DAVID P. BORGESON M. S. 1959

THE MOVEMENT OF RADIOACTIVE PHOSPHORUS THROUGH A STREAM ECOSYSTEM

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THE MOVEMENT OF RADIOACTIVE PHOSPHORUS THROUGH A STREAM ECOSYSTEM

by

DAVID P. BORGESON

AN ABSTRACT

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

MASTER OF SCIENCE

Department of Fisheries and Wildlife

1959

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ABSTRACT

Twenty-three millicuries of radioactive phosphorus were added to a small cold-water trout stream in August, 1958, and its movement was traced through the stream's ecosystem.

It was found that the P^{32} was rapidly taken up by the stream's biota and inanimate bottom complex. Very little of the P^{32} passed directly through the 3000-yard experimental area.

Differences were observed in the manner in which the P^{32} passed through the aquatic plants *Chara sp*, *Potamogeton sp*, and *Fontinalis sp*. *Chara* and *Potamogeton* lost activity rapidly after four days and reached a "base level" of activity in about two weeks. *Fontinalis* lost activity at a much slower rate. The highest activity in these plants was not observed immediately below the isotope entry but a few hundred yards downstream. This was attributed to the "feeding back" of P^{32} into the stream followed by uptake farther downstream, resulting in a gradual downstream movement of the P^{32} through the system.

The levels of activity reached by the brown trout and muddlers were very similar. Both species increased slowly in activity for about two weeks and then showed a

rapid increase in a few days. This was followed by a loss in activity in brown trout and a reduced rate of increase in muddlers. It was postulated that these fluctuations were caused by variability in feeding, changes in the activity of invertebrates, and loss of P^{32} from the digestive tract. Brown trout were found to reach their highest activity farther downstream than the muddlers and to maintain a higher activity at the more downstream sampling stations than did muddlers. From this it was postulated that brown trout received a greater portion of their food from drifting organisms than did muddlers.

Of the various parts of the brown trout, ribs and vertebrae showed the highest concentration of P^{32}, followed by the viscera and head and gills. The lowest concentration of P^{32} was found in the edible portion of the fish.

From a population estimate of all species of fish in a section of stream, it was found that the stream, though considered unproductive, compared favorably in standing crop with Michigan's good eutrophic lakes.

An estimate of the total amount of P^{32} which found its way into the fish was made using the population estimate data and the activity levels in the fish.

THE MOVEMENT OF RADIOACTIVE PHOSPHORUS

THROUGH A STREAM ECOSYSTEM

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A THESIS

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INTRODUCTION

On August 5, 1958, 23 millicuries of radioactive phosphorus (P^{32}) were introduced into the West Branch of the Sturgeon River, a small coldwater trout stream in the upper part of Michigan's lower peninsula. By radioactive counting, the P^{32} was traced through the stream's ecosystem; through its water, periphyton, aquatic plants, invertebrate fauna, and fish.

The results obtained may help us to better understand the functioning of a stream ecosystem, especially with reference to the practicality of phosphorus fertilizers as a method of increasing fish production. Results of previous studies (Grzenda 1955, Colby 1956, Carr 1958) showed that an increase in periphyton production followed the addition of phosphorus fertilizer to the stream. But as the increase in the phosphorus content of the water could be detected only one or two miles downstream, while the effects of fertilization on periphyton often extended six or seven miles downstream, it was not certain that the increase in Periphyton growth was due directly to the fertilizer. In the present study, due to the sensitivity of radioactive counting, the relative amounts of P^{32} present in the various parts of the food chain could be determined. The results of this study will also add to our knowledge of the behavior of radioactive isotopes, which is of ever increasing public health significance.

