year of the study there was an increase in the aufwuchs flora at the outlet of the lake following fertilization. None of the downstream stations exhibited significant increases in aufwuchs flora, as indicated by the density of extracted phytopigments.

There was an increase in the number of bottom fauna collected in 1956 over the two previous years. However, the volume of the bottom fauna remained essentially the same. Comparison of number and volume of bottom fauna with other trout streams showed production to be extremely low in the West Branch of the Sturgeon River.

Trout species comprised over 90 per cent of the number of fish present and over 99 per cent of the weight. No significant differences were observed in the length-weight relationship of brook and brown trout between the three years of study. Significant differences were found to exist in the length-weight relationship of rainbow trout between each of the years of study.

J.F.C.

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INTRODUCTION

Since before the time of Christ men have been fertilizing their soils and waters to increase the production of food. The use of animal manures, marl, chalk, and wood ashes was practiced by the Chinese, Greeks, and Romans more than one thousand years ago (Millar and Turk, 1954). In this country fertilization of lakes, ponds, and to a very limited extent streams, is a relatively new practice, beginning about 1920. These early fertilization experiments were concerned largely with the production of plankton in small fish ponds (Maciolek, 1954).

The primary purpose of fertilization is to provide additional nutrients to the base of the food chain. The ultimate purpose in aquatic fertilization is to increase the fish yield. Fisheries biologists, in an effort to provide more and better fishing for the increasing number of anglers, have adopted artificial fertilization of certain aquatic environments as an aid in solving this problem.

Although considerable research has been done in America on the application of fertilizers, this is still a pioneering field (Welch, 1952). A paper summerizing fertilization experiments, Maciolek (*op. cit.*), describes many of the important works including methods and findings in this field. The author points out the almost complete lack of research on stream fertilization. Only one paper was found that dealt with a deliberate attempt to fertilize a natural stream. This was published in 1948 by Huntsman who reported some success in the use of fertilizers on an unproductive stream. By the addition of inorganic fertilizer he was able to increase both the plant growth and the number of fish in a barren Nova Scotia stream. Many reasons probably could be given for the lack of studies on the artificial enrichment of lotic environments, but the one used most frequently is that it is presumed that any added nutrients would immediately be flushed out or diluted to an ineffective concentration. Huntsman found that the chief effects were observed immediately below the point of fertilization.

In 1954 a series of experiments was started to determine the fate and effects of added nutrients entering a stream at its headwater, which in this instance was a marl lake. The study was divided into two areas of investigation, one on the stream and the other on the lake. This series of studies was designed primarily to determine: (1) the immediate effect of added fertilizer, and (2) the long range effect on the two bodies of water. The project was carried out during the summers of 1954, 1955, 1956 and each summer was divided into a pre and post-fertilization period of investigation. During each period four lines of investigation were followed: (1) the chemical and physical properties of the lake and stream water, (2) the primary production levels, (3) the bottom fauna production, and (4) the fish fauna growth. It was anticipated that any immediate effects would be detected by the first two types of investigation and any long range effects by the last two. The plan of the study was to establish a reservoir of nutrients through the application of commercial fertilizer to the lake and study the effect of these upon the biology of the lake. It was thought that these nutrients would be released into the stream and result in a higher level of production. This dissertation is concerned with the third year of study on the stream. Similar studies on the stream were made by Grzenda in 1954 and Colby in 1955. Studies on the lake in 1954, 1955, and 1956 were reported by Alexander, Anton, and Plosila.

In each of the three years of study two applications of fertilizer were made to a lake, following approximately five weeks of pre-fertilization investigations. Subsequent to the addition of fertilizer, studies were continued for approximately the same period. These investigations included measurement of the following: the level of chemical constituents, the growth of aufwuchs on artificial substrates, the bottom fauna, and fish growth. Each of these measurements were made for four stations on the stream in 1956 (eight stations were used in 1954 and 1955). In 1955 and 1956 a control stream was added to the study for comparative purposes.

Description of the Study Area

The West Branch of the Sturgeon River is a relatively short stream covering approximately 14 miles between its origin in Hoffman Lake and its confluence with the Sturgeon River near Wolverine, Michigan. Hoffman Lake covers an area of 128 acres in the southeast corner of Charlevoix County, Michigan. It is a marl lake having a maximum depth of 23 feet. Non-trout fish species comprise the bulk of the fish present.

At its beginning the West Branch has the chemical and physical features of the lake. The water is comparatively warm and sluggish as it leaves the lake. However, within one mile of the outlet the stream receives a supply of cold spring water great enough to decrease the water temperature more than 10° F. during the summer months. The West Branch from this point (one mile below the lake outlet) receives large volumes of seepage water plus flow from springs and three tributaries. This constant addition of cool water helps maintain relatively uniform temperatures along the entire length of the stream (Table 1).

Throughout the summer of 1956 the West Branch maintained, in addition to constant temperatures, a relatively

TABLE 1

WATER TEMPERATURES IN THE WEST BRANCH OF THE STURGEON RIVER, JUNE TO SEPTEMBER, 1956 (TEMPERATURES IN °F)

Date		I	II-A	II	IV	VII	VIII	X
July 2	Water	72	--	61	65	--	63	53
	Air	70						
4	Water	72	--	58	65	61	61	50
	Air	69						
9	Water	68	--	55	59	--	56	48
	Air	62						
16	Water	68	--	55	58	--	54	46
11	Water	71	--	60	64	64	63	50
	Air	72						
18	Water	70	--	58	60	60	58	50
25	Water	70	--	58	60	60	62	48
30	Water	70	56	53	53	--	50	48
	Air	72						
31	Water	68	56	53	54	--	51	46
Aug. 1	Water	68	60	56	58	57	58	48
4	Water	69	--	54	57	--	--	47
6	Water	70	61	57	60	55	55	48
	Air	76						
8	Water	74	--	59	62	60	60	50
14	Water	72	62	57	60	--	57	50
	Air	70						
20	Water	67	--	60	54	55	60	50
	Air	64						

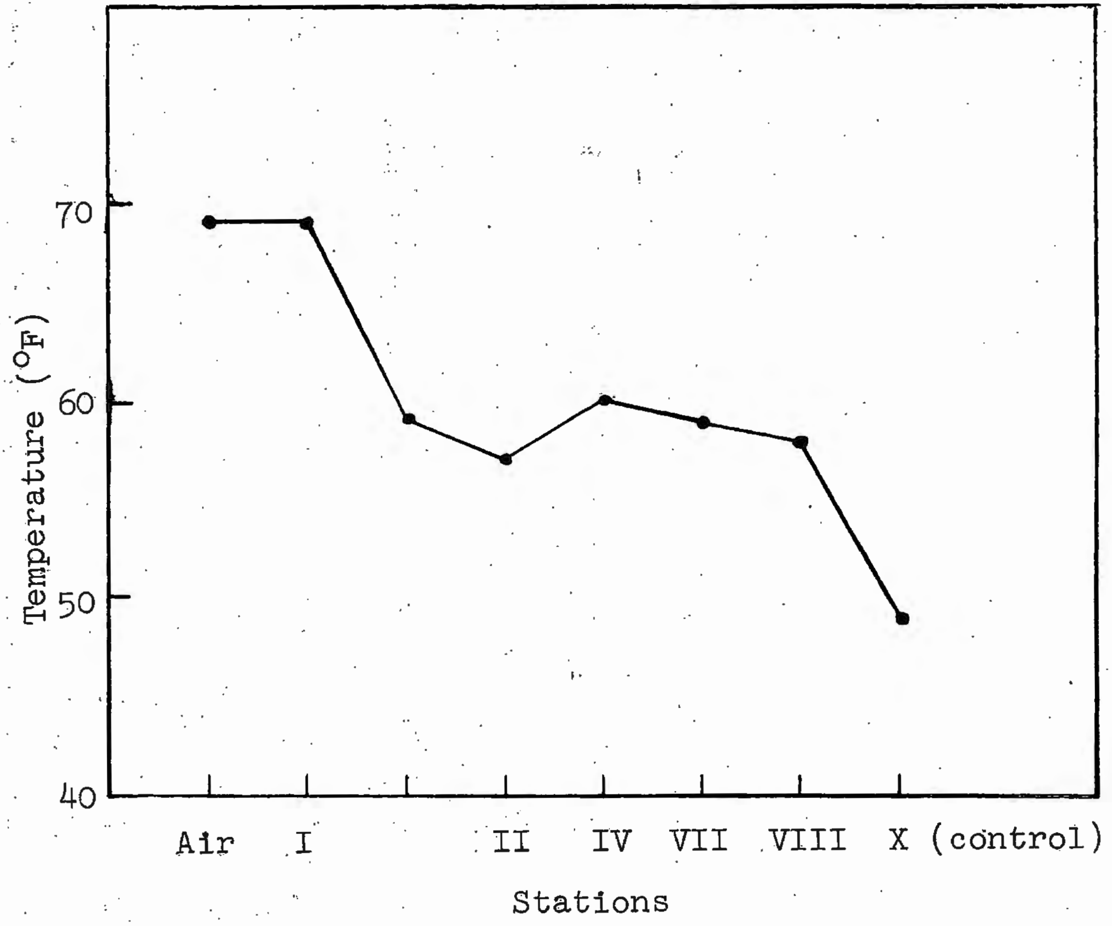
TABLE 1 (Continued)

Date		I	II-A	II	IV	VII	VIII	X
Aug. 26	Water Air	66 67	--	56	62	--	58	48
29	Water	70	--	55	60	--	55	48
Sept. 3	Water Air	70 70	60	56	59	--	56	50

constant water level. The total area drained by the stream is slightly less than 14 square miles (Grzenda, 1955). This area supports stands of maple along the moderately steep hills that form the outer boundary of the watershed. Immediately adjacent to the stream is a narrow valley composed of cedar swamp fringed with aspen.

There is a gradual transition of the stream bottom type from the headwater to the mouth. At the outlet of the lake the bottom is a soft marl-slit type. One mile downstream it is a mixture of silt and sand. At the five mile point the bottom is mostly sand and fine gravel, and from about seven miles downstream to the mouth there is an increasing amount of coarse gravel and a decrease in the amount of sand. Contrary to most streams, the gradient of the West Branch increases from the source to the mouth. The lower portions have considerably more swift water.

Figure I. The mean water temperature at each station for the summer of 1956.


70
60
50
40
Temperature (°F)
Air
I
II
IV
VII
VIII
X (control)
Stations

There is a well defined channel throughout the entire course of the stream, with the exception of two short stretches. The first area is about one quarter of a mile below the lake. At this point the stream forms several wide channels through an open area approximately 200 yards wide. This pond-like area is completely devoid of trees, but supports scattered shrubs and dense beds of higher aquatic plants. The open area is the result of a beaver dam being filled in with silt, sand, and marl. The bottom here is spongy being completely saturated with water. The depth of the filler material varies from a few inches to more than six feet at the old dam site. Another similar area is located approximately four miles from the lake. The origin is the same as the one just described but probably not as old. The stream here still maintains a channel, but it is considerably expanded. Silt and sand to a depth of two to four feet are the bottom materials. Heavy growths of burweed (Sparganium sp.) and water cress (Nasturium officinale) occupy the entire width of the stream except for a rather narrow channel of swifter water.

The entire length of the study area was free from sources of pollution with two minor exceptions. One of these was one mile downstream from the lake where a pasture bordered the stream. At this point cattle often entered the stream to drink. The other exception was approximately four miles from the lake, where there were two summer cabins along the stream that might contribute small quantities of domestic sewage during short periods of the summer.

Description of Stations

Station I (See map--Figure II)

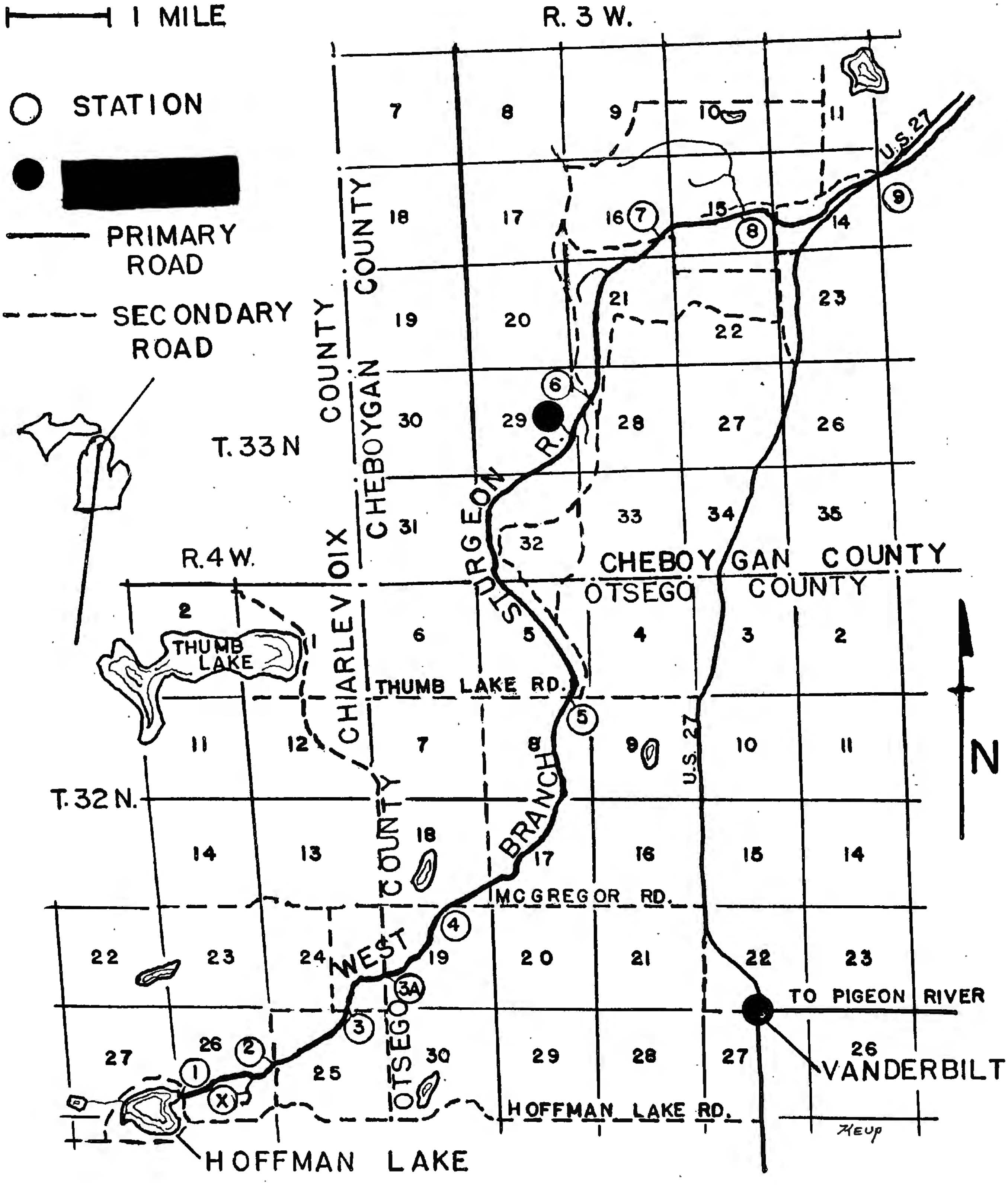
This area included the immediate outlet of Hoffman Lake and about 150 feet of the stream. The flow was sluggish, and the water at its maximum temperature. The bottom was extremely soft, composed of marl, slit, and sand. The stream at this station had the most dense plant growth--both algae and higher aquatics. Algal composition was primarily *Spirogyra sp*. and *Chara sp*; the higher aquatics were cattail (*Typha latifolia*), arrowhead (*Sagittaria latifolia*), and pondweed (*Potamogeton sp*.). A power line and road crossing the stream at this station created an open area which provided maximum sunlight.

Station X (Control Station)

A cold spring entering the West Branch just above Station II and one mile below the lake was selected as the control stream. The spring is formed from an accumulation of seepage water near the base of a moraine. The total length of the stream is less than one-half mile. The gradient is rather steep the entire length of the stream. The bottom is mostly sand with an accumulation of silt, sometimes reaching the surface in the quieter water.

FIGURE II

WEST BRANCH STURGEON RIVER AREA



Plant life was sparse in the stream itself with a few scattered mats of filamentous algae present. The banks adjacent to the water supported dense clumps of monkey flower (_Mimulus_ _sp_.).

Station II

Station II was located about one mile below the lake outlet. Immediately above this station was the upstream limit of the trout species for the summer months. The bottom was washed sand with large patches of accumulated silt where the current was slow. On the silty bottom areas there were thick mats of mare's tail (_Hippuris_ _vulgaris_). The sandy areas supported growths of bureed (_Sparganium_ _sp_.) and two species of pondweed. Patches of Chara were also common and in the latter part of the study long dense strands of filamentous algae (principally Rhizoclonium and Spirogyra) were present.

Station III

Used in 1954 and 1955 but not used in this study.

Station IV

Station IV, approximately four and one-half miles from Hoffman Lake, was divided into two physically different sections. A bridge crossing the stream at this station served as a dividing line between the two areas. The upstream section was used for weekly sampling, and the downstream area for 30-day sampling. The upstream section had a nearly-complete canopy of cedar trees. In this area the stream was divided into several channels, uniting just before going under the road. The bottom was composed mostly of silt with a few scattered patches of sand and fine gravel. Burreed (Sparganium sp.) was the principal aquatic plant with scattered clumps of pondweed, mare's tail, and crowfoot (Ranunculus trichophyllus) also present.

The downstream section was more open than the upstream section, but still received less sunlight than any other station. The gradient was steeper in this area and the increased stream velocity prevented the deposition of silt to any great extent. The bottom was composed mostly of gravel with intermixed patches of sand.

This station was the downstream limit of soft silty bottom areas of great extent. The West Branch below Station IV had a sand and gravel bottom. Silted areas occurred only behind stream improvement structures and in narrow patches where the current was slow. Station IV was the upstream limit of other than occasional fishing. Stream improvement structures were present here and at all the remaining stations.

Stations V and VI

Used in 1954 and 1955, but not used in this study.

Station VII

Station VII, nine and one-half miles below the lake outlet, was limited in sampling to measurements of aufwuchs production. The stream in this area was relatively open, bordered on each side by birch and aspen trees with a heavy undergrowth of herbs and shrubs. Aquatic plants, with the exception of Chara beds, were limited to a very narrow area adjacent to the bank. The bottom was rather uniform in both conformation and composition. Coarse sand and gravel comprized the entire benthic area with the exception of elongated patches of silt overgrown with Chara. This station was subjected to relatively heavy fishing pressure.

Station VIII

This, the farthest downstream station, was approximately ten and one-half miles from the source and three and one-half miles from the mouth and because of its accessibility, had the greatest fishing pressure. It was a comparatively open area with the greatest discharge and width of any station. The stream width and depth were relatively uniform except where stream improvement structures narrowed the channel. The bottom was mostly gravel with isolated areas of sand and silt. Large boulders were scattered throughout this section of the river. With the exception of Chara beds, all vegetation was limited to the banks.

METHODS AND PROCEDURES

Application of Fertilizers

Hoffman Lake received two applications of fertilizer during the summer of 1956, as it did in 1954 and 1955. On July 30 2480 pounds of inorganic fertilizer (12-12-12 NPK) were broadcast from power boats on the western half of the lake (side opposite the outlet). Again on August 3, 2400 pounds of the same type of fertilizer were applied to the eastern half of the lake, including the area near the outlet.

Physiochemical

Water samples were taken at least once each week from all stations. The following chemical and physical analyses were made for each sample: conductivity, measured with a portable battery-operated conductivity bridge; alkalinity according to procedures outlines in "Standard Methods for Examination of Water and Sewage" (1955); ammonia nitrogen by direct Nesslerization also as outlines by "Standard Methods"; total phosphorus by the molybdate method as described by Ellis, Westfall, and Ellis (1948); hydrogen ion concentration using a Beckman pH meter.