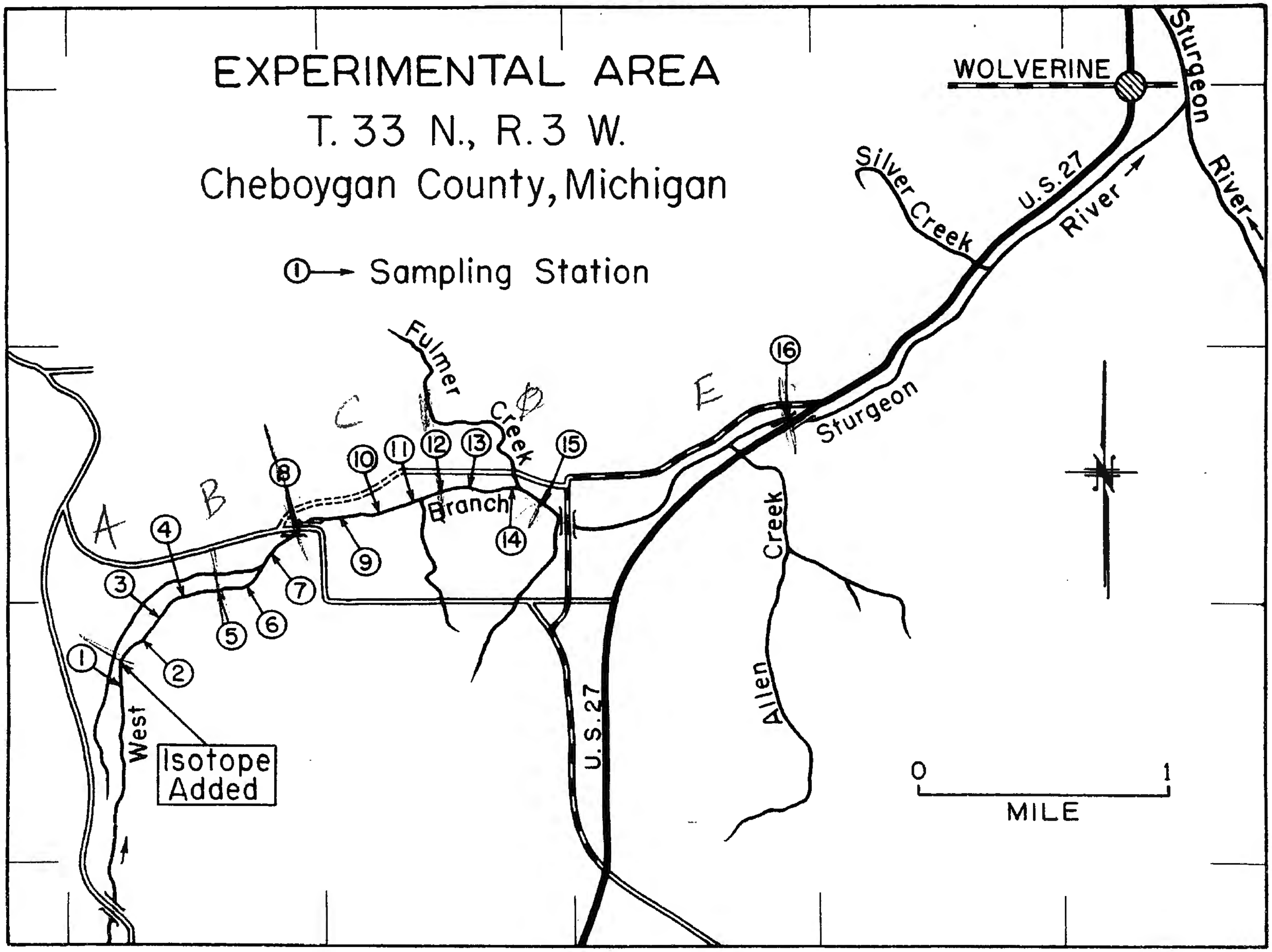
Description of the Study Area

The West Branch of the Sturgeon River has its source at Hoffman Lake, a marl lake of 128 acres, in Charlevoix County, Michigan (T.32 N, R.4W, Sec. 27). It flows thirteen miles in a northeasterly direction through Charlevoix, Otsego, ahd Cheboygan Counties before it joins the Sturgeon River at the town of Wolverine. The river flows in a narrow valley through Maple forested Morainic hills. The vegetation of the valley is chiefly aspen, cedar, tamarack, balsam fir, birch and tag alder. The area of the watershed is approximately fourteen square miles (Grzenda, 1955). Throughout its length the stream gains much ground water from springs and seepage which partially accounts for its persistently cold summer temperatures. The stream in the study area has a total alkalinity of approximately 180 p.p.m. and a total phosphorus concentration of around 7 p.p.b. The study area is a 3,000 yard section of stream whose lower boundary is at the U. S. highway 27 bridge, two miles upstream from the confluence of this stream with the main branch of the Sturgeon. The river in this section has a bottom of sand and gravel which supports luxuriant growths of *chara sp.* and lesser amounts of pondweed, *Potamogeton pectinatus*, and watermoss, *Foutinalis antipyretica*. The fish present are brown trout, *Salmo trutta*, brook trout, *Salvelinus fontinalis*, rainbow trout, *Salmo gairdnerii*, and great lakes muddler, *Cottus bairdii*. For the first 500 yards in the study area the river is heavily shaded by conifers. Here it is swift and narrow and has a gravel bottom. Aquatic plants are very abundant. Below this for the next 400 yards the stream broadens and flows swiftly over a gravel and sand bottom which supports a relatively light growth of aquatic vegetation. The direction of flow here is more northerly and the stream is more sunlit. Streamside vegetation is chiefly alder, birch, and aspen, with fewer conifers. In the remainder of the study area down to the U. S. 27 bridge the river is moderately shaded and has a predominantly gravel bottom which supports an abundance of aquatic plants. The stream's flow is approximately 40 cubic feet per second. Human habitation along the stream is limited to the lower 1000 yards of the study area and downstream to Wolverine. Fishing pressure is heaviest near the bridges (see Figure 1) with very little pressure exerted on the area between stations 1 and 8.

Sampling Stations

Figure 1 shows the locations of the sampling stations that were set up for this study. Station 1 is a control station 100 yards upstream from the isotope entry. Station 2 is 100 yards below the isotope entry. Stations 2 through 15 are spaced at 150 yard intervals. Station 16 is 600 yards below station 15. All measurements were made 1600 ? with a 100 foot steel tape except stations 15 and 16 which were approximations.

Figure 1. Experimental area and sampling stations.



EXPERIMENTAL AREA
T. 33 N., R. 3 W.
Cheboygan County, Michigan
Sampling Station
WOLVERINE
Sturgeon River
Silver Creek
U.S. 27
River
Fulmer Creek
Sturgeon
Branch
West
Isotope Added
Allen Creek
U.S. 27
0
1
MILE