Biological

Aufwuchs

The methods used the third year for collecting aufwuchs on artificial substrates was modified slightly from those used the two previous years. Grzenda, in 1954, used ten shingles and five bricks at each station and collected them at the end of thirty days. Colby the following year increased the number of shingles at each station to fifteen but continued to use five bricks. Colby in addition to the above substrates, which were also submerged for thirty days, placed ten shingles in the stream above Station IV and removed them weekly. The purpose of this additional procedure was to detect weekly changes in aufwuchs production. In 1956 the number of sampling stations was reduced from eight to five but the number of substrates at each station was increased. There were at each station a total of thirty substrates. Twenty of the substrates, fifteen shingles and five bricks, were removed and replaced at thirty day intervals; the remaining ten substrates were shingles and were removed and replaced at weekly intervals. In addition to the above, forty shingles were placed in the stream at Station VII to measure the length of time required for the accumulation of aufwuchs to reach a maximum level. The shingles at Station VII were removed in blocks of ten at weekly intervals, this provided four blocks that had been submersed for one, two, three, and four weeks. There were two complete sets of substrates at all stations, one before fertilization and one after fertilization. The modification of sampling the aufwuchs differed from the two previous studies in the number of substrates used and the schedule of removal, all other procedures were essentially the same.

The bricks used in all three years of study were cinder building bricks measuring 2.5 x 3.5 x 7.5 inches. The method of suspending the bricks in the water was by means of a wire fastened to a stable object overhanging the stream. The shingles were regular roofing singles cut to a uniform size of 3 by 12 inches. The method of attachment of these shingles was to nail them to submerged logs, parallel to the current, with the entire surface free for the attachment of organisms. Care was also taken to replace fresh substrates in the exact position as those removed.

At the time of replacement each shingle was carefully removed from the stream to prevent the accumulated material from being washed off. Immediately upon removal, they were placed in polyethylene bags and taken to the laboratory. The attached material was removed by flushing with water and brushing with a stiff nylon brush. This material was collected in white porcelain pans. Each sample was picked by hand to remove the faunal organisms and any large pieces of inorganic matter. Approximately two quarts of rinse water were needed to clean each shingle. The water and the solid material were run through a Foerst plankton centrifuge. The collected solid material was placed in small bottles containing 95 per cent ethyl alcohol (to extract the pigments) and stored.

On no occasion did the total elapsed time between removal of the shingle and extraction of the pigments exceed 72 hours. All shingles not processed the day of removal were refrigerated to prevent the breakdown of the plant material. The bricks were treated in the same manner, but were cleaned at the stream upon removal.

The final processing of the extracted material consisted of filtering the sample through #2 filter paper to separate the liquid containing the pigments from the residue. The liquid was brought to a uniform volume and the pigment density was measured in a Klett-Summerson photoelectric colorimeter, using a red (number 66) filter. The Klett unit was used for comparative purposes and statistical tests.

Bottom Fauna

Station VIII served as the bottom sampling site for this study, as it had done for the two previous years. A riffle area having a relatively uniform width and depth and a bottom of gravel intermixed with sand was selected for sampling. Twelve samples were taken weekly in a straight line across the stream, beginning at the downstream end of the riffle and moving upstream each successive week.

All samples were taken with a Surber square foot bottom sampler and picked at the time of collecting. The benthic organisms were preserved in 10 per cent formalin solution until identified and counted in the laboratory. A total of one hundred twenty samples were taken in an eleven week period from June 29, 1956 to September 7, 1956.

Fish Fauna

Stations II, V, and VIII were sampled with a 220 volt direct current shocker on July 12, 1956. Approximately two hundred trout over three inches in length were taken at the three stations. Length and weight of each fish were measured and scale samples taken for age determination. The trout species exhibited longitudinal distribution apparently associated with bottom type (Grzenda, 1955, and Colby, 1957). At Station II, where the bottom is mostly silt and sand, only brook trout (*Salvelinus fontinalis*) were found. Station V yielded approximately equal numbers of brook trout and rainbow trout (*Salmo gairdnerii*) and only a few brown trout (*Salmo Trutta*). The bottom was composed of fine gravel and sand. Station VIII produced the largest number of fish. Brown and rainbow trout made up the bulk of the total with only a few brook trout in the sample.

RESULTS AND DISCUSSION

Physiochemical

Phosphorus

After the first application of fertilizer to Hoffman Lake on July 30 no significant increase in total phosphorus was detected at the outlet of the lake (Station I) or any of the downstream stations (Table 2). This application was to the side of the lake opposite the outlet. The fate of the first application of fertilizer, since increases were not detected either in the lake or the stream, was probably one or both of the following: precipitated as an insoluble calcium compound as described by Neess (1949); taken up by plants (Clarke, 1954; Ruttner, 1953).

A very large increase in total phosphorus was detected at Station I following the second application of fertilizer on August 3. A slight increase in total phosphorus at Station II was also found. Less than one hour after adding the fertilizer to the outlet, a water sample was taken at Station I. An analysis of this sample showed a total phosphorus concentration of 500 parts per billion (P.P.B.). Twenty-four hours later samples from this station had a total phosphorus concentration of 256 P.P.B., Station II on the same day had the highest phosphorus content of the

TABLE 2

PARTS PER BILLION OF TOTAL PHOSPHORUS IN WATER SAMPLES TAKEN FROM THE WEST BRANCH OF THE STURGEON RIVER DURING THE SUMMER OF 1956

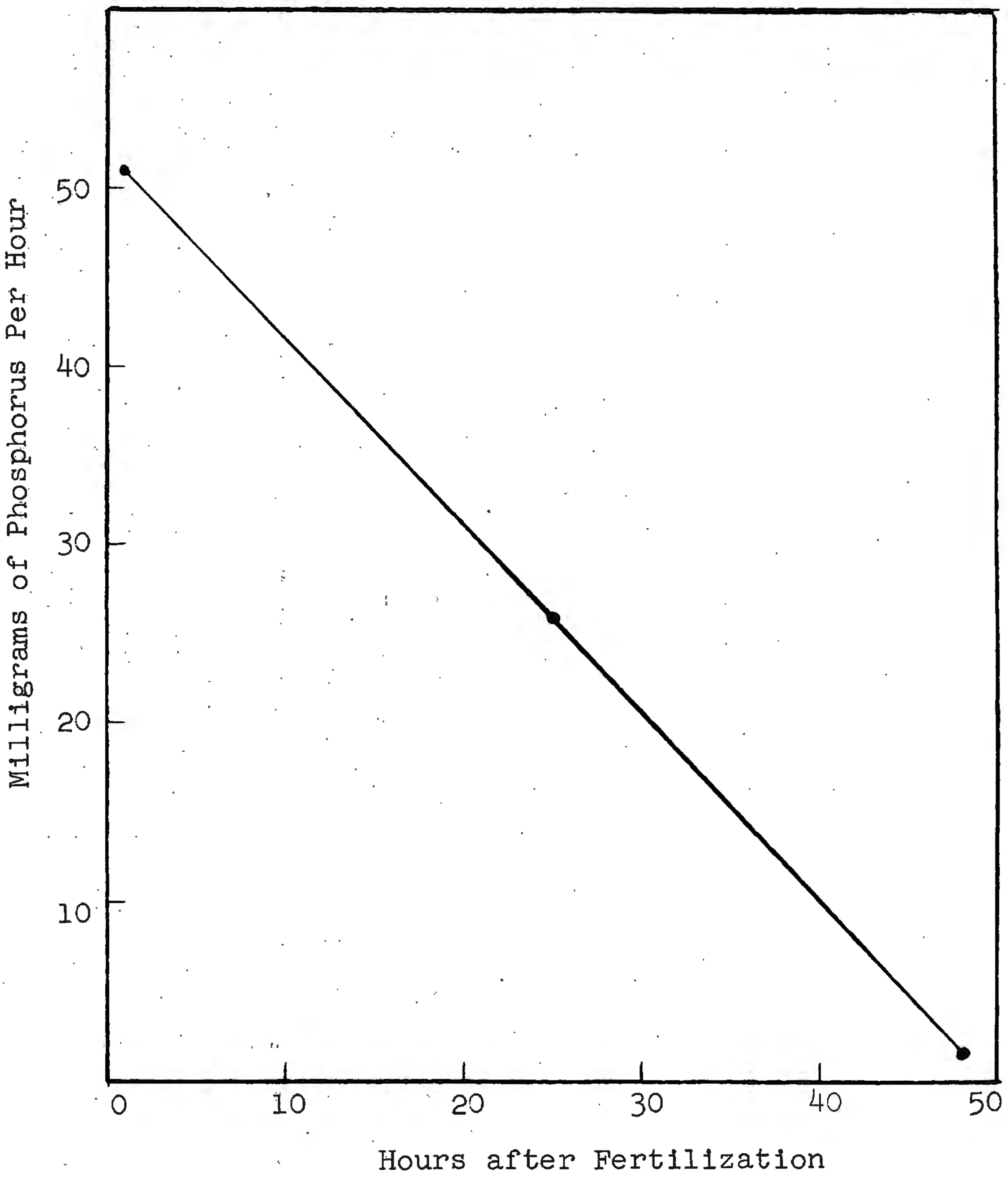
Date	Station				
	I	II	IV	VIII	X
July 2	4	3	5	2	1
9	9	6	6	5	1
16	6	6	10	8	5
30*	11	8	10	9	8
31	15	14	10	6	6
Aug. 1	--	7	6	14	--
2	14	6	9	5	6
3*	500	12	--	--	--
4	256	23	16	--	--
6	18	8	6	11	8
9	5	19	17	--	--
10	16	--	--	8	--
14	50	19	24	16	14
20	16	8	9	8	4
26	26	16	12	8	8
Sept. 3	15	20	8	8	4

*Dates of fertilization.

summer, 23 P.P.B. Station IV also showed an increase but probably not of significant magnitude to justify attributing the increase to the addition of fertilizer. Three days after the application of fertilizer to the lake the phosphorus content of the water at Stations I and II had returned to prefertilization levels. Assuming a constant discharge from the lake of 28.3 liters (one cubic foot) of water per second the amount of phosphorus entering the West Branch decreased at a near uniform rate over a period of forty-eight hours. Immediately after adding the fertilizer approximately 51 milligrams of phosphorus per hour were entering the stream; twenty-four hours later the rate of phosphorus had decreased to approximately 26 milligrams per hour, and at the end of forty-eight hours the phosphorus was approximately 1.8 milligrams per hour (Figure III).

Ruttner (1953), explained the rapid decrease in phosphorus concentration following fertilization, gives the results of Einsele (1941), "Fertilization experiments in Schleinsee in which phosphate added to the water disappeared in a few days, having been taken up by plants." Ruttner (op. cit.) further states that, "From related experiments it was found that the plankton algae were able to store more than ten times as much phosphorus as they normally contained." In a laboratory controlled experiment Rice (1949) found that the diatom (Nitzchia frustrulum) in a population of 40 million cells per liter reduced the

Figure III. Rate of phosphorus release from Hoffman Lake following fertilization.


Milligrams of Phosphorus Per Hour
50
40
30
20
10
0
10
20
30
40
50
Hours after Fertilization

phosphorus concentration of its media from 1.6 Ug-atoms/ liter to zero in twenty-four hours. Clarke (1954), relates similar results from fertilization experiments--that is the rapid depletion of phosphorus by plants. Uptake by plants together with the precipitation of phosphorus were probably the causes of the rapid decrease in this element following the addition of fertilizer.

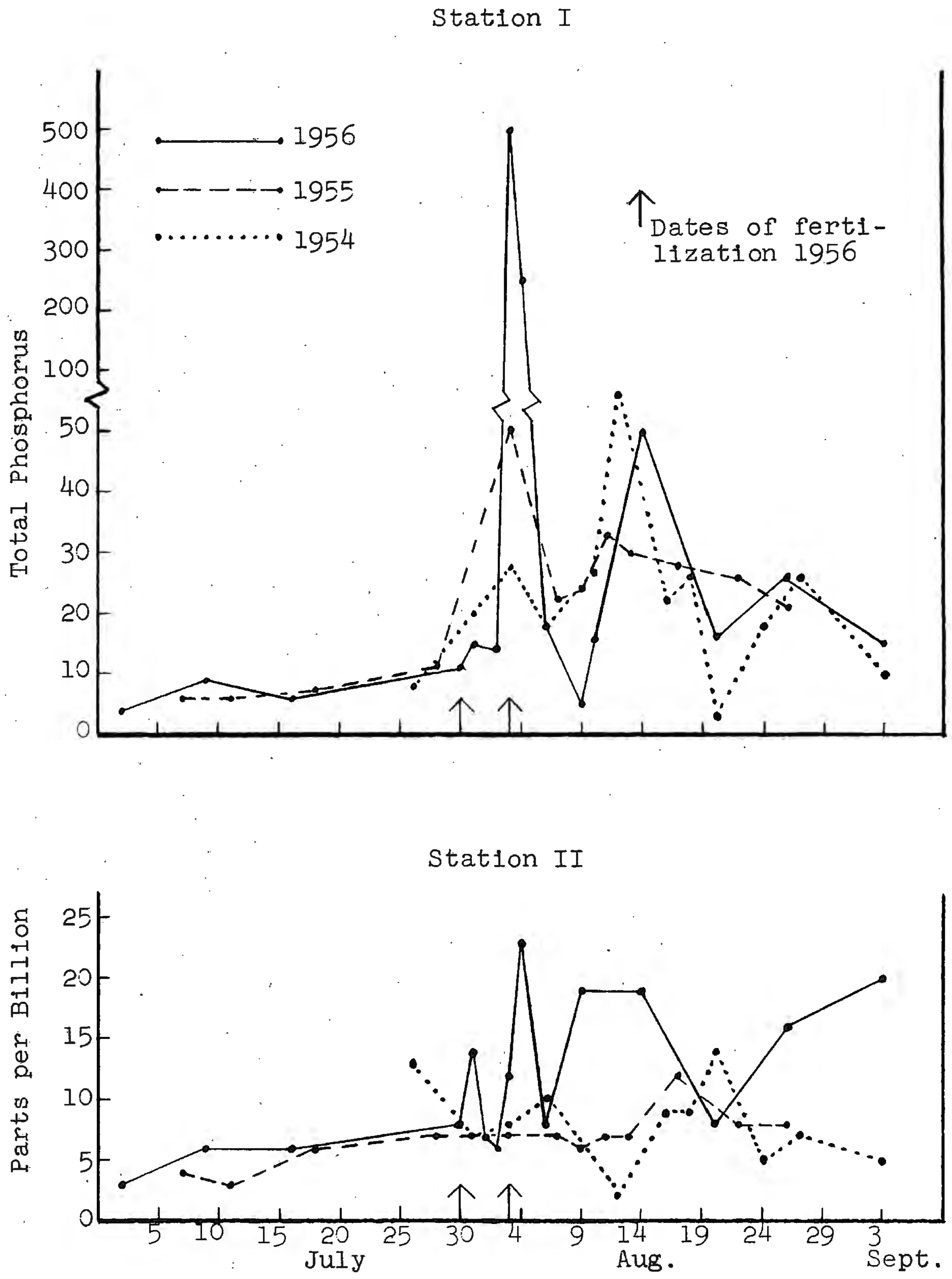
The phosphorus content of the waters of the West Branch is very low in comparison to other trout environments (Colby, 1957). The reasons for a low phosphorus concentration in this stream are many. Phosphorus in ground or seepage water is primarily in a soluble form as it first comes out of the ground. The amount of phosphorus present would depend on the phosphorus content, the types of soil, the types of vegetation, and the seasonal conditions occurring within the drainage area (Millar and Turk, 1954). The watershed of the West Branch consists mainly of rather poor soil types, therefore, a low concentration of nutrients would be expected in the waters draining the area. Another factor contributing to low phosphorus concentrations is the absence of large volumes of runoff water entering the stream. Runoff water carrying suspended matter would contribute new sources of organic and inorganic material from the top of the soil layer. Upon breakdown and dissolving, these materials would add a new and perhaps greater supply of phosphorus to the West Branch than would ground water.

From comparisons of the data for 1954, 1955, and 1956 the phosphorus content of the West Branch appears to have remained rather constant. Little differences are found either between years or during the months of the studies (Figure IV). Following the addition of fertilizer all years' data show an increase in total phosphorus at Station I. By applying the fertilizer in the immediate vicinity of the lake outlet, in 1956, a greater increase occurred at Station I. All stations for the three study years show a slight increase in phosphorus content in the latter part of the summer, probably as a result of a decrease in production at the higher trophic levels.

A second peak in total phosphorus was detected on August 14. The greatest increase was again at Station I but all other stations including the control, exhibited increases. These increases followed a week of rainy weather plus relatively high winds. The increases were probably due to runoff water. Agitation of the lake bottom was the probable cause of a larger increase at Station I.

One further reason for the failure to detect larger phosphorus concentrations at the downstream stations is the effect of dilution. The estimated flow at Station I during the time of fertilization was one cubic foot per second (C.F.S.). The measured flow at Station II was 8.76 C.F.S. in 1954 and 6.56 in 1955 (Table 3). As mentioned before, two large springs entered the West Branch

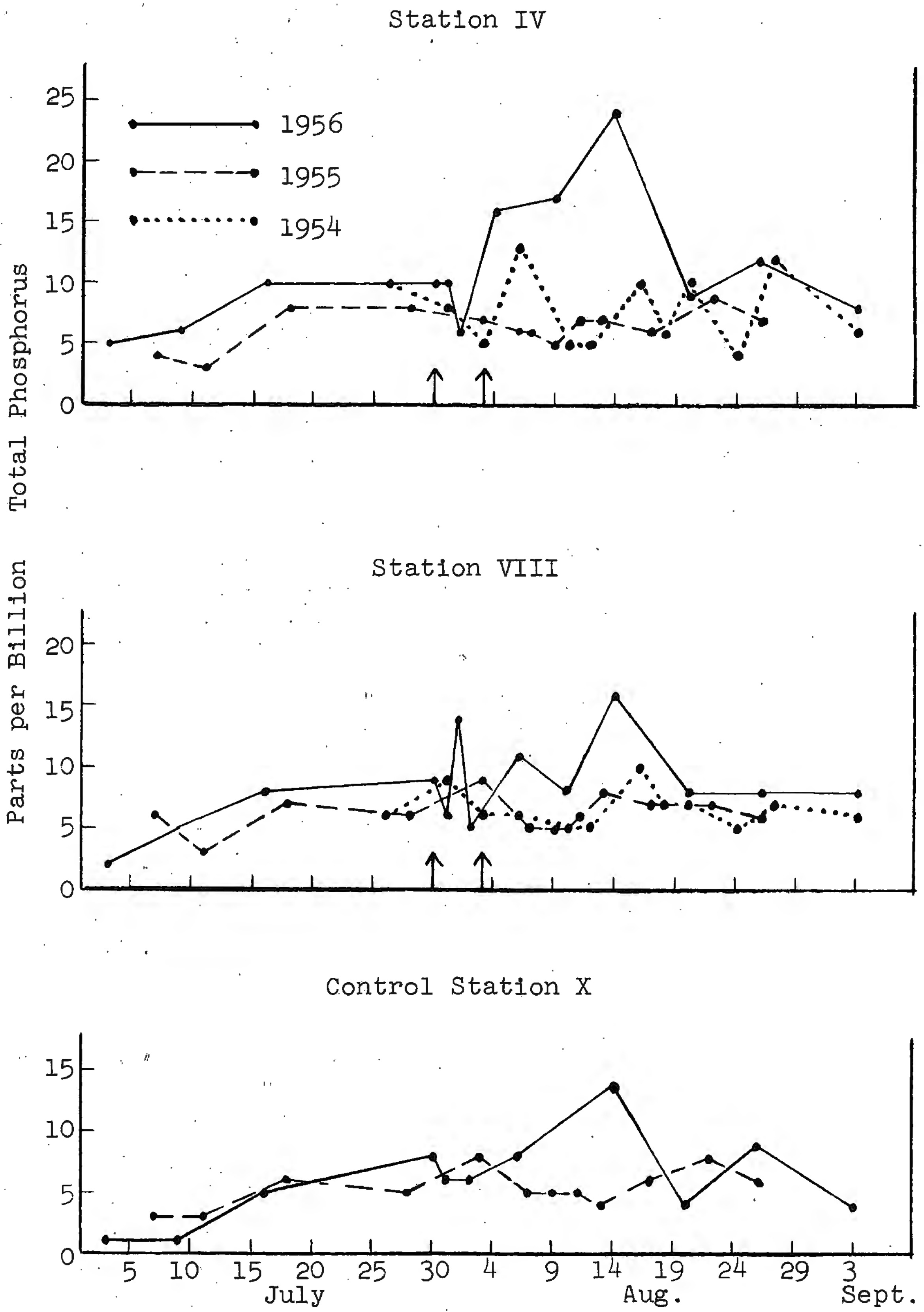
Figure IV. Phosphorus content of water samples taken from the West Branch of the Sturgeon River, during the summers of 1954, 1955, and 1956.