METHODS AND PROCEDURES

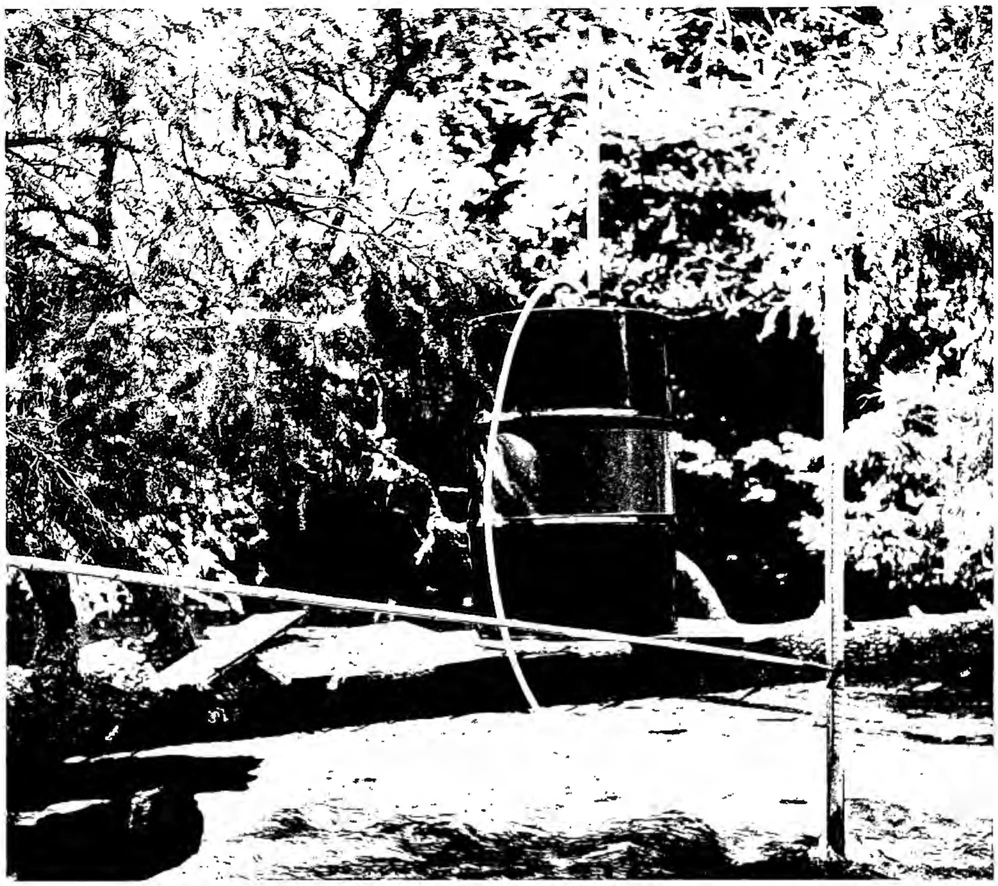
Adding Isotope

The 23 millicuries of P^{32} purchased from the Atomic Energy Commission arrived at the Pellston, Michigan, airport on the morning of August 5, 1958. The 2 milliliter solution of P^{32} as H_3PO_4 and dilute HCl was mixed thoroughly with 50 gallons of stream water in a 55-gallon drum and was siphoned into the stream at a constant rate of 1.116×10^{-5} microcuries of P^{32} per milliter of stream water. The siphon was started at 2:01 P.M. on August 5 and the drum was empty at 2:38 P.M.

The siphoning apparatus (See Figure 2) is quite simple yet it efficiently produced the desired result, namely that the isotope should enter the stream at a predetermined constant rate not exceeding Committee on Radiation, Atomic Energy Commission specifications (2×10^{-5} microcuries per milliliter), (Federal Register, 1957).

The drum has a 55-gallon capacity and was 33 inches in inside height, therefore each gallon represented 33/55 inches in height. The siphoning rate for a given head of water was determined experimentally by timing the filling

Figure 2. Photograph of siphoning apparatus.



of a small container of known capacity. Arbitrarily the head was set at 17 inches and the siphoning rate was found to be 1 inch per minute. It was decided that the isotope should enter the stream in 37½ minutes. The required siphoning rate if the drum were filled with 30 inches of water would therefore be:

$$\frac{30 \text{ in.}}{37.5 \text{ min.}} = .8'' \text{ per minute}$$

and the head required to produce this rate would be:

$.8 \times 17 = 13.6$ inches of head. The rate of application was maintained by this simple method of calculating the correct head.

A board was graduated in 38 .8" intervals with a nail to mark each interval. The board and barrel were then suspended above the stream so that the top nail was 13.6 inches below the 30 inch mark on the barrel. By taping the discharge end of the polyethylene siphon to the end of a long bamboo pole and moving the pole down at the rate of one nail per minute a constant rate was maintained and the barrel was emptied without radiation hazard in 37.5 minutes. The fact that the P^{32} was thoroughly mixed with over 50 gallons of water before being siphoned into the stream further assures that it entered at a constant rate. The siphon was started simply by filling the polyethylene tube with water, closing the discharge end with the operator's thumb, and then emersing the other end in the barrel and releasing the thumb. A weighted bamboo pole taped to the intake end of the siphon kept it at the bottom of the barrel and also served as a stirring device.

Measuring Activity

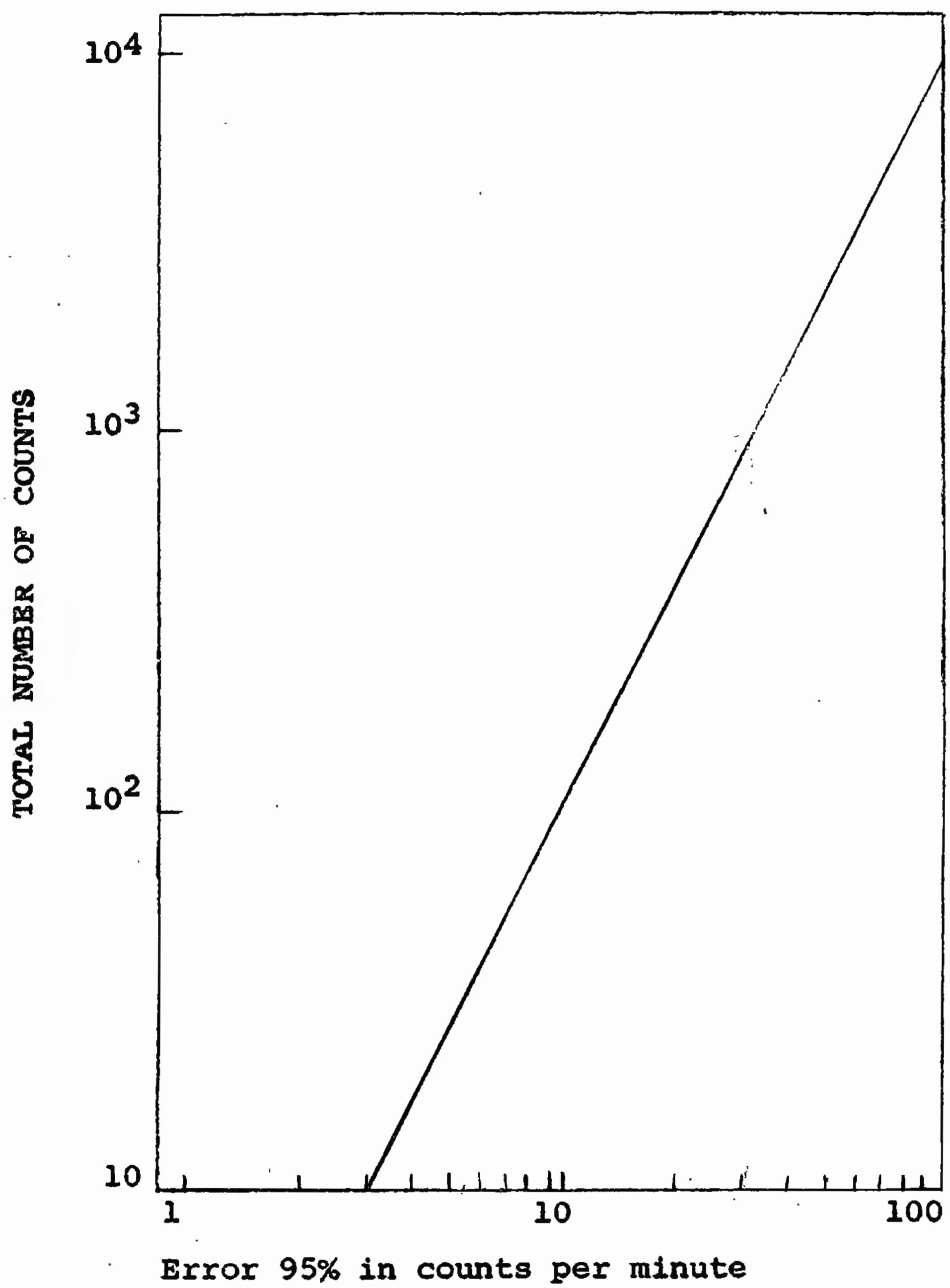
The instrument used for measuring activity in this study was a Nuclear Measurements Corporation Model PC 3A internal flow center. Because time was a major consideration in this study and almost all samples were at a relatively high activity level, it was decided that a maximum number of samples should be prepared and counted for a 2 minute period rather than preparing fewer samples and counting for a longer period of time. Figure 3 shows the error envolved for counts of 2 minutes (From Kinsman, 1957).

Activity as recorded on the scaler of an internal flow counter must undergo several corrections to be meaningful. (These are from Robeck et al, 1954)

Background: (BG) Because of cosmic radiation and the radioactivity of substances in or near the counter, the instrument always records a somewhat variable background count. Fifteen minute background counts were run daily during this study. The average background count was 50.15. Before the other correction factors could be applied, this value had to be subtracted from the total counts per minute.