Station I

Station II

Figure IV. Continued



Station IV

Station VIII

Control Station X

between Stations I and II. Any addition of nutrients at Station I would be diluted six to nine times before reaching Station II. If no uptake by plants occurred or no chemical tie-up of nutrients took place, then an addition of 100 micro-grams per liter of phosphorus at Station I would be diluted to about 14 micro-grams per liter at Station II. At Station VIII, ten and one-half miles downstream, this amount (100 micro-grams at Station I) would be diluted to less than 2 micro-grams per liter.

TABLE 3

DISCHARGE (VOLUME OF FLOW) MEASUREMENTS TAKEN FROM THE WEST BRANCH OF THE STURGEON RIVER ON JULY 2, 1954, AND AUGUST 27, 1955*

Station	Discharge (CFS)	
	1954	1955
II	8.76	6.56
III	9.68	--
IV	16.50	--
V	21.0	23.2
VI	29.6	--
VII	45.2	--
VIII	--	68.3

*Colby, 1957.

Phosphorus in a lotic environment has a many and varied fate. Most factors in the lotic environment tend to reduce the phosphorus content. As a result of this study and the two previous ones by Grzenda and Colby, it appears that enrichment of this stream would require a continuous source of nutrients in addition to those already present. The above would be necessary if the enrichment was to be felt throughout the length of the stream. Because of the remarkable ability of plants to store vast quantities of nutrients it appears that, not until a section of stream has absorbed all the phosphorus possible (at any one time), will more move downstream. In effect, only Station I and possibly Station II received additional phosphorus to any measurable extent, at least by the methods used and during the period under study.

Ammonia Nitrogen

Because of a constant positive error in the determination of ammonia nitrogen a correction factor was applied to all values obtained in this study. This correction was necessary for comparison purposes with the previous years data. The actual un-corrected values are shown in Table 4. Table 5 shows the corrected ammonia nitrogen values (actual determinations minus a constant based on the mean values of the two previous years).

After the second application of fertilizer on August 3, 1958 ammonia nitrogen values increased

TABLE 4

PARTS PER MILLION OF AMMONIA NITROGEN IN WATER SAMPLES TAKEN FROM THE WEST BRANCH OF THE STURGEON RIVER DURING THE SUMMER OF 1956*

Date	Stations				
	I	II	IV	VIII	X
July 2	.14	.14	.11	.12	.12
9	.14	.14	.13	.14	.14
16	.13	.13	.12	.12	.12
23	.12	.13	.11	.11	.12
30**	.10	.11	.10	.11	.10
Aug. 2	.12	.12	.13	.12	.13
3**	1.56	.12	--	--	--
4	1.12	.32	.16	--	.11
6	.25	.14	.11	.12	.12
14	.12	.13	.14	.13	.16
20	.13	.13	.13	.14	.14
26	.12	.13	.12	.13	.13
Sept.3	.13	.14	.13	.12	.13

* Uncorrected values.

** Dates of fertilization

TABLE 5

PARTS PER MILLION OF AMMONIA NITROGEN IN WATER SAMPLES TAKEN FROM THE WEST BRANCH OF THE STURGEON RIVER DURING THE SUMMER OF 1956*

Date	Stations				
	I	II	IV	VIII	X
July 2	.04	.02	.01	.02	.01
9	.04	.02	.04	.04	.03
16	.03	.02	.02	.02	.01
23	.02	.01	.02	t	.01
30**	t	.00	.00	.01	.00
Aug. 2	.02	.01	.03	.01	.02
3**	1.46	.01	--	--	--
4	1.02	.21	.06	--	t
6	.15	.03	.02	.01	.01
14	.02	.02	.04	.02	.05
20	.03	.02	.03	.03	.02
26	.02	.01	.02	.02	.02
Sept.3	.03	.02	.04	.02	.02

* Corrected values.

** Dates of fertilization.

t = trace amounts

significantly for a period of 96 hours at Station I, and at least for 24 hours at Station II. Station IV exhibited a change of small magnitude (.03 P.P.M.) which is possibly of significance because of the rather constant values recorded at this and other stations throughout the study. The high value of 1.46 P.P.M. on August 3 at Station I, was obtained from a water sample taken immediately after the addition of fertilizer to the lake outlet. The samples from Stations II and IV on the same date were taken before any added nutrients could have reached there from the lake.

It is apparent from Table 5 that the West Branch of the Sturgeon River received an additional amount of ammonia nitrogen following the addition of fertilizer to Hoffman Lake. At least a portion of this increased amount reached Station IV, four and one-half miles downstream from the lake outlet. The duration of the increase was from over 72 hours at Station I to at least 24 hours at Station IV. Figure V indicates a uniform decrease in the rate of ammonia nitrogen release to the stream. Figure VI shows that the ammonia nitrogen increase lasted for a longer period than did the phosphorus increase. The ammonium increase also was detected further downstream. The detectable increase in nutrients leaving Hoffman Lake following fertilization was a short-lived occurrence. The effects of this temporary increase in nutrients on production were measured by the rate of aufwuchs accumulation on artificial substrates.

Figure V. Rate of ammonia nitrogen release from Hoffman Lake following fertilization.

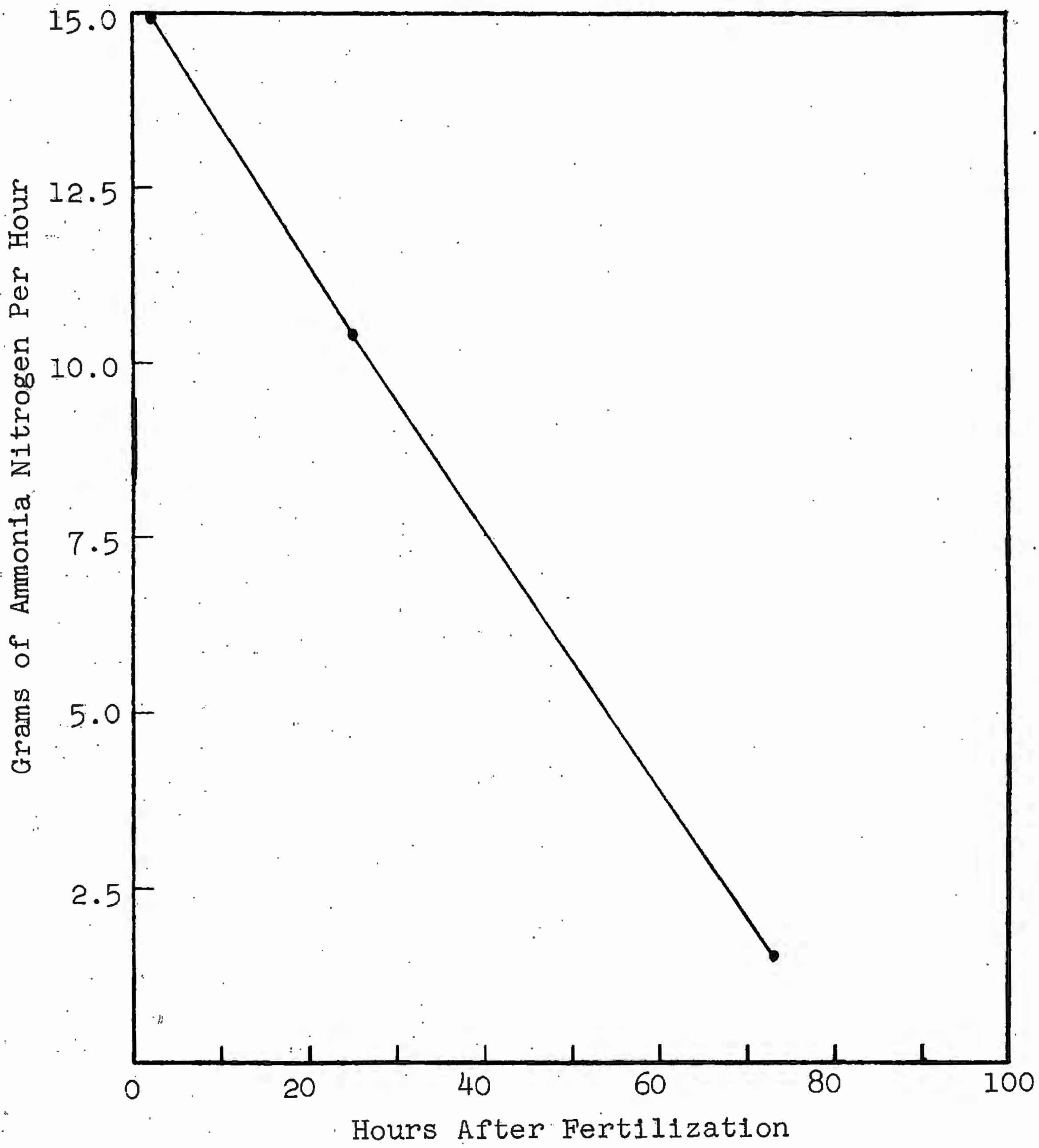
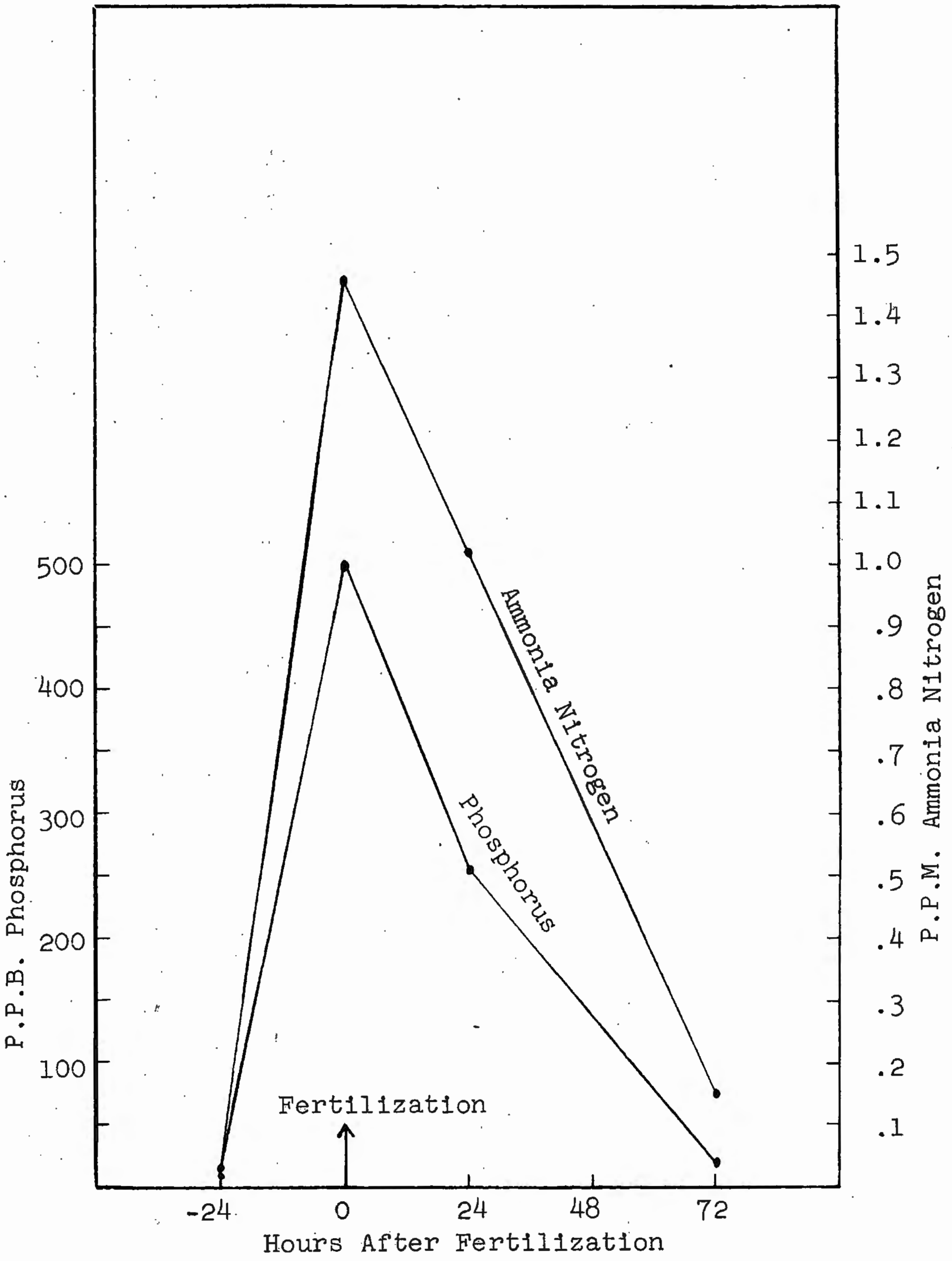

15.0
12.5
10.0
7.5
5.0
2.5
Grams of Ammonia Nitrogen Per Hour
0
20
40
60
80
100
Hours After Fertilization

Figure VI. Concentration of phosphorus and ammonia nitrogen during the period of fertilization at Station I.


P.P.B. Phosphorus
500
400
300
200
100
P.P.M. Ammonia Nitrogen
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
Ammonia Nitrogen
Phosphorus
Fertilization
-24
0
24
48
72
Hours After Fertilization

All ammonia nitrogen values for the three years study were determined by direct Nesslerization. This is not a recommended method for waters of low ammonia content (Standard Methods, 1955), however, relatively constant values were obtained in all the studies. Ignoring values obtained immediately after fertilization, the mean ammonia concentration at all stations and for all three years is .02 P.P.M.

Reasons for low concentration of ammonia in the West Branch are about the same as those for natural waters in general, but perhaps more pronounced. The usual sources of ammonia in natural waters are products of plant and animal material breakdown, sewage, and other organic wastes (Ellis *et al*., 1948), and from precipitation (Ruttner, 1953). Ammonia in the presence of oxygen is almost immediately transformed by nitrifying bacteria into nitrites and nitrates (Ruttner, *op*. *cit*.). Ground and spring waters, not contaminated by human activities, generally contain nitrogen only in the above two forms (Ruttner, *op*. *cit*.). The West Branch would receive a minimal amount of ammonia because of the large volume of ground water entering, and the absence of organic pollution to any measurable extent. Decomposition is probably the main source of ammonia and that is inhibited by the deposition of marl in the West Branch.

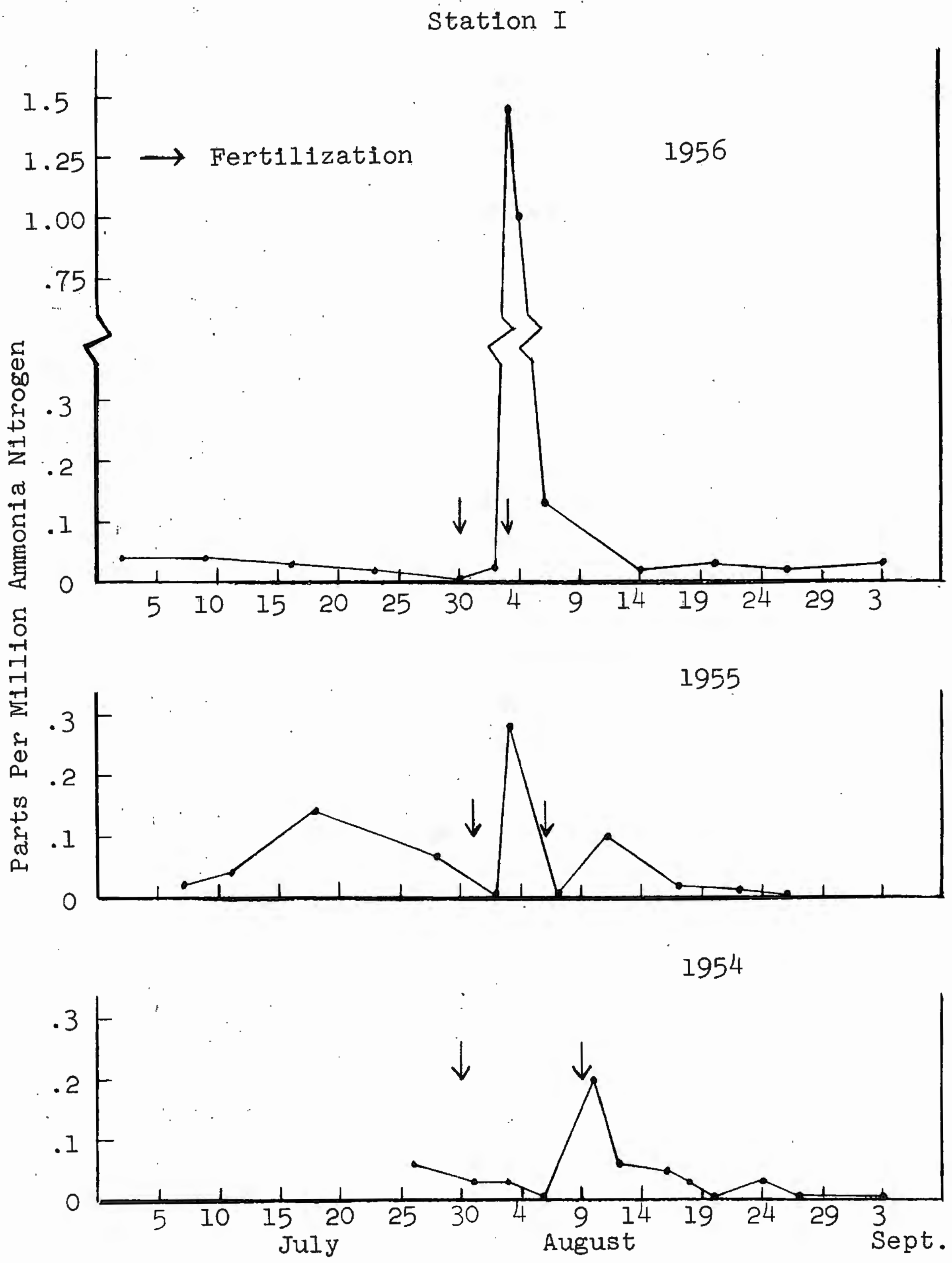
Uptake by plants and chemical combination of ammonia were apparently at a slower rate than of phosphorus. The ammonia values for August 4 at Stations I, II, and IV agree rather closely with a direct dilution effect. A concentration of 1.02 P.P.M. at Station I with no removal or addition would at Station II be diluted to approximately 0.20 P.P.M. and to approximately .05 - 0.07 P.P.M. at Station IV. These figures, based on the discharge measurement in Table 3, agree very closely with the actual results. A second peak in ammonia did not occur as with phosphorus (Figure VII). This is explained by the rather rapid conversion of ammonia to nitrites and nitrates in the presence of oxygen. Therefore, agitation by wind of thelake sediments would not cause a second pulse of ammonia as it appears to have done with phosphorus.