Decay factor (D.F.): Radiophosphorus has a half life of 14.3 days (loses half its activity in 14.3 days). The counts should be corrected for this decay of radioactive

Figure 3: Error in counts per minute for 2 minute counts.
(95 per cent confidence level)



10^4
10^3
10^2
10
TOTAL NUMBER OF COUNTS
1
10
100
Error 95% in counts per minute

P^{32} to stable P^{31}.

Volume factor (V.F.) This factor corrects for differences in the size of samples. The total count of the sample minus background is divided by the volume of the sample in milliliters (or its weight in grams).

Geometry (G): The counting chamber's shape and construction limits its ability to detect disintegrations. Therefore, to determine the number of disintegrations per minute a correction factor for geometry must be used.

Self Absorption (SA). The residue that remains on the counting plate after preparing the sample absorbs some of the beta particles emitted, especially those of low energy. To determine disintegrations per minute a self-absorption factor must be used.

Backscatter (BS): This is the backscattering of beta particles from the counting plate, and a correction factor for it must be used to determine disintegrations per minute (D.P.M.)

To summarize:

D.P.M. = (CPM - BG) x D.F. x G x S.A. x B.S. x V.F.

To convert disintegrations per minute to microcuries per milliliter (or gram) the following relations are used (Robeck, *et al*, *op. cit.*).

It is known that:

$$1 \text{ curie (c)} = 3.7 \times 10^{10} \text{ D.P.S.}$$

$$1 \text{ microcurie } (\mu c) = 3.7 \times 10^{4} \text{ D.P.S.}$$

$$1 \text{ microcurie } (\mu c) = 2.22 \times 10^{6} \text{ D.P.M.}$$

$$\therefore 1 \text{ D.P.M.} = \frac{1}{2.22} \times 10^{6} = 4.5 \times 10^{-7} \mu c = \text{C.F.}$$

(conversion factor)

and μc/gram (or ml) =

$$(\text{CPM} - \text{BG}) \times \text{SA} \times \text{BS} \times \text{G} \times \text{D.F.} \times \text{V.F.} \times \text{C.F.}$$

In this study; BG = 50.15

SA = Fish = 1.08. water = 1.04, and aquatic plants = 1.10

BS = .73

G = 2

D.F. = variable depending on time sample was counted.

C. F. = 4.5×10^{-7}

V. F. = variable depending on sample size.

It should be obvious that if all samples are corrected for background, decay, and volume, comparisons and interpretations of them will be meaningful. Converting them to microcuries per milliliter merely involves multiplying them by a series of constants. Therefore both scales [microcuries per milliliter and (CPM-BG) x D.V. x V. F.] can be used on the same graph, as is done in this paper. Counts corrected for background, decay, and volume are referred to as corrected counts per minute on these graphs.

Water

Sampling

Water samples were collected at ten to thirty minute intervals at stations 2,3,5,8, 11, 14 and 16 as the radio-phosphorus passed through the area on the afternoon of August 5, 1958. The samples were taken from the main current in 140 c.c. polyethylene bottles which were stream rinsed for 30 seconds prior to filling. To keep sampling consistent from station to station relative to the moving isotope mass, fluoriscein dye was released 10 minutes before the isotope. The appearance of the dye at each sampling point instigated sampling. At stations 8 and 14 additional dye was released to bolster that in the stream which had lost intensity from dilution. Preliminary experiments with fluorescein provided flow data such as: flow time between stations; relative dilution (from color intensity); and the total time required for the dye to pass each station. Sampling procedure was planned on the assumption that the isotope would perform physically in the same manner as the dye.

Preparation of Samples

A 50 ml. portion of each sample was digested in 1 c.c. of concentrated nitric acid and prepared for counting as suggested for water samples by Robeck *et al*, (*op*. *cit*)

Computing Total Activity in Water Mass

The total amount of P^{32} in millicuries that passed each sampling station as part of the primary isotope mass on August 5 was calculated by the following method:

(1) The average activity in corrected counts per minute was computed for the water at each station by taking the sum of the activity of the samples at each station and dividing by the number of 10 minute intervals in each sampling period (weighted average).