Alkalinity

No change in alkalinity was observed as a result of fertilization. There was no phenolphtholein alkalinity at any station, therefore, total alkalinity was in the form of bicarbonates. An efficient buffer system exists in the West Branch (Grezenda, 1955 and Colby, 1957) in the form of bicarbonates (probably calcium and magnesium). Heavily buffered water such as this would be expected to exhibit little fluctuation in alkalinity.

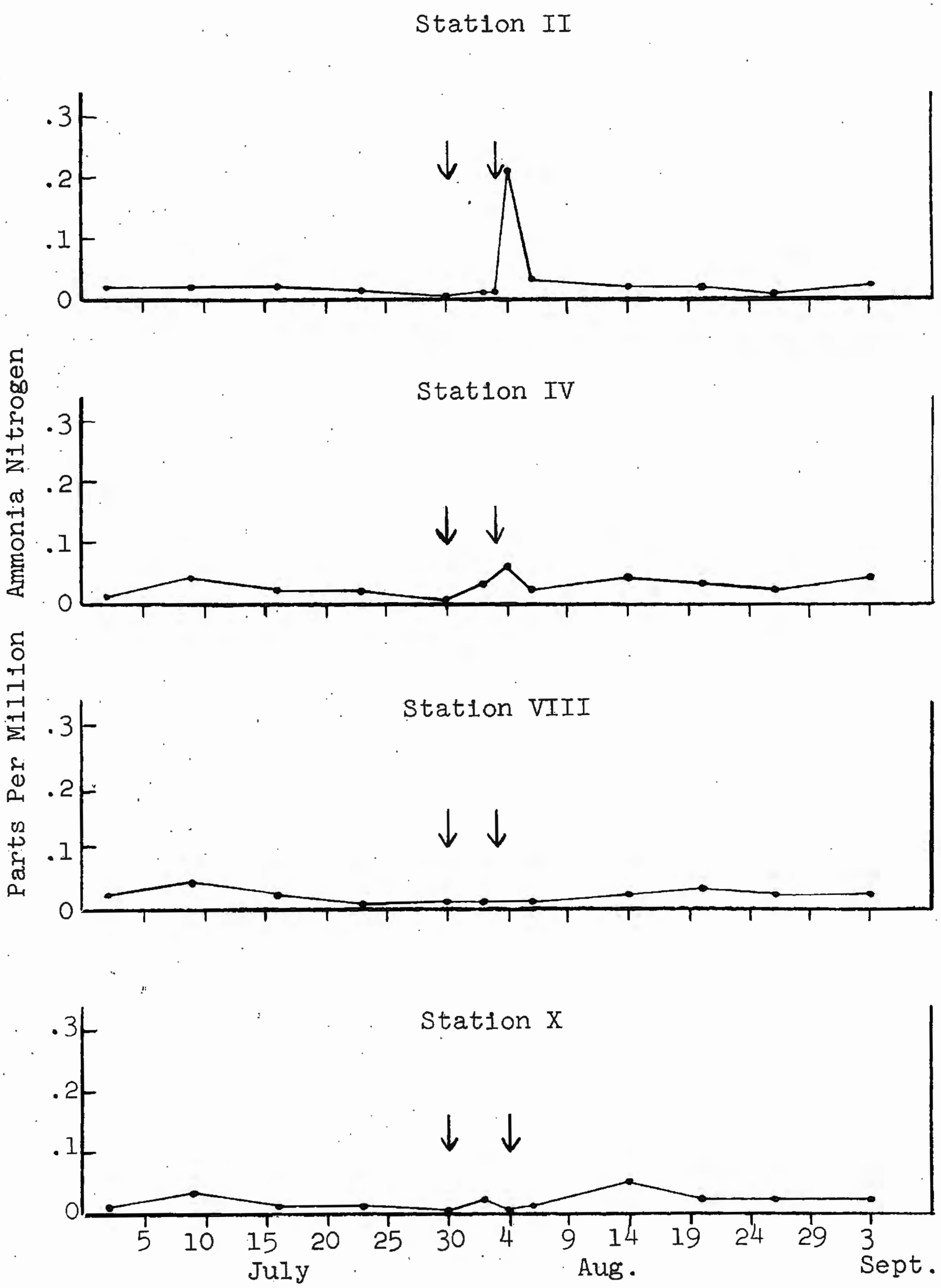
The lowest mean alkalinity value was at Station I, the highest at Station VIII. The mean alkalinity of the

Figure VII. Comparison of the ammonia nitrogen content of water samples taken from the West Branch of the Sturgeon River, during the summers of 1954, 1955, and 1956.



Station I
1.5
1.25
1.00
.75
.3
.2
.1
0
→ Fertilization
1956
5
10
15
20
25
30
4
9
14
19
24
29
3
Parts Per Million Ammonia Nitrogen
1955
.3
.2
.1
0
1954
.3
.2
.1
0
5
10
15
20
25
30
4
9
14
19
24
29
3
July
August
Sept.

Figure VIII. Ammonia nitrogen content of water samples from the West Branch of the Sturgeon River, summer of 1956.


Station II
Station IV
Station VIII
Station X
Ammonia Nitrogen
Parts Per Million
.3
.2
.1
0
5
10
15
20
25
30
4
9
14
19
24
29
3
July
Aug.
Sept.

control stream was 176 P.P.M. (Table 6). If Station X is considered characteristic of the ground water entering the stream, then the gradual increase in alkalinity from Stations I to VIII is probably associated with the increased amounts of ground water entering the stream. Reference to the table of discharge measurements (page 31) shows the magnitude of increase between stations. These increases are caused primarily by ground water entering the stream. Alkalinity values recorded for Station VIII approach those of the control station. The mean alkalinity values for Stations I, II, IV, and VIII are 128, 159, 163, and 173 P.P.M., respectively. In relation to alkalinity, the West Branch quickly loses the characteristics of Hoffman Lake and assumes those of the inflowing ground water (Figure X). Alkalinity values for 1955 (Colby, 1957) also show increasing amounts of bicarbonates in succeeding downstream stations.

Hydrogen ion Concentration

Because of the highly buffered water of the West Branch no appreciable change in pH occurred during fertilization or at any other time during the study. The maximum pH variation at any one station was less than six-tenths. and this occurred over a period of more than four weeks. Table 7 gives the results of pH determinations. The mean pH value for Stations I, II, IV, VIII, and X was 8.1, 8.0, 8.2, 8.2, and 7.8, respectively, for both 1955 and 1956.

TABLE 6

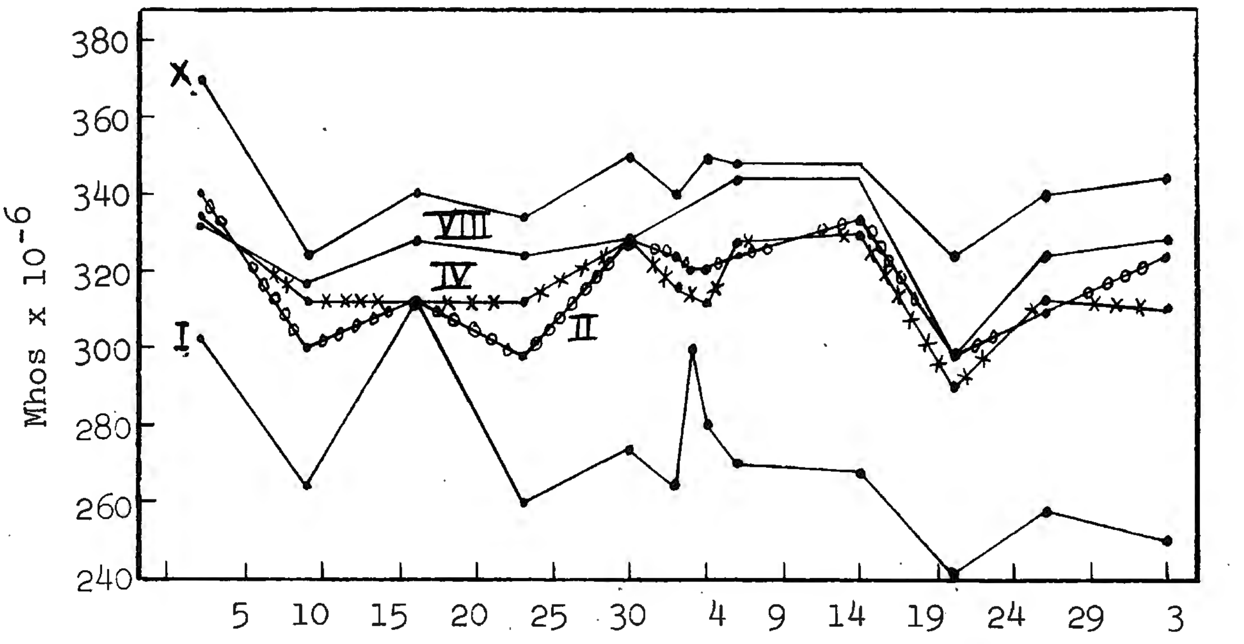
PARTS PER MILLION OF METHYL ORANGE ALKALINITY IN WATER SAMPLES TAKEN FROM THE WEST BRANCH OF THE STURGEON RIVER FOR THE SUMMER OF 1956

Date	Stations				
	I	II	IV	VIII	X
July 2	133	160	165	167	--
9	135	162	166	175	161
16	122	147	153	167	166
23	122	145	156	163	170
30*	130	160	166	178	174
Aug. 1	133	162	165	176	177
2	125	157	162	168	174
3*	129	161	--	--	--
4	128	160	162	--	177
6	126	157	162	176	177
14	124	165	166	178	182
20	126	164	164	176	177
26	126	163	164	173	180
Sept.3	126	164	166	174	181

*Dates of fertilization.

Figure IX. Conductivity values for the separate stations, 1956.

Figure X. Alkalinity values for the separate stations, 1956.


Mhos x 10^{-6}
380
360
340
320
300
280
260
240
X
VIII
IV
II
I
5
10
15
20
25
30
4
9
14
19
24
29
3

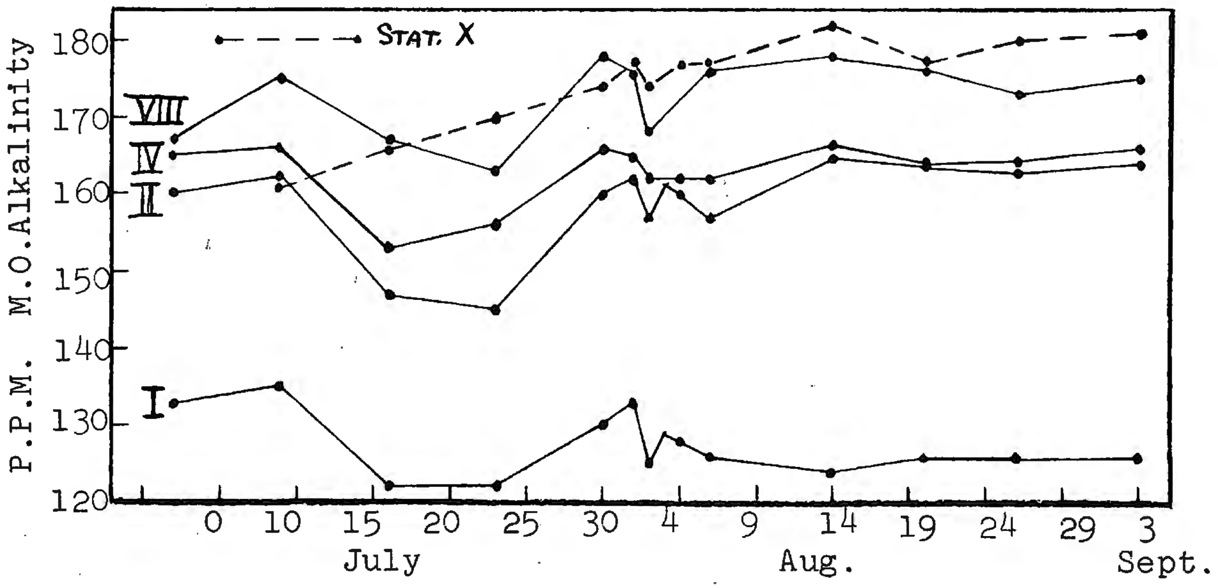

P.P.M. M.O.Alkalinity
180
170
160
150
140
130
120
STAT. X
VIII
IV
II
I
0
10
15
20
25
30
4
9
14
19
24
29
3
July
Aug.
Sept.

TABLE 7

THE HYDROGEN-ION CONCENTRATION OF WATER SAMPLES TAKEN FROM THE WEST BRANCH OF THE STURGEON RIVER DURING THE SUMMER OF 1956*

Date	Stations				
	I	II	IV	VIII	X
July 2	7.9	7.8	8.0	8.0	7.7
9	8.0	7.8	7.9	8.0	7.7
16	7.8	7.9	8.1	8.1	7.7
23	8.1	7.9	8.2	8.1	7.8
30	8.2	8.0	8.3	8.2	7.8
Aug. 6	8.2	8.0	8.2	8.1	7.7
14	8.4	8.1	8.3	8.3	7.9
20	8.3	8.1	8.3	8.3	8.0
26	8.1	8.1	8.4	8.3	8.0
Sept.3	8.2	7.9	8.2	8.2	7.8

*Dates of fertilization: July 30 and August 3.

Although rather homogenous pH and alkalinity values were obtained in this study, they furnish useful information. Theoretically, addition of a large quantity of acid fertilizer should produce at least a temporary change in pH and alkalinity unless the addition was to highly buffered water. In some pond fertilization projects it was necessary to add lime before fertilizing to prevent an undesirable change in pH (Clarke, 1954) and consequently a change in the form of carbon dioxide.

The form in which CO_2 occurs in an aquatic environment is of utmost importance in primary production (Clarke, op. cit.). Any factor changing the pH will affect the CO_2 equilibrium and conversely addition, removal, or change in the form of CO_2 will affect pH (Dye, 1952). When the total alkalinity is constant, pH change is proportional to CO_2 change and, therefore, is a useful measure of the latter (Odum, 1954). Odum (op. cit.) states that moderate increases in CO_2 in water seems to speed up photosynthesis and other developmental processes of many organisms.

In a marl lake and stream, such as Hoffman Lake and the West Branch, the vegetation is limited to those species which can utilize carbon dioxide in the combined form. By the addition of a substance yielding hydrogen ions, the free carbon dioxide should increase if the ions of hydrogen were not combined with a buffer. Increased amounts of free carbon dioxide should enable the growth of a more diversified community and/or an increase in those already present. The fact that increased amounts of carbon dioxide did not occur is indicated by the relatively constant pH and alkalinity values obtained. This also points out the buffering capacity of the water in the West Branch.

Conductivity

No change occurred in the conductivity of the water, following the addition of fertilizer. Colby (1957), also found no change due to fertilization. Table 8 shows the conductivity values in mhos x 10^{-6} for the entire study. The concentration of electrolytes varies from station to station in a manner similar to the methyl orange alkalinity (Figure XI). The ground water entering the stream, as indicated by the control station, has the highest concentration of electrolytes; Station I (and Hoffman Lake) has the lowest. Figure XI shows that the mean conductivity values approach those of the control stream in succeeding downstream stations, as with alkalinity, the stream quickly loses characteristics of the lake and assumes those of the inflowing ground water.

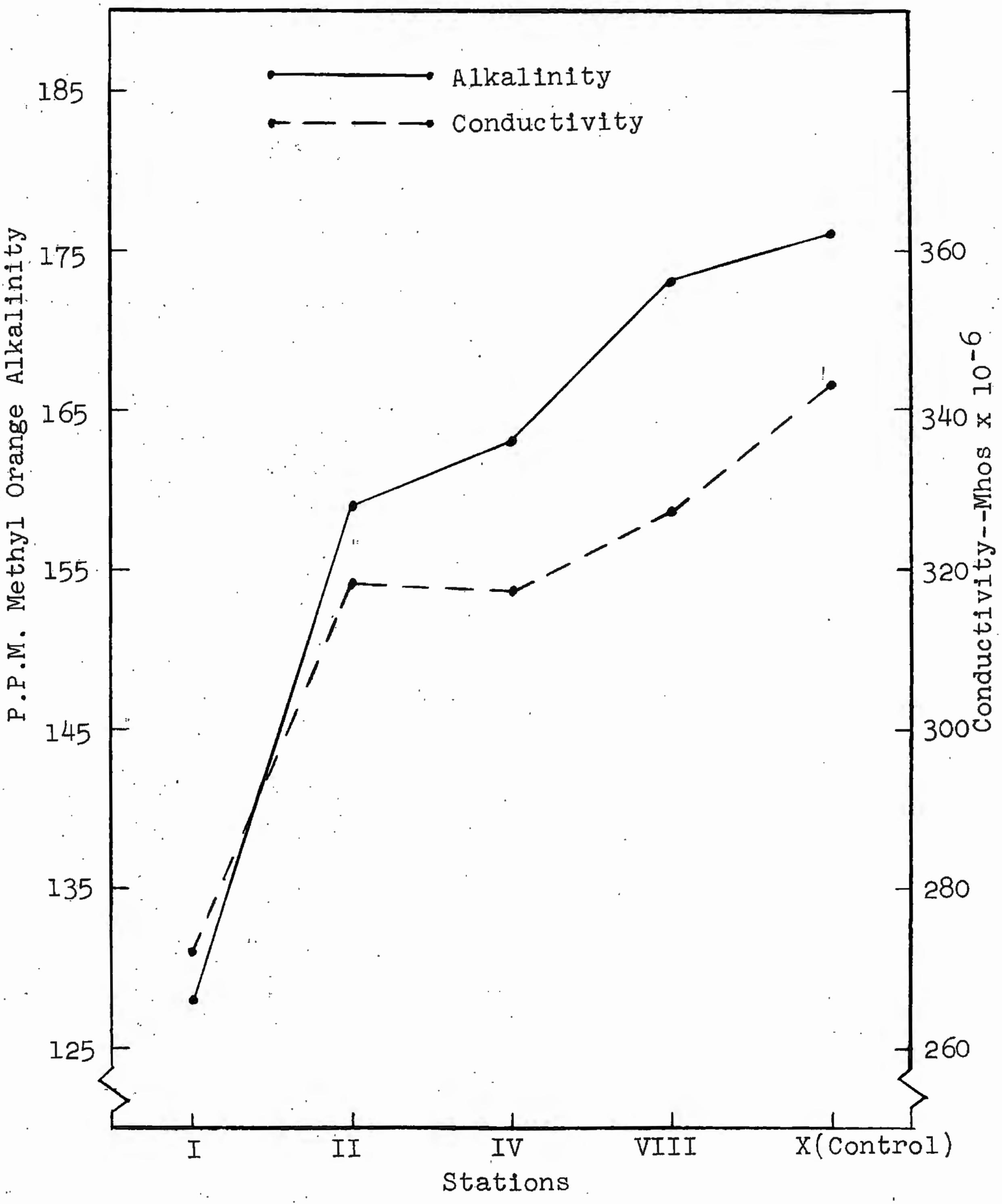
TABLE 8

CONDUCTIVITY (IN MHOS x 10^{-6} AT 18° C) OF WATER SAMPLES TAKEN FROM THE WEST BRANCH OF THE STURGEON RIVER DURING THE SUMMER OF 1956

Date	Station				
	I	II	IV	VIII	X
July 2	302	304	334	333	370
9	263	300	312	317	323
16	312	311	312	328	339
23	260	298	312	323	333
30*	274	328	328	328	351
Aug. 2	263	323	317	--	339
3*	298	321	--	--	--
4	281	321	312	--	351
6	270	325	328	344	347
14	267	333	331	344	347
20	241	298	290	298	324
26	258	310	312	325	341
Sept. 3	250	323	310	328	345

* Dates of fertilization.

Figure XI. Mean alkalinity and conductivity values for the separate stations of the West Branch (1956).


Alkalinity
Conductivity
P.P.M. Methyl Orange Alkalinity
185
175
165
155
145
135
125
Conductivity--Mhos x 10^{-6}
360
340
320
300
280
260
I
II
IV
VIII
X(Control)
Stations

BIOLOGICAL

Aufwuchs

Ruttner (1953) gives the following as a definition of aufwuchs: "By the term aufwuchs we mean all those organisms that are firmly attached to a substrate but do not penetrate into it (in contrast to plants rooted in the bottom or certain parasites)." The closest English equivalent is periphyton but its application is not as wide as the term aufwuchs. Cooke (1956) gives a detailed account of the terminology used for this group of organisms. The reader is referred to his paper for a comprehensive account of this terminology and its history. Grzenda (1955) and Colby (1957) give general discussion of the aufwuchs community and its composition.

Butcher (1932) in an early study of several streams in Great Britain found three important groups of algae attached to submerged glass slides. These groups are Diatomacea, Chlorophyceae, and Myxophyceae. He also found that, with few exceptions, all the organisms in the potamoplankton (plankton found in running water) can be found in the aufwuchs community at one time or another. Potamoplankton has a double relationship with the aufwuchs, it is a contributor to the aufwuchs community and also receives a portion of its constituents from it (Butcher, op. cit. and Cooke, op. cit.).

Chlorophyll bearing plants being the principal biological constituent of the aufwuchs, serve as a basis for measuring this community. Quantitative measurement of basic or primary productivity (photosynthetic and chemosynthetic activity) is a measure of the tropic level having the most rapid rate of energy transformation and the greatest biomass (Odum, 1953). The measurement of this level by counting individual cells is not practical when large volumes of plant material are involved. Colorimetric measurement of pigment density has been found to be closely associated with actual cell counts and is a more rapid method. Tucker (1949) gives a review of the important works on the process of determining the abundance of phytoplankton from colorimetric measurement of extracted pigment density. Harvey (1934) showed that there is rather close agreement between the density of extracted pigments and actual cell counts of phytoplankton. Tucker (1949) in a statistical approach to the problem found that "it (Harvey method) has not been perfected sufficiently to be used other than as a general indicator." However, Grzenda (personal communication) has found a remarkably close correlation between pigment density and total organic weight of aufwuchs on artificial substrates.

In this study there were four slightly different ways in which the accumulation of aufwuchs was measured, the methods differing only in time of submersion and the type of substrate material. The first method to be discussed is the one in which wooden shingles were the substrate material and the time of submersion was seven days.

An increase in the density of extracted pigments occurred at all stations the latter part of July, one week before fertilizing, including the control station (Table 9). This increase was apparently a natural seasonal increase as the higher values were obtained throughout the study at all stations. The week following fertilization (August 8) again showed increases at all stations but of much greater magnitude at Station I (Table 9 and Figure XII). Following fertilization all stations except Station I maintained a rather uniform level of aufwuchs production. The pigment density of material collected at Station I after the addition of fertilizer was six to twenty times greater than the mean of the five-week period before fertilization. The unusually high density reading at Station I on September 5 was a result of a heavy growth of filamentous algae on all submerged objects.

In order to determine if a significant increase in aufwuchs occurred following fertilization, the effect of the natural increase that occurred simultaneously with fertilization had to be minimized. This was accomplished

TABLE 9

MEAN DENSITY OF CHLOROPHYLL EXTRACTED FROM AUFWUCHS ON WEEKLY SHINGLES--EXPRESSED IN KLETT UNITS, 1956

Date of Removal		Station				
		I	II	III	VIII	X
Before Fertilization	July 4	10	9	18	11	8
	July 11	8	19	36	27	14
	July 18	5	16	24	15	14
	July 25	4	12	13	15	13
	Aug. 1	14	25	24	31	25
After Fertilization	Aug. 8	58	40	44	38	26
	Aug. 15	82	27	25	27	28
	Aug. 22	43	34	21	30	24
	Aug. 29	70	43	24	35	21
	Sept. 5	170	31	8	32	34

Sample size = 10 observations for each station and each week.

Figure XII. Graphical representation of mean density of chlorophyll extracted from aufwuchs on weekly shingles--expressed in Klett units, 1956.

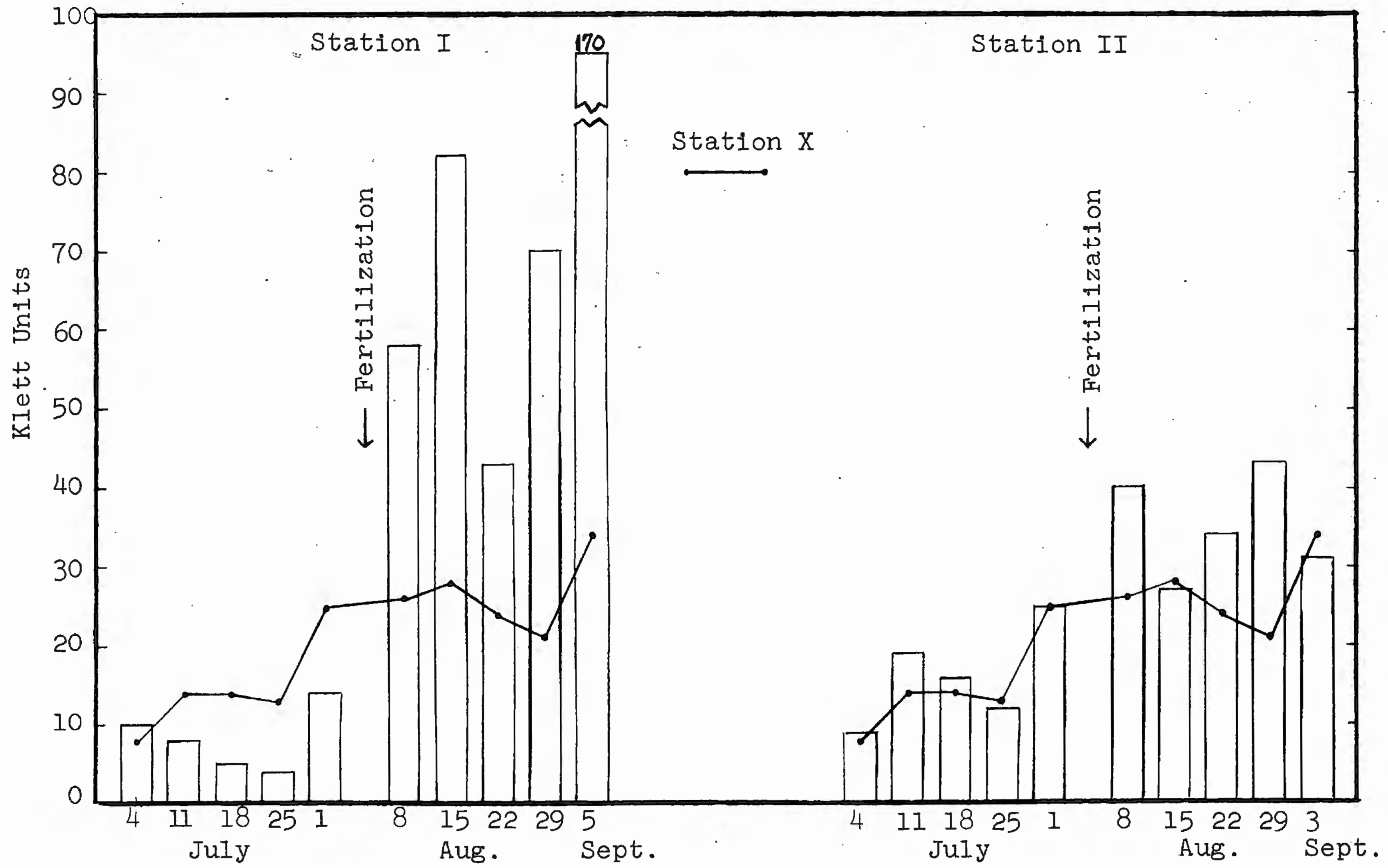
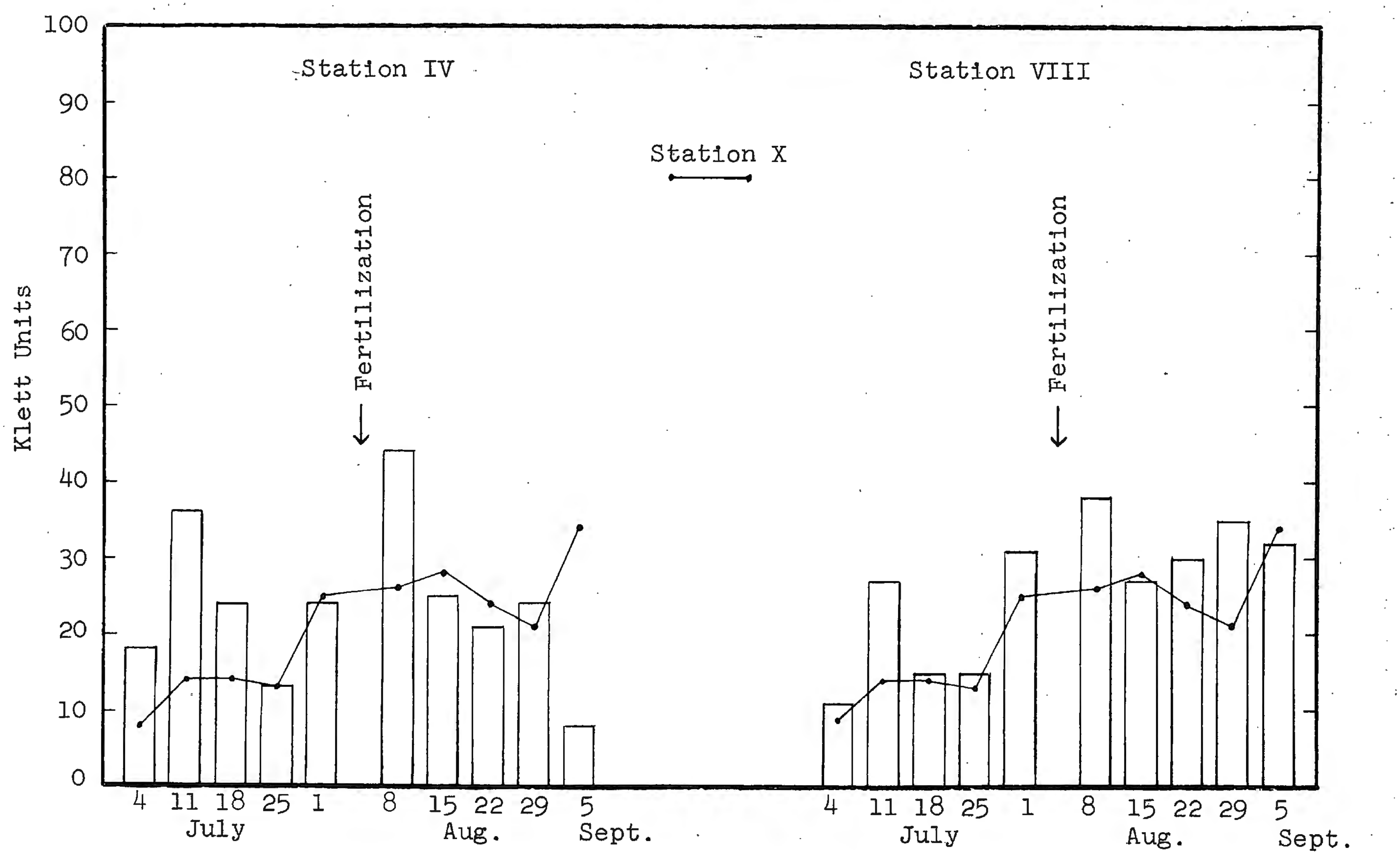

Klett Units
100
90
80
70
60
50
40
30
20
10
0
Station I
170
Station X
Station II
Fertilization
Fertilization
4
11
18
25
1
8
15
22
29
5
July
Aug.
Sept.
4
11
18
25
1
8
15
22
29
3
July
Aug.
Sept.

Figure XII. Continued.


Station IV
Station VIII
Station X
Fertilization
Fertilization
Klett Units
100
90
80
70
60
50
40
30
20
10
0
4
11
18
25
1
8
15
22
29
5
July
Aug.
Sept.
4
11
18
25
1
8
15
22
29
5
July
Aug.
Sept.

in two ways with similar results. First a ratio between the mean density of pigments at Station X and the mean density of all the remaining stations for each week was calculated. It was then hypothesized that if an increase occurred due to seasonal causes the increase would occur in the same proportions at all stations. Since Station X was the only station that could not possibly be effected by the addition of fertilizer, any increases that occurred there would be due to natural causes. Thus, by calculating a ratio between Station X and all other stations, the effect of natural increases would be minimized, that is, any changes occurring at the other stations could be interpreted as differing from natural fluctuations. The second method was to calculate a series of "t" tests between Station X and all other stations (using mean Klett units) to determine if differences existed either before or after fertilization.

Table 10 lists the values obtained by calculating a ratio between Station X and the remaining stations for each weekly reading. Table 11 lists the results of a series of "t" tests using the ratio values from Table 10. Both before and after fertilization significant differences existed between Station I and all other stations. No significant differences were found between any of the other stations. It should be noted that the differences existing before fertilization between Station I and the other stations were due to the much lower values of Station I. After

TABLE 10

RATIO VALUES OBTAINED BY DIVIDING THE MEAN WEEKLY DENSITY VALUES OF THE CONTROL STATION INTO THE MEAN WEEKLY DENSITY VALUES OF THE FOUR REMAINING STATIONS

Date	Station			
	I	II	IV	VIII
July 4	1.21	1.01	2.12	1.33
July 11	0.58	1.34	2.51	1.89
July 18	0.37	1.14	1.75	1.09
July 25	0.35	0.95	1.04	1.14
Aug. 1	0.54	0.98	0.94	1.21
Aug. 8	2.26	1.59	1.74	1.49
Aug. 15	2.88	0.96	0.88	0.94
Aug. 22	1.80	1.41	0.88	1.24
Aug. 29	3.30	2.02	1.12	1.67
Sept. 5	4.92	0.90	0.22	0.92

TABLE 11

RESULTS OF "T" TESTS CALCULATED FROM THE COMPUTED RATIO VALUES

Test	"t" Value	
	Before Fertilization	After Fertilization
Stat. I vs II	2.75*	2.89*
Stat. I vs IV	3.12*	3.49**
Stat. I vs VIII	3.42**	3.24*
Stat. II vs IV	1.90	1.28
Stat. II vs VIII	0.49	0.52
Stat. IV vs VIII	1.03	1.00

Stat. I before fert. vs Stat. I after fert. = 4.21**

Stat.II before fert. vs Stat. II after fert. = 1.36

Stat.IV before fert. vs Stat. IV after fert. = 1.79

Stat.VIII before fert. vs Stat.VIII after fert. = 0.38

* Significant at the 5 per cent level.

** Significant at the 1 per cent level.

Degrees of freedom = 8.

Critical value of t = 2.306.

fertilization the differences were caused by high values at Station I. It appears from the ratio series of "t" tests that Station I is not characteristic of any other station and that there was a sudden increase in the aufwuchs growth at this station only, following fertilization.

Comparison of results within stations, between the pre and post fertilization periods, shows no significant change in aufwuchs growth except at Station I. Again this series of "t" tests leads to the conclusion that the addition of fertilizer to Hoffman Lake caused no significant increase in the growth of aufwuchs on the weekly shingles except at the outlet of the lake (Station I).

In order to obtain a more direct comparison between and within stations, another series of "t" tests was computed, using the mean Klett units (6 Klett units equal one Harvey unit) for the five weekly periods before and after fertilization (Table 9).

Table 12 lists the results of the two series (within stations and between stations) of "t" tests. Slightly different results were obtained in this series as compared to the ratio series. Significant differences exist, at the 5 per cent confidence level, within all stations (before versus after fertilization) except Station IV. Apparently the seasonal increase in aufwuchs growth occurring during the latter part of the study was the primary cause of these differences. Had not the control station shown an increase, the differences would have appeared to have been caused by the addition of fertilizer.

TABLE 12

RESULTS OF "T" TESTS CALCULATED FROM THE MEAN KLETT UNIT VALUES OF EACH STATION FOR EACH WEEK

Test	Result
Station I before vs after fertilization	T = 3.42**
Station II before vs after fertilization	T = 4.70**
Station IV before vs after fertilization	T = 0.20
Station VIII before vs after fertilization	T = 2.89*
Station X before vs after fertilization	T = 3.26*
Station X before vs Station I before fertilization	T = 2.02
Station X before vs Station II before fertilization	T = 0.28
Station X before vs Station IV before fertilization	T = 1.72
Station X before vs Station VIII before fertilization	T = 1.01
Station X after vs Station I after fertilization	T = 2.59*
Station X after vs Station II after fertilization	T = 2.28
Station X after vs Station IV after fertilization	T = 0.37
Station X after vs Station VIII after fertilization	T = 1.83

* Significant at the 5 per cent level.

** Significant at the 1 per cent level.

Degrees of freedom = 8.

Critical value of "t" = 2.306.

In order to determine if increases occurred over and above the apparent natural increase a series of "t" tests were again computed between the control stream (Station X) and all other stations. The "t" tests were computed using the mean Klett readings of pigment density for the five week period before fertilization and for the five week period following fertilization. The results of these tests are tabulated in Table 12. Prior to the addition of fertilizer there were no significant differences found to exist between any station on the West Branch and the separate control station. Following the addition of fertilizer to the headwaters, only Station I (the station closest to the site of fertilization) differed significantly from the Control Station. Although all stations increased in aufwuchs production following fertilization only Station I increased to a statistically significant degree. Again the test results lead to the conclusion that the addition of fertilizer to Hoffman Lake effected the plant growth on the artifical substrates at Station I only.

In 1955, Colby used singles submerged for weekly periods at Station IV-A only (located a short distance above Station IV proper). Although no comparisons were made between this station and the control station, so as to eliminate seasonal effects, Colby found a highly significant difference (1 per cent confidence level) between the weeks before fertilization and those after fertilization.

These results again show a rather large increase in aufwuchs production in the latter part of the summer. Grzenda (1955) did not use weekly periods for measuring aufwuchs.

In addition to weekly measurements of aufwuchs accumulation there were also monthly measurements. At each station, intermixed with the weekly substrates, there were fifteen wooden shingles, one set of which was removed shortly before fertilization and another set thirty days following fertilization.

Since it was discovered that a natural or seasonal increase in aufwuchs production occured at about the time the second set of substrates were in the stream, it was again necessary to make comparisons between the control station and the main stream stations. To test for an increase in chlorophyll production, the prefertilization results were subtracted from the post-fertilization results. These differences (Table 13) showed increases for 66 out of 74 pairs of shingles. The range of difference was from a minus 56 Klett units (Station X) to 570 Klett units (Station I).

The thirty day shingle data were tested for homogeneity of variance using the method described by Bartlett (Snedecor, 1956). Significant evidence of heterogeneity was found to exist even after the test was computed using a logarithmic transformation of the data. It was, therefore, necessary to use a nonparametric procedure to test for

TABLE 13

INCREASE IN THE DENSITY OF CHLOROPHYLL EXTRACTED FROM AUFWUCHS SAMPLES AFTER FERTILIZATION (30 Day Shingles)

Station	Mean Reading of Each Set of 30 Day Shingles (Klett Units)		Mean Increase After Fertilization (Klett Units)
	First Set	Second Set	
I	16	210	194
II	131	160	29
IV	59	125	184
VIII	71	107	36
X	108	139	31

First set removed July 27, 1956.

Second set removed August 26, 1956.

significant increase. The procedure used was the Mann-Whitney "U" Test as described by Siegel (1956). This test is used to test whether two independent groups have been drawn from the same population. "This is one of the most powerful of the nonparametric tests, and it is a most useful alternative to the parametric "t" test when the researcher wishes to avoid the "t" test's assumptions," Siegel (1956). The formula for the Mann-Whitney "U" test is as follow:

$$U = n_1 n_2 + \frac{n_1 (n_1 + 1)}{2} - R_1$$

or, equivalently,

$$U = n_1 n_2 + \frac{n_2 (n_2 + 1)}{2} - R_2$$

where R_1 = sum of the ranks assigned to group whose sample size is n.

R_2 = sum of the ranks assigned to group whose sample size is n_2.

The smaller of the two "U" values, is the one whose sampling distribution is the basis for determining significance. The critical "U" value for this test, where n_1 and n_2 are both equal to fifteen, is 56 (alpha equals 0.02). The hypothesis that two independent groups are drawn from the same or equal populations is rejected if the computed "U" value is equal to or less than 56.

The results of the Mann-Whitney "U" Test are summarized in Table 14. No significant differences were found

TABLE 14

RESULTS OF MANN-WHITNEY "U" TEST

Stations Tested	"U" Value	Significantly Different
I and X	11.5	Yes
II and X	100.0	No
IV and X	38.5	Yes
VIII and X	104.0	No

to exist between Station X and Stations II and VIII. Significant increases occurred at Stations I and IV over the increase that occurred at the control station. These results differ somewhat from the results obtained by treatment of the weekly substrates. The significant difference that was found to exist between Station IV and Station X in the thirty day shingles was not found in the weekly collections. It is believed that the increase over and above the natural increase at Station IV was a direct result of fertilization. Station IV, as was stated earlier, was in an area of near complete shade. The thirty day shingles were separate from the weekly shingles and located in the downstream area of Section IV. This was the only section in which the two sets of shingles were not intermixed. The near complete shade is believed to have caused slower growth of the aufwuchs on the shingles and, therefore, the weekly substrates were removed before the growth on the shingles had reached a rate comparable to that of the other stations.

Station I had the greatest increase in aufwuchs production following fertilization. The mean density readings of the extracted pigments increased more than ten times, to go from the lowest value of all stations to the highest value. The cause for this high magnitude of increase is believed to be the extremely low nutrient level existing prior to fertilization providing a favorable condition for the maximum effect of the added nutrients.

Results of the thirty day shingles of this study compared with those of 1954 and 1955 show that Station I, following fertilization, increased significantly in aufwuchs production. However, when comparing results at Stations II to VIII we find differences apparently occurring. In 1954 Grzenda found a statistically significiant gain in aufwuchs at these stations following fertilization. The method of testing for differences used by Grzenda was an analysis of variance of the mean density values. Since no control was utilized in 1954 the effect of any seasonal increase could not be detected. Colby, the following year, using the same test found no significant difference in aufwuch flora following fertilization. In 1955 the mean difference from zero for the thirty days singles was a negative value, indicating a decrease in the attached flora. Although the control station was not used directly for comparison purposes, the aufwuchs growth in 1955 at the control station was approximately the same for both thirty day sets of shingles, indicating little or no seasonal increase. The results in 1956 at the downstream stations show increases at all stations but not significantly different from the increase at the control stream. It, therefore, appears possible that if a control had been utilized during all three years of study, the effect of seasonal increases could account for the differences found to have existed.

In addition to wooden shingles, building bricks were also used as artificial substrate material. Five bricks were placed in the stream at each station on the same time schedule as the thirty day shingles. Table 15 lists the mean Klett readings for each station before and after fertilization and also the per cent increase. As before with the wooden substrates, the extracted material from the bricks showed increases at all stations following fertilization.

Station I had nearly a ten fold increase in aufwuchs production and led all other stations in per cent increase. The natural or seasonal increase in production, as indicated by the control station, was somewhat higher on the brick substrates than on the shingles. This may be due to the qualitative differences in the flora found on the two types of substrates. Colby (1957) found that diatoms made up the major components of the flora attached to the bricks while filamentous green algae was the primary constituent on the shingles. This was particularly noticeable at Station I where the shingles were covered with long strands of algae while the bricks were relatively free.

TABLE 15

MEAN DENSITY OF CHLOROPHYLL EXTRACTED FROM AUFWUGHS ON THIRTY DAY BRICKS (Klett Units)

Station	Mean Klett Units Before Fertilization	Mean Klett Units After Fertilization	Per Cent Increase
I	12	132	963
II	8	47	503
Control	20	80	294
IV	15	31	113
VIII	12	27	118

The results of the 1954 study showed a similar trend in production on both the bricks and shingles, therefore, Grzenda pooled the two sets of data and treated the results as one. Grzenda (1955) found increased production following fertilization on the bricks at all stations. Colby (1957) found no significant difference from zero when treating the data for the brick substrates. The results obtained during the three years of study, although different from each other, follow a consistent pattern within each study.

Thus far, all three types of aufwuchs collections in 1956 show essentially the same results. The nutrient concentration was raised, by the addition of fertilizer, to a sufficiently high level to enable a significant increase in aufwuchs production at Station I. They further indicate the probability that points below the vicinity of fertilization received additional nutrients in varying detectable amounts.

In order to determine the optimal time of submersion and the effects of erosion on the shingles, a set of forty shingles were placed in the stream and removed at varying lengths of time. Station VII was selected as the site for this type of collection. Ten of the forty shingles were removed at weekly intervals, resulting in four complete sets before fertilization and four sets following fertilization. Table 16 gives the time each set was submerged, the dates of submersion, the per cent increase of the second set, and the mean Klett units of each set. During the post-fertilization period the aufwuchs growth reached a plateau in only two weeks, as compared to three weeks for the first period. It appears, at least in the lower section of the West Branch, the optimal time of submersion depends on the rate of aufwuchs accumulation. The most rapid rate of growth at Station VII occurred within the first few days of submersion, but the maximum growth was not obtained until sometime after the second week. It, therefore, appears that the weekly collections were removed before maximum growth had occurred and that the thirty day collections were removed sometime after the accumulation had reached its peak.

TABLE 16

MEAN DENSITY OF CHLOROPHYLL EXTRACTED FROM AUFWUCHS ON SHINGLES AT STATION VII

Days in Stream	Dates in Stream (Before)	Mean Klett Units		Dates in Stream (After)	Per Cent Increase
		Before Fert.	After Fert.		
7	6-27 to 7- 4	18	43	7-25 to 8- 1	139
14	6-27 to 7-11	30	78	7-25 to 8- 8	163
21	6-27 to 7-18	52	75	7-25 to 8-15	44
28	6-27 to 7-25	48	72	7-25 to 8-22	51

Bottom Fauna

The number of bottom organisms increased more than 200 per cent in 1956, over the two previous years (Table 17). This increase was mainly due to substantial increases in caddisflies (Trichoptera), two-winged flies (Diptera) and aquatic earthworms (Figure XIII). The per cent composition of the different orders of insects changed relatively little in the three years of study (Figure XIV). The numerical increases (insects only) in 1956 were

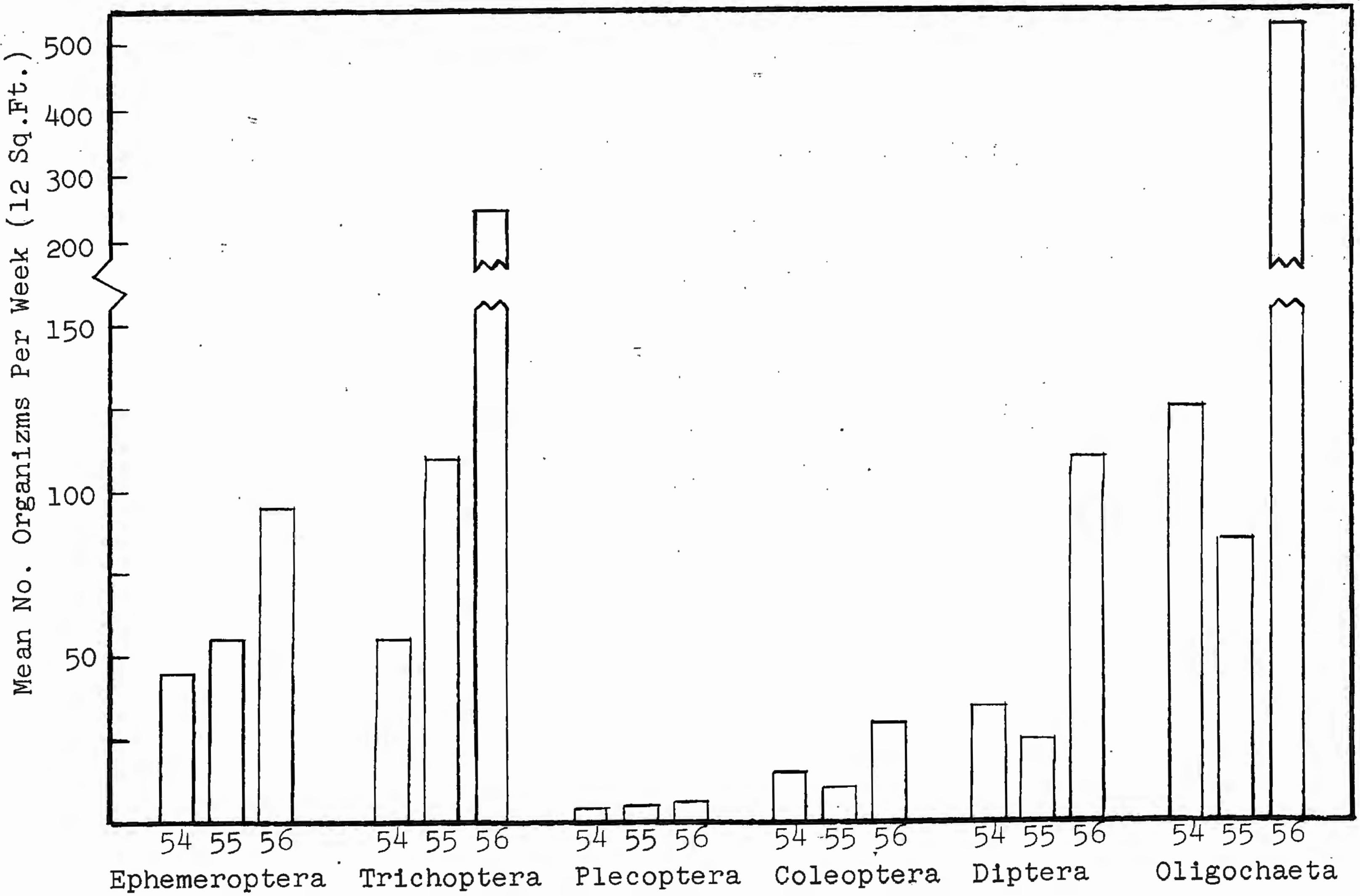
TABLE 17

COMPARISON OF THE MEAN NUMBER AND VOLUME OF ORGANISMS COLLECTED FROM THE WEST BRANCH OF THE STURGEON RIVER IN 1954, 1955, AND 1956

Date*	Mean Number Per Square Foot			Volume (CC) Per Square Foot		
	1954	1955	1956	1954	1955	1956
June 29	12.9	27.7	53.5	.28	.17	0.21
July 6	10.7	29.5	73.8	.15	.29	0.25
July 13	21.6	28.2	45.5	.16	.44	0.16
July 20	40.8	23.2	90.3	.24	.33	0.27
July 26	47.4	17.8	101.8	.31	.44	0.36
Aug. 10	19.2	31.2	100.3	.44	.36	0.28
Aug. 17	16.6	26.3	87.4	.11	.50	0.25
Aug. 24	25.5	17.7	95.1	.20	.41	0.27
Aug. 31	26.8		75.4	.28		0.30
Sept. 7	12.0		121.4	.13		0.37

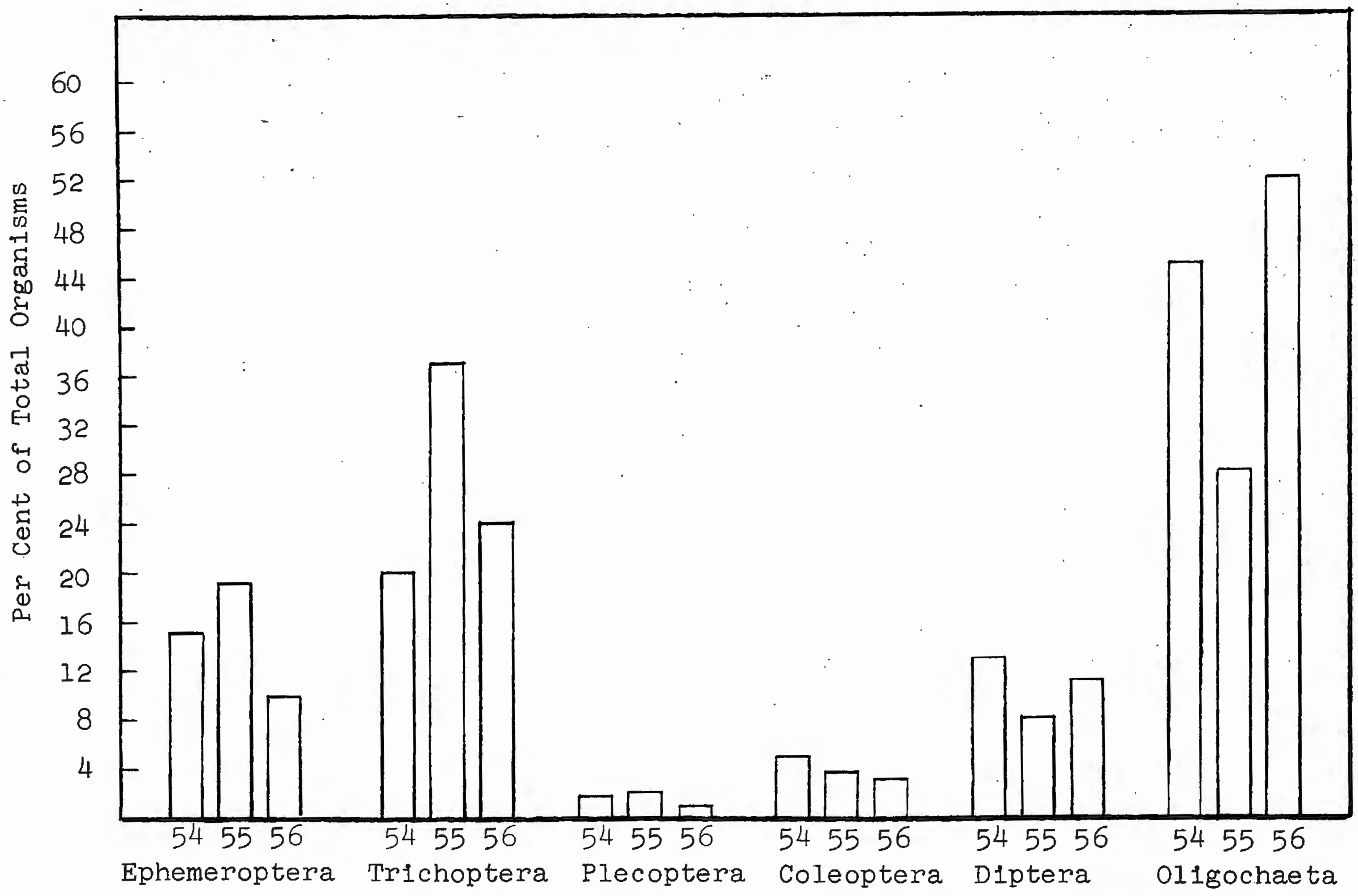
*Dates of sampling are those for 1956, dates for 1954 and 1955 were within two days of the above dates.

Figure XIII. Mean number of principal organisms per twelve square feet of stream bottom for the three years of study.



Mean No. Organizms Per Week (12 Sq.Ft.)
500
400
300
200
150
100
50
54 55 56
Ephemeroptera
54 55 56
Trichoptera
54 55 56
Plecoptera
54 55 56
Coleoptera
54 55 56
Diptera
54 55 56
Oligochaeta

Figure XIV. Comparison of per cent composition of the dominant groups of organisms for the three years of study.


Per Cent of Total Organisms
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
54 55 56
Ephemeroptera
54 55 56
Trichoptera
54 55 56
Plecoptera
54 55 56
Coleoptera
54 55 56
Diptera
54 55 56
Oligochaeta

primarily due to the Family Rhyacophilidae of the Order Trichoptera, the Families Tendipedidae, Heleidae and Empididae of the Order Diptera (Table 18).

The increase in numbers of organisms was not followed by a corresponding increase in volume (Table 17). The total volume per unit area of organisms for 1956 was approximately the same as for 1954 but considerably less than 1955.

There are several possible reasons why large increases in numbers of bottom fauna did not yield increase in volume. As stated before, the increase in numbers was caused largely by increases in aquatic earthworms, midges, and caddis flies of the family Rhyacophilidae, all of these organisms are relatively small and would increase the total volume only slightly. A higher per cent of larger organisms (mayflies and stoneflies in particular) would probably increase the total volume more than larger numbers of smaller organisms. Other reasons for the discrepancy would be differences in individual investigators and differences in the accuracy of the measuring equipment.

The direction of weekly variation in numbers (increase or decrease) was primarily due to two groups of organisms, Oligochaeta and Trichoptera (Table 19). Over one-half the total number of Trichoptera belonged to Subfamily Glossosomatinae of the Family Rhyacophilidae. The larva of this group are "saddle case" makers and are chiefly omnivorous

TABLE 18

COMPARISON OF THE MEAN NUMBER* PER WEEK OF PRINCIPAL GROUPS OF ORGANISMS SAMPLED DURING THE THREE YEARS OF STUDY

Taxonomic Groups	1954 Mean No./Week	1955 Mean No./Week	1956 Mean No./Week
PLECOPTERA			
Perlodidae	T	1	5
Perlidae	3	T	T
Pteronarcidae	1	3	T
Nemouridae	T	T	0
EPHEMEROPTERA			
Ephemeridae	T	27	T
Baetidae	36	31	65
Heptageniidae	8	3	29
TRICHOPTERA			
Rhyacophilidae	5	12	134
Brachycentridae	38	81	86
Hydropsychidae	11	10	15
Philopotamidae	T	T	1
Psychomyiidae	T	1	4
Hydroptilidae	0	T	3
Helicopsychidae	0	0	T
Lepidostomatidae	T	0	1
Limnephilidae	0	2	T
Leptoceridae	1	1	0
Molannidae	0	1	0
Phryganeidae	0	T	0
DIPTERA			
Rhagionidae	8	3	2
Tendipedidae	13	11	67
Simuliidae	8	3	8
Heleidae	1	T	10
Empididae	5	3	22
Tipulidae	T	1	T
Tabanidae	0	3	0
Culicidae	0	T	0

* Mean number per twelve square feet.

T Mean less than one organism per week.

TABLE 19

ENUMERATION OF BOTTOM FAUNA TAKEN FROM THE WEST BRANCH OF THE STURGEON RIVER

Taxonomic Groups	Collection Date June			July				August		Sept.
	29	6	13	20	27	10	17	24	31	7
PLECOPTERA										
Perlodidae	1						2	2	11	38
Perlidae				2			2		1	
Pteronarcidae									1	
Sub-Totals	1			2			4	2	13	38
EPHEMEROPTERA										
Ephemeridae		3								
Baetidae	20	18	19	23	24	61	32	14	17	38
Heptageniidae	28	25	28	48	39	43	39	15	13	16
Ephemerellidae	53	65	45	56	62	27	6	17	12	29
Leptophlebiidae		9	1		3					1
Sub-Totals	101	120	93	127	128	131	77	46	42	84
HEMIPTERA										
Veliidae		1								
TRICHOPTERA										
Rhyacophilidae	46	65	49	123	141	184	205	220	140	165
Brachycentridae	44	34	35	39	108	120	93	88	106	192
Hydropsychidae	7	2	1	2	3	33	16	41	14	31
Philopotamidae			1					3		3
Psychomyiidae	2					1		5	8	22
Hydroptilidae	6	16	4	1	3					
Helicopsychidae						1				
Lepidostomatidae								6		6
Limnephilidae								1	3	
Sub-Totals	105	117	90	165	255	339	314	364	271	419
DIPTERA										
Rhagionidae	4	3			2		6	5	2	2
Tendipedidae	51	48	25	100	122	86	66	75	26	68
Simuliidae	5	9	5	18	4	16	6	15	1	1
Heleidae	8	10	11	16	8	11	14	16	1	8
Empididae	17	9	6	21	43	29	34	21	20	21
Tipulidae					1					
Sub-Totals	85	79	47	155	180	142	126	132	50	100

TABLE 19 (Continued)

Taxonomic Groups	Collection Date									
	June	July				August				Sept.
	29	6	13	20	27	10	17	24	31	7
MEGALOPTERA										
Corydalidae	1	3								
Sialidae		1								
Sub-Totals	1	4								
COLEOPTERA										
Elmidae	21	24	7	16	33	43	20	44	41	31
Hydrophilidae	1				1					
Haliplidae	1									
Gyrinidae								1		
Sub-Totals	23	24	7	16	34	43	20	45	41	31
OLIGOCHAETA	322	535	306	616	621	543	504	550	483	780
HYDRACARINA	1	1	1		2	3	2		2	2
GASTROPODA	3	5	2	3	2	3	2	2	3	3

(Pennak, 1953). The other group exhibiting a substantial increase was three families of the Order Diptera. The family Tendipedidae showed the greatest increase of the three families. This family, like the Glossosomatiae, is is also omnivorous, the larva feeding mostly upon algae and decayed vegetation (Morgan, 1930 and Pennak, 1953). The remaining two families, although not numerous in comparison to other groups, were more frequently found in 1956 than in preceding years. Members of these two families are predaceious, feeding mainly on minute organisms (Usinger, 1956). Feeding habits of the aquatic Oligochaetes are similar to those of the terrestrial earthworm, that is obtaining nutriment by ingesting quantities of the substrate (Pennak, 1953).

Colby (1957) found that the main difference between the first two years of the study to be in the increased number of Ephemeridae, Rhyacophilidae, and Brachycentridae in 1955. However, the magnitude of the increase was slight compared to the increases that occurred in 1956. Figure XIII shows that of six groups of organisms only one, the Order Trichoptera, increased to any significant degree, and in three groups there were decreases in 1955 over 1954. The data for 1956 show large increases in number in all groups except the stoneflies.

Although variables such as climatic conditions and investigators enter into a study of bottom fauna, constants such as similar locations, methods of sampling, and time of sampling contributed to comparable results. Allen (1951), in his study of the Horokiwi River in New Zealand discusses the amount of variation which may occur between apparently similar bottom samples. Allen (*op. cit.*) states "the general conclusion which emerges is that the standard deviation of the total numbers in a series of faunistic collections, taken by similar methods under similar conditions, usually lies between 20 per cent and 50 per cent of the mean, and that the numbers of any particular form are generally distributed with a larger and more variable standard deviation, usually between 30 per cent and 100 per cent of the mean." The review of several papers on this subject and as a result of his own work, Allen (op. cit.) further concluded that even smaller deviations appear to occur where sampling procedures are more standardized and the bottom is of relatively uniform composition.

In this series of studies on the West Branch of the Sturgeon River the sampling procedures were highly standardized. The samples for all three years of study were taken in the same riffle area, with identical equipment, on dates of the year that did not differ by more than three days, and sorted in the same manner. It is, therefore, believed that the more than 200 per cent increase in total number of organisms in 1956 is a true increase. The increase in all major groups of organisms show at least better survival of bottom fauna in 1956. It is believed that the subgroups showing the greatest change, increased because of greater production at the producer level. This greater production is thought to be due to the added nutrients to the headwaters over a three year period. That increase occurred primarily in herbivorous forms supports the belief in an increase in producer organisms.

Both Grzenda (1955) and Colby (1957) compared the mean volumes they obtained per square foot sample with values obtained by Surber (1951) in a trout stream he

TABLE 20

SUMMARY OF THE TOTAL NUMBER AND TOTAL VOLUME OF BOTTOM FAUNA COLLECTED FROM THE WEST BRANCH OF THE STURGEON RIVER, IN 1956

Collection Date	Total Number	Number Per Square Foot	Total Volume (CC)	Volume Per Square Foot (CC)
June 29	642	53.50	2.48	0.21
July 6	886	73.83	3.03	0.25
July 13	546	45.50	1.87	0.16
July 20	1084	90.33	3.27	0.27
July 26	1222	101.83	4.26	0.36
Aug. 10	1204	100.33	3.30	0.28
Aug. 17	1049	87.42	2.96	0.25
Aug. 24	1141	95.08	3.23	0.27
Aug. 31	905	75.42	3.66	0.30
Sept. 7	1457	121.42	4.40	0.37

termed to be of average richness. On the basis of Surber's results the level of bottom fauna production in the West Branch is very low. Using a conversion of one cubit centimeter equaling one gram (Ball, 1948) the highest values obtained for the West Branch for June, July, and August were 0.33, 0.33, and 0.41 grams (in 1955) compared to 1.65, 1.18, and 1.96 grams, respectively, for Surber's findings.

Because the total volumes were so small (less than 0.5 CC per square foot), no breakdown of the samples into groups was attempted. The highest mean number per square foot was 121.4 on September 7, 1956 and the corresponding volume was 0.37 cubic centimeters. The above figures help illustrate the small size of the organisms found in the bottom fauna samples. The smallness of the bottom organisms, together with absence of an appreciable population of forage fish points to a slow growing or a small population of trout, because of the energy required to obtain a sufficient volume of food.

Fish Samples

The fish samples together with the bottom samples give the best means of comparing the West Branch of the Sturgeon with other trout streams, particularly those of the northern lower peninsula of Michigan. Tarzwell (1936) in a series of investigations in 1931 to 1935 on trout streams in the vicinity of the West Branch, found a close relationship between the water temperatures (summer maximum) and trout composition. Trout species, in two warm-water trout streams, East Branch of the Black River and Pigeon River, comprized 9.6 per cent and 14.3 to 19.7 per cent, respectively, of the total number of fish. Tarzwell (1936) in studies made during the same period on the West Branch found that trout comprized 93.8 to 98.7 per cent of the total number of fishes and over 99 per cent of the total weight.

Cooper (1951) in a study of three trout streams in northern Michigan, North Branch Au Sable, Pigeon River, and Hunt Creek, found mean lengths of brook trout to be 6.9, 5.7, and 5.1 inches (age group I), respectively. By the middle of June brook trout in the above three streams average 0.5 to 2.0 inches longer than those in West Branch. The North Branch of the Au Sable and Pigeon River, are considered as having average productivity, and Hunt Creek is considered unproductive. The mean length of brook trout in the West Branch is slightly below that of the unproductive stream. Temperature in the West Branch appears exceptionally favorable to trout in terms of per cent composition, but the growth of these trout is below that of other trout in streams in the same vicinity.

Comparison of mean lengths of the trout species from the West Branch for all three years of the study show only small deviations from year to year (Tables 21, 22, 23). The only significant differences found in comparing mean

TABLE 21

A COMPARISON OF THE MEAN LENGTH IN INCHES OF BROOK TROUT SAMPLES FROM THE WEST BRANCH OF THE STURGEON RIVER

	Year	Mean Length	Standard Error	Sample Size
Age Group I	1954	4.7	0.07	88
	1955	5.0	0.06	134
	1956	4.7	0.07	71
Age Group II	1954	6.5	0.15	48
	1955	7.6	0.20	19
	1956	6.9	0.16	27
Age Group III	1954	9.3	0.27	9
	1955	10.4	--	1
	1956	10.1	--	1

	1954	1955	1956
Total Number	145	154	99

TABLE 22

A COMPARISON OF THE MEAN LENGTH IN INCHES OF BROWN TROUT SAMPLES FROM THE WEST BRANCH OF THE STURGEON RIVER

	Year	Mean Length	Standard Error	Sample Size
Age Group I	1954	5.4	0.11	23
	1955	5.1	0.14	29
	1956	5.4	0.12	17
Age Group II	1954	8.4	0.51	7
	1955	8.2	0.24	11
	1956	8.4	0.24	11
Age Group III	1954	10.4	0.26	9
	1955	11.4	0.27	12
	1956	10.8	0.41	7
Age Group IV	1954	11.7	0.60	5
	1955	--	--	--
	1956	13.0	0.64	4

	1954	1955	1956
Total Number	44	52	39

TABLE 23

A COMPARISON OF THE MEAN LENGTH IN INCHES OF RAINBOW TROUT SAMPLES FROM THE WEST BRANCH OF THE STURGEON RIVER

	Year	Mean Length	Standard Error	Sample Size
Age Group I	1954	4.5	0.09	46
	1955	4.6	0.07	63
	1956	4.7	0.06	50
Age Group II	1954	7.2	0.16	30
	1955	6.4	0.08	9
	1956	6.4	0.19	11
Age Group III	1954	--	--	--
	1955	8.2	--	2
	1956	--	--	--

	1954	1955	1956
Total Number	76	74	61

lengths were between age group II brook trout and age group II rainbow trout. These differences were slight and were not consistent between the years of study. In order to make a more valid comparison between the growth rate of each species, a second variable (weight) was included. The use of these two variables enables one to test whether changes occurred in the length-weight relationship of a species from year to year. The statistical test used for comparing the length-weight relationship is a regression coefficient. Regression (Snedecor, 1956) is defined as the dependence of one variable (weight) on another (length). The growth curve of weight is spoken of as the regression of weight on length. The formula for this relationship is:

$$W = cL^n$$

in which W = weight
L = length
c and n = constants

or expressed logarithmically

$$\log W = \log c \text{ plus } n \log L$$

The values of the constants c and n may be determined by fitting a straight line to the logarithms of L and W by computing them from the following normal equations (Rounsefell and Everhart, 1953):

$$\log c = \frac{\Sigma \log W . \Sigma (\log L)^2 - \Sigma \log L . (\Sigma \log L . \log W)}{N . \Sigma (\log L)^2 - (\Sigma \log L)^2}$$

and

$$n = \frac{\Sigma \log W - N \log c}{\Sigma \log L}$$

The length-weight relationship of the three species of trout for 1956 is given in Figures XV, XVI, and XVII.

Testing for differences in the length-weight relationship between years was accomplished by using a covariance analysis as described by Ostle (1954). This analysis enables the investigator to determine: (1) if a common regression line can be used for all three years data, (2) if a regression line with a common slope can be used, or (3) if a regression line with a common position can be used for the separate regression lines. A common regression line indicates that there are no significant differences in either slope or position of the separate lines. A significantly different slope, as indicated by the value of n, between regression lines means that the weight does not change in the same proportion as the length. A difference in position, as indicated by the value of c, means that the weight for any given length is significantly greater or less for the separate regression lines. When there are real differences in the slope of several regression lines there will also be real differences in position, but the reverse is not necessarily true.

Colby (1957) found that common regression lines could be used for both the brown and brook trout data for 1954 and 1955. However, the regression lines for the

Figure XV. The length-weight relationship of the brook trout sample from the West Branch of the Sturgeon River. Curve A represents actual values; Curve B represents the log-log transformation.

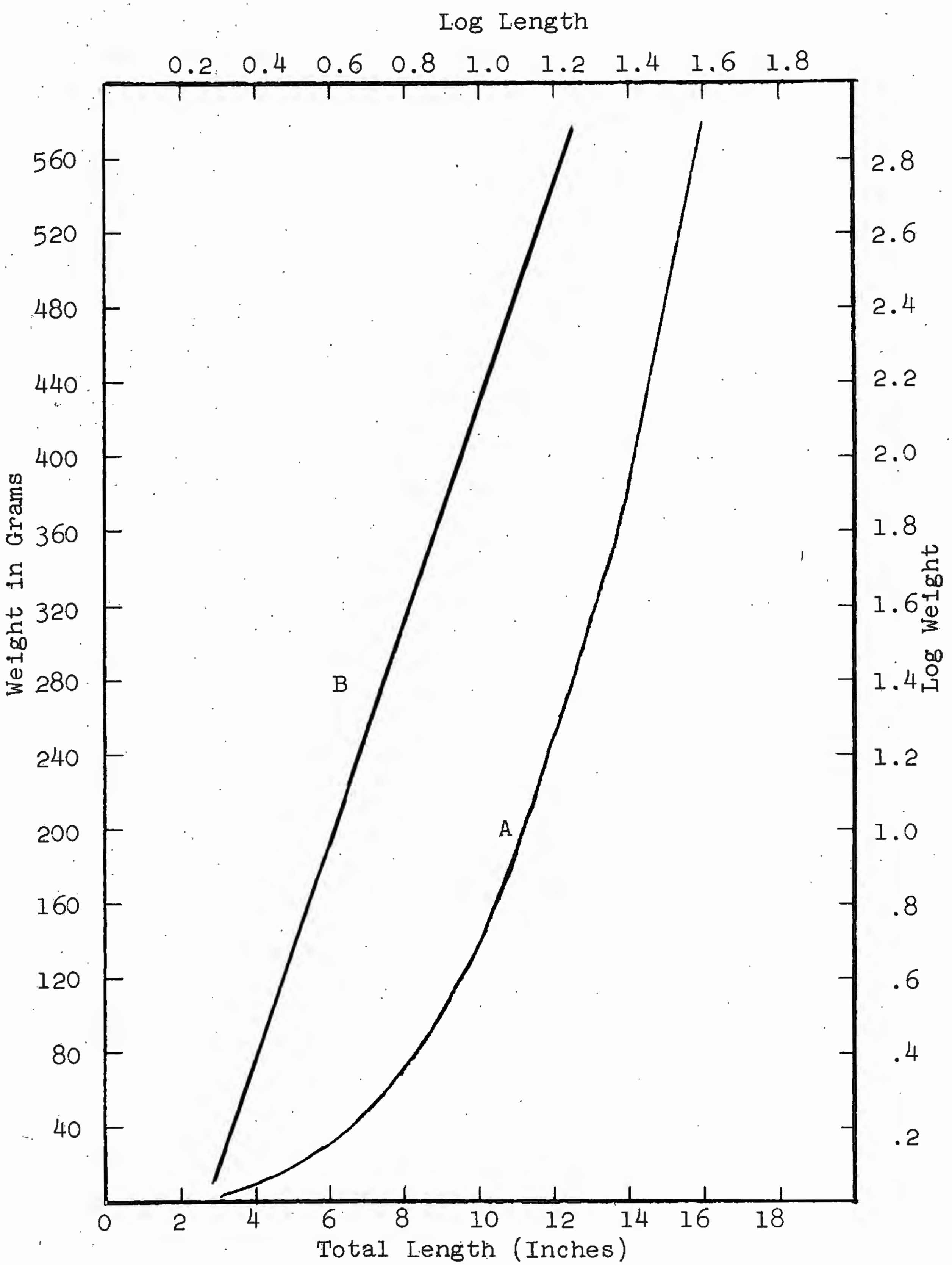

Log Length
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Weight in Grams
560
520
480
440
400
360
320
280
240
200
160
120
80
40
Log Weight
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
B
A
0
2
4
6
8
10
12
14
16
18
Total Length (Inches)

Figure XVI. The length-weight relationship of the brown trout sample from the West Branch of the Sturgeon River. Curve A represents actual values; Curve B represents the log-log transformation.

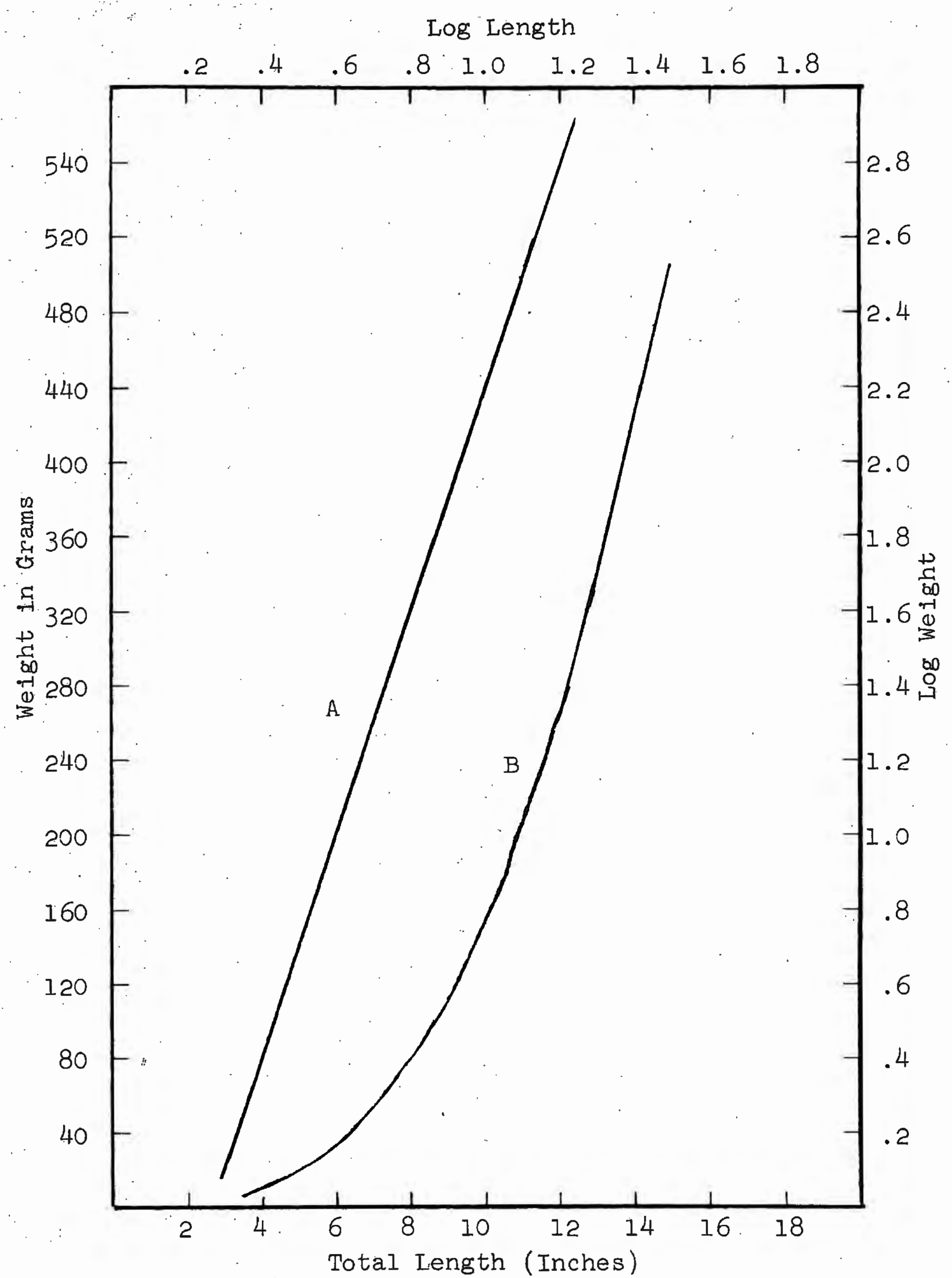
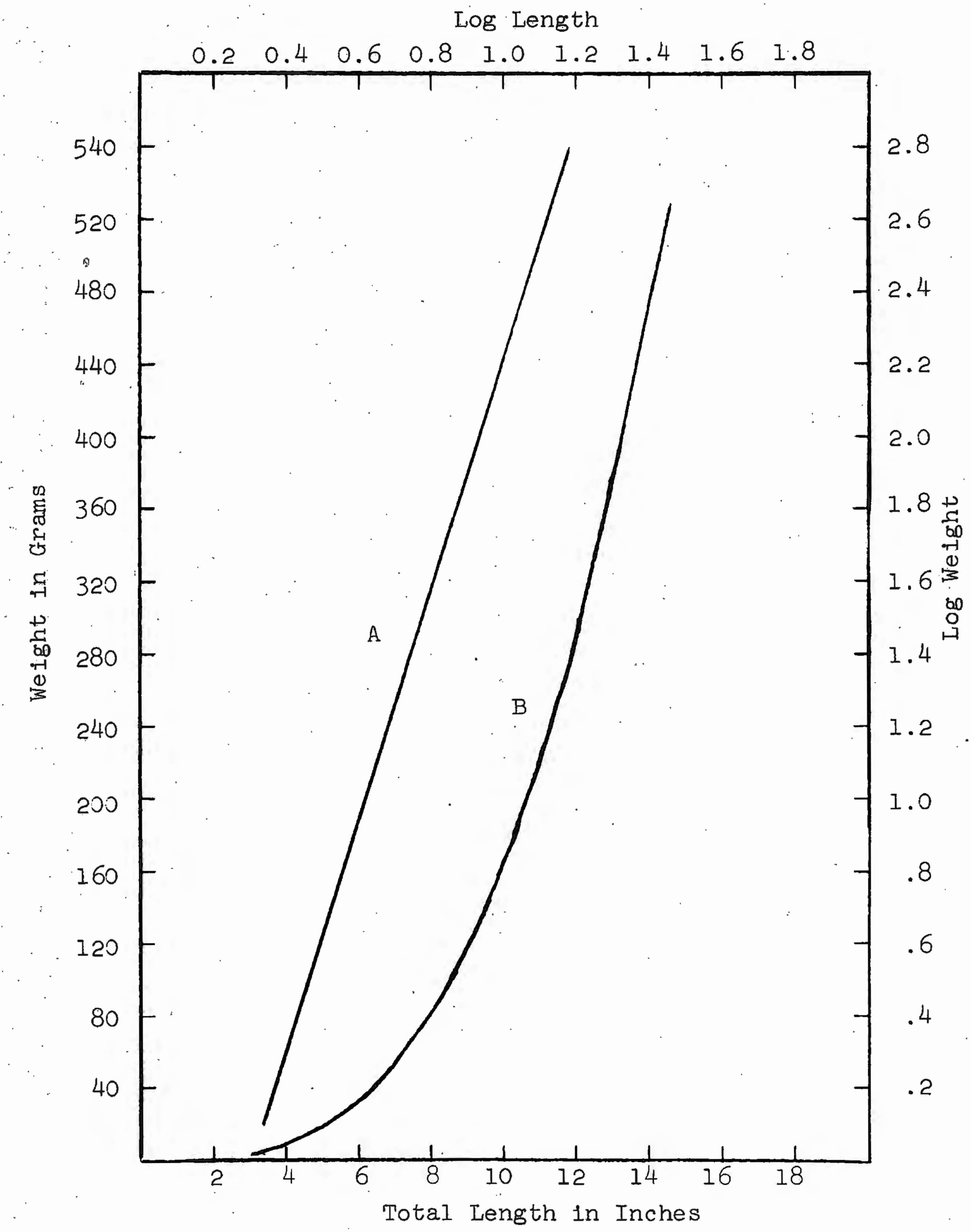

Log Length
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
Weight in Grams
540
520
480
440
400
360
320
280
240
200
160
120
80
40
Log Weight
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
A
B
2
4
6
8
10
12
14
16
18
Total Length (Inches)

Figure XVII. The length-weight relationship of the rainbow trout sample from the West Branch of the Sturgeon River. Curve A represents actual values; Curve B represents log-log transformation.


Log Length
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Weight in Grams
540
520
480
440
400
360
320
280
240
200
160
120
80
40
Log Weight
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
A
B
2
4
6
8
10
12
14
16
18
Total Length in Inches

rainbow trout of 1954 and 1955 were significantly different in both position and slope. Colby (op. cit.) attributed the difference to the two year old rainbow trout being in better condition in 1955 (n = 3.21) than in 1954 (n = 2.90). Results for the 1956 study were similar to those found in 1955. Regression analysis for all three years (1954, 1955, and 1956) show that a common regression line can be used for all brook and brown trout sampled during the combined studies. This means that there is no statistical difference between years in the length-weight relationship of brook and brown trout (Tables 24 and 25). Again in 1956, significant differences between the separate regression lines of the rainbow trout were found (Table 26). The regression line was intermediate for 1956 to those of 1954 and 1955 and differed significantly from both (Table 27). The n values for 1954, 1955, and 1956 are 2.90, 3.21, and 3.11, respectively. The values found for c are 0.18, 0.11, and 0.13 for 1954, 1955, and 1956, respectively. The n values indicate the steepness of the regression line and the c values indicate the position of the regression line.

No one concrete statement concerning the changes in the length-weight relationship of the rainbow trout can be made. Two possible factors, one of which is independent of fertilization, are suggested as partial causes of the length-weight relationship change of the rainbow trout. The first factor concerns population turnover. Grzenda

TABLE 24

REGRESSION (COVARIANCE) ANALYSIS OF ln LENGTH-ln WEIGHT RELATIONSHIP IN BROOK TROUT TAKEN FROM WEST BRANCH STURGEON RIVER, 1954, 1955, AND 1956

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Total	332	155.1044		
Due to general regression. . . .	1	147.8129	147.8129	
Deviations from general regression .	331	7.2915	.0220	
Can one regression line be used for all observation of the Brown Trout data? Yes (F = 1.995)				
Gain from 3 separate regressions over general regression .	4	.1739	.0435	1.995
Deviations from separate regressions. . . .	327	7.1176	.0218	

TABLE 25

REGRESSION (COVERIANCE) ANALYSIS OF ln LENGTH-ln WEIGHT RELATIONSHIP IN BROWN TROUT TAKEN FROM WEST BRANCH STURGEON RIVER, 1954, 1955, AND 1956

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Total	136	151.7002		
Due to general regression. . . .	1	150.0542		
Deviation from general regression. . . .	135	1.6460		
Can one regression line be used for all observation of the Brown Trout data? Yes (F = .88)				
Gain from 3 separate regressions over general regression. . . .	4	.0429	.0107	.88
Deviation from separate regressions	131	1.6031	.0122	

TABLE 26

REGRESSION (COVARIANCE) ANALYSIS OF ln LENGTH-ln WEIGHT RELATIONSHIP IN RAINBOW TROUT TAKEN FROM WEST BRANCH STURGEON RIVER, 1954, 1955, AND 1956

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Total	159	67.4630		
Due to general regression	1	66.0408		
Deviation from general regression.	158	1.4222		

Can one regression line be used for all observations of the Rainbow Trout data? No (F = 6.35)

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Gain from 3 separate regressions over general regressions.	4	.2010	.0502	6.3544**
Deviations from separate regressions.	154	1.2212	.0079	

Can a common slope be used for the separate regression line? No (F = 8.24)

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Deviation about lines with common slope but fitted through mean of each set of data . . .	156	1.3514		
Further gains from fitting separate regression (diff.between slopes)	2	0.1302	0.0651	8.24**
Deviations about separate regressions.	154	1.2212	.0079	

TABLE 27

REGRESSION (COVERIANCE) ANALYSIS OF ln-LENGTH ln WEIGHT RELATIONSHIP IN RAINBOW TROUT, WEST BRANCH STURGEON RIVER

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
	1954 vs 1956			
Total	129	54.5472		
Due to general regression. . . .	1	53.3982		
Deviations from general regression. . . .	128	1.1490		
Can one regression line be used for the Rainbow Trout data for 1954 and 1956? No (F = 11.42)				
Gain from 2 separate regression. . . .	2	.1758	.0879	11.42**
Deviations from separate regressions . . .	126	0.9732	.0077	
	1955 vs 1956			
Total	90	25.0929		
Due to general regression. . . .	1	24.21212		
Deviations from general regression. . . .	89	0.8808		
Can one regression line be used for all Rainbow Trout data for 1955 and 1956? No (F = 4.15)				
Gain from 2 separate regressions over general regression. . . .	2	.0764	.0382	4.15*
Deviations from separate regressions . . .	87	0.8044	.0092	

(1955) gives migration of rainbow trout to the main Sturgeon River as the reason no rainbow trout of age group III were found (in 1954) and presumed that those present are progeny of a population originating from the Sturgeon River. Support of the above hypothesis is the known spawning run of rainbow trout in the Sturgeon River and that in three years of sampling only two rainbow trout have been found in age groups above II. If rainbow trout migrate from the West Branch to the Sturgeon River before their third year, there is a completely new population of rainbow trout in the West Branch every two years. In a population changing this rapidly large differences in the growth rate would probably occur. A highly successful spawning year would perhaps result in a temporary overpopulation and cause a decrease in the growth rate. This decrease in growth and overpopulation would possibly change with the migration at the end of the second year. An unsuccessful spawning year would probably have the opposite effect.

The second factor concerns food supply (kind and size) and the ratio of age group I trout to age group II trout. Theoretically the addition of nutrients would at first enrich the lower portion of the food chain. Bottom sampling revealed that increases in bottom fauna occurred only in relatively small organisms and with few exceptions only small organisms were present in large numbers. A statement has also been made that trout species comprized about 96 per cent of the fish present (Tarzwell, 1936), which indicates that a food supply of small minnow-type fish is very scarce. With the absence of large food organisms, the efficiency of obtaining food would favor small and, therefore, younger trout. Referring to Table 23, the rainbow trout of age group I increased in average length slightly each year, and age group II trout decreased slightly each year. If fertilization increases the lower level of the food chain, it would tend to aid in survival of young trout. Greater survival of young trout would probably increase the competition for food between young and older trout. Because of the paucity of large food organisms the compeition would favor the smaller trout. Support of a shift in age composition of rainbow trout is indicated by the relative number of age group I fish to age group II fish (Table 23). In 1954 the ratio of age group I to age group II was 1.5 to 1; in 1955, 7 to 1; and in 1956, 4.6 to 1. Again the data for the rainbow trout in 1956 is intermediate. It appears that as the ratio of age group I to age group II increases the growth rate also increases. Further support of the idea that the West Branch is more favorable to young rainbow trout is given by Greeley (1933). Greely (_op_. _cit_.) found that the rainbow trout in Michigan waters average 3.3 inches in total length the first year, and 7.8 inches the second. Comparing these averages to the West Branch, it is found that rainbow trout of age group I are more than one inch above this average, and those of age group II are approximately one inch below average.

The rather rapid turnover in rainbow trout populations and the apparent shift in age composition (due to factors favoring younger trout) are believed to be the principal reasons for differences occurring in the length-weight relationship between years.

Mean lengths of each age group of the three trout species for the three study years are shown in Tables 21, 22, and 23. No definite trends in growth (with the possible exception of rainbow trout) are apparent for any species of trout. If increased production did occur as indicated by bottom fauna and aufwuchs study, the increase has not as yet reached this trophic level. A further indication that higher trophic level production has not occurred is the lack of an appreciable increase in the larger predaceous species of bottom fauna.

An increase in fish growth would theoretically first occur with the brook trout, since they occupy areas closer to the source of enrichment. However, the food habits of rainbow trout may alter the above concept. At least two investigators have found that rainbow trout consume vegetable matter in significant quantities. Metzelaar (1929), states that approximately 20 per cent of 87 fish sampled had vegetable matter in the material they had consumed. He further states that "the outstanding feature of the rainbow diet certainly is the 15 per cent vegetation, formed largely by filamentous algae." Surber (1933) in an investigation of a trout stream in West Virginia also found that 20 per cent of the fish collected had considerable quantities of algae in the stomach. Colby (1956) states that the improved condition of the rainbow trout in 1955 was at least partially due to the fish eating algae.

According to the data collected there does not appear to be any definite changes in the characteristics of the fish population of the West Branch of the Sturgeon River due to the addition of fertilizer. Apparently the growth rage of trout in the West Branch is below that of trout in other streams. The stream under study differs from most trout streams in the area, in the absence of a large minnow population, colder water temperature, sharp longitudinal distribution of species, absence of large food fauna, low fishing pressure in the upper waters, and the sterile characteristics of the water.

SUMMARY

1. No trace of the first application of fertilizer on July 30, 1956 was detected entering the West Branch of the Sturgeon River.

2. The second application of fertilizer to Hoffman Lake on August 3, 1956 produced a large increase in total phosphorus and ammonia nitrogen concentrations entering the stream.

3. The duration of the increase in nutrients was short. Forty-eight hours after the second addition of fertilizer the concentration of phosphorus entering the stream had returned to the prefertilization level. The concentration of ammonia nitrogen was at a higher level following fertilization for a period in excess of 72 hours.

4. No increase in nutrients was detected beyond 1.5 miles below the headwaters following the addition of fertilizer.

5. The methyl orange alkalinity and the pH remained relatively constant at all main stream stations throughout the study. The control station exhibited a gradual increase in alkalinity and pH from June until September. The reason for the increase at the control station is not known.

6. There was a sudden increase in aufwuchs production at all stations, including the control, one week prior to fertilization, and production remained at the higher level throughout the study. This natural increase apparently occurred during each year of the project. No reason was found for the increase and it is recommended that future studies try to ascertain why the increase occurs.

7. The measurement of aufwuchs production by the use of artificial substrates showed an increase at Station I (lake outlet) following fertilization. There were indications, of an inconclusive nature, that Stations II and IV also had an increase in aufwuchs production as a result of fertilization.

8. The measurement of primary production appeared to be the best method for detecting the effect of headwater fertilization.

9. Results from Station VII, where shingles were left in the stream for varying lengths of time, indicate that submersion of the substrates for approximately two weeks is required for plant growth to reach a maximum level.

10. An increase of over 200 per cent in the total number of bottom organisms occurred in 1956 over the two previous years. The bulk of the increase occurred in herbivorous forms. This increase is attributed to a higher production at the producer level as a result of the addition of fertilizer over a period of three years.

11. No changes in the length-weight relationship of brook and brown trout were detected between the years of study.

12. Statistically significant differences were found to exist in the length-weight relationship of rainbow trout between each of the years of study. The length-weight relationship of rainbow trout for 1956 was intermediate to the other two years.

13. It is believed that changes in the length-weight relationship of rainbow trout was independent of fertilization. The change from year to year is thought to be caused by two factors: migration of rainbow trout before age III, which would result in a complete population turnover every two years; changes in the ratio of age group I to age group II fish, environmental factors in the West Branch apparently favor younger trout more than older and larger ones.

14. Recommendations for future studies include: a complete summer of investigation, particularly at the outlet of the lake, without fertilizing; tagging of rainbow trout to determine the pattern of migration, if any; complete population estimate of the fish in the West Branch; determination of the reasons for the mid-summer increase in primary production.

LITERATURE CITED

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

Allen, K. Radway
1951. The Horokiwi Stream--A study of a trout population. New Zealand Marine Dept., Fish. Bull. No. 10, 231 pp.

American Public Health Association
1955. Standard methods for the examination of water, sewage, and industrial wastes. 10th ed., New York, 522 pp.

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

Ball, Robert C.
1958. 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.

Bartlett, M. S.
1947. The use of transformations. Biometrics, 3, pp. 39-52.

Butcher, R. W.
1932. Studies in the ecology of rivers. Annals of Bot. Vol. 44, No. 184, pp. 813-862.

Burks, B. D.
1953. The mayflies, or Ephermeroptera, of Illinois. Ill. Nat. Hist. Survey Bull. Vol. 26, Art. 1, 216 pp.

Clarke, George L.
1954. Elements of ecology. John Wiley and Sons, Inc., New York, 534 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.
1953. Periodicity of growth and change of condition of brook trout (Salvelinus fontinalis) in three Michigan trout streams. Copeia, May 29, No. 2, pp. 107-114.

Cooke, William B.
1956. Colonization of artificial bare areas by microorganisms. The Botanical Review, Vol. 22, No. 9, pp. 613-638.

Dye, J. F.
1952. Calculation of effect of temperature on pH, free carbon dioxide, and the three forms of alkalinity. Jour. Am. Water Works Assoc., 44, 356 pp.

Ellis, M. M., B. A. Westfall, and M. D. Ellis
1948. Determination of water quality. U. S. Dept. Inter., Fish. and Wild. Ser., Research Rept. No. 9.

Fasset, Norman C.
1957. A manual of aquatic plants. The Univ. of Wisc. Press, Madison, Wisconsin, 405 pp.

Greely, John R.
1933. The growth rate of rainbow trout from some Michigan waters. Trans. Am. Fish. Soc., 1933, Vol. 63, pp. 361-378.

Grzenda, Alfred R.
1956. The biological response of a trout stream to headwater fertilization. Master's thesis, Michigan State University.

Harvey, H. W.
1934. Measurement of phytoplankton population. Jour. Mar. Bio. Assoc., 19, pp. 761-773.

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

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

Maciolek, John A.
1954. Artificial fertilization of lakes and ponds--A review of the literature. U.S. Dept. Int., Fish. and Wild. Ser., Spl. Scien. Rpt.--Fish. No. 113, 41 pp.

Metzelaar, Jan
1929. The food of the trout in Michigan. Trans. Am. Fish. Soc., 1929, Vol. 59, pp. 146-152.

Millar, C. E. and L. M. Turk
1954. Fundamentals of soil science. John Wiley and Sons, Inc., New York, 510 pp.

Morgan, Ann Haven
1930. Field book of ponds and streams. G. P. Putnam's Sons, New York, 448 pp.

Muenchner, Walter Conrad
1944. Aquatic plants of the United States. Comstock Pub. Co., Inc., Ithaca, New York, 374 pp.

Neess, John C.
1949. Development and status of pond fertilization in Central Europe. Trans. Am. Fish. Soc., 1946, Vol. 76, pp. 335-358.

Odum, Eugene P.
1953. Fundamentals of ecology. W. B. Saunders Co., Philadelphia, Pennsylvania, pp. 384.

Ostle, Bernard
1954. Statistics in research. Iowa State College Press, Ames, Iowa, 487 pp.

Pennak, Robert W.
1953. Freshwater invertebrates of the United States. Ronald, New York, 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.

Rice, T. R.
1949. The effect of nutrients and metabolites on populations of planktonic algae. Ph. D. thesis, Harvard University, Biology Dept.

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

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.

Siegel, Sidney
1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill Book Co., Inc., New York.

Snedecor, George W.
1956. Statistical methods. The Iowa State College Press, Ames, Iowa, 534 pp.

Surber, Eugene W.
1933. A quantitative study of rainbow trout production in one mile of stream. Trans. Am. Fish. Soc., 1933, Vol. 63, pp. 251-256.

1951. Bottom fauna and temperature conditions in relation to trout management in St. Mary's River, Augusta County, Virginia. Va. Jour. Sci. 2 (3), pp. 190-202.

Tarzwell, Clarence M.
1936. Environmental improvement in trout streams. Parts I and II. Unpublished Doctorate thesis, Univ. Lib., Univ. Mich., Ann Arbor, Michigan.

Tucker, Allan
1949. Pigment extraction as a method of quantitative analysis of phytoplankton. Trans. Am. Micros. Soc., 68 (1), pp. 21-23.

Usinger, Robert L.
1956. Aquatic insects of California--with keys to North American genera and California species. Univ. Calif. Press, Berkley and Los Angeles, Calif., pp. 508.

Welch, Paul S.
1952. Limnology. McGraw-Hill Book Co., Inc., New York, 538 pp.