(2) The total flow of water in milliliters that passed each sampling station during the sampling period was computed with the use of the figures in Table I.

(3) Total flow in milliliters x average activity per milliliter = total activity in total flow as (CPM - BG) x D.F.

(4) Total activity in millicuries =

1.04 .73 2

(CPM - BG) x D.F. x SA x BS x G x 4.5 x 10^{-10}

TABLE I

FLOW, LENGTH OF SAMPLING PERIOD, MEAN ACTIVITY, AND TOTAL ACTIVITY OF WATER OF WEST BRANCH OF STURGEON RIVER ON AUGUST 5, 1958

Station	Flow Ft.^{3}/sec.	Sampling Period (Seconds)	Mean Activity (cps/Ml.)	Microcuries per total flow
Isotopy Entry	34.0	-----	---------	23000.0
2	34.25	7800	.043882	13610.0
3	34.75	3600	.063134	9169.3
5	35.5	3600	.041889	6214.7
8	37.1	3600	.045839	~~7107.5~~ 4990
11	41.3	6000	.015068	~~4334~~.7 4228
14	45.5	6000	.009741	3087.1
16	52.5	5400	.001982	652.1

Aquatic Plants

Sampling

Samples of *chara* *sp*., *Potamogeton* *pectinatus*, and *Fontinalis* *antipyretica* were washed thoroughly by hand in the stream before being placed in individual 140 cc. polyethylene collecting bottles. In order to keep sampling procedures as consistent and representative as possible, successive plant samples of each species were collected as near as possible to previous samples, i.e., all *chara* samples at a given sampling station were taken from the same part of a given *chara* bed. Furthermore, each sample consisted of leaves and stems (no roots) taken from several places within each sampling area. In choosing sampling areas atypical sites such as backwaters and embayments were avoided. *Chara* and *Potamogeton* were sampled at six stations (2,3,5,8, 13 and 16) and *Fontinalis* at four (2,3,5, and 8) as *Fontinalis* was uncommon at stations downstream from number 8.

Preparation of Samples

One to two grams, wet weight, of each sample was prepared for counting. The method used for preparing the samples is that described by Robeck *et* *al*.,(*op*. *cit*.), for filimentous algae.

Fish

Sampling

Fish were collected at stations 2,3,5,8, 13, 15, and 16 with a 220 volt D.C. electric shocker mounted on a small flat bottomed skiff. Brown trout, Salmo trutta, and muddlers, Cottus bairdii, were the fish used in this study because (1) they are the two most plentiful species, (2) they are not stocked in the West Branch, and (3) they do not migrate appreciably. The muddlers collected varied in weight from 1 to 3 grams and the brown trout between 1.5 and 90 grams. Two fish of each species were collected at each station with the exception of August 25 when one of each was taken. In most cases the brown trout sample consisted of one small fish (less than 6 grams) and one large fish (more than 40 grams). In addition to these, several brown trout 5 to 7 inches in length were collected and used to determine the activity in individual parts of the fish.

Preparation of Samples

The various individual parts of fish and the small fish were weighed and prepared for counting as described by Robeck et al (ibid.). The larger fish were blended with water in a Waring blender and an aliquot containing approximately 2 grams of fish was taken and prepared for counting as above.

The parts of fish used to determine activity levels in edible and non-edible parts of the fish are as follows:

Flesh. A fillet weighing approximately two grams was taken from the back below the dorsal fin.

Head and gills. This included the entire head and gills.

Vicera. This included the entire contents of the body cavity.

Ribs and Vertebra. This included the entire backbone and as many ribs as possible. All flesh was removed with a knife and paper toweling.

Population Estimate

A population estimate of the fish between the point of isotope entry and station 8 was made with the use of the electric shocker. The area was shocked twice for marking by fin clipping and a third time for the population estimate. A scale sample was taken from a large proportion of the trout and all were measured and weighed. All muddlers were measured and some were weighed. From these data an estimate of the fish biomass was made.

RESULTS AND DISCUSSION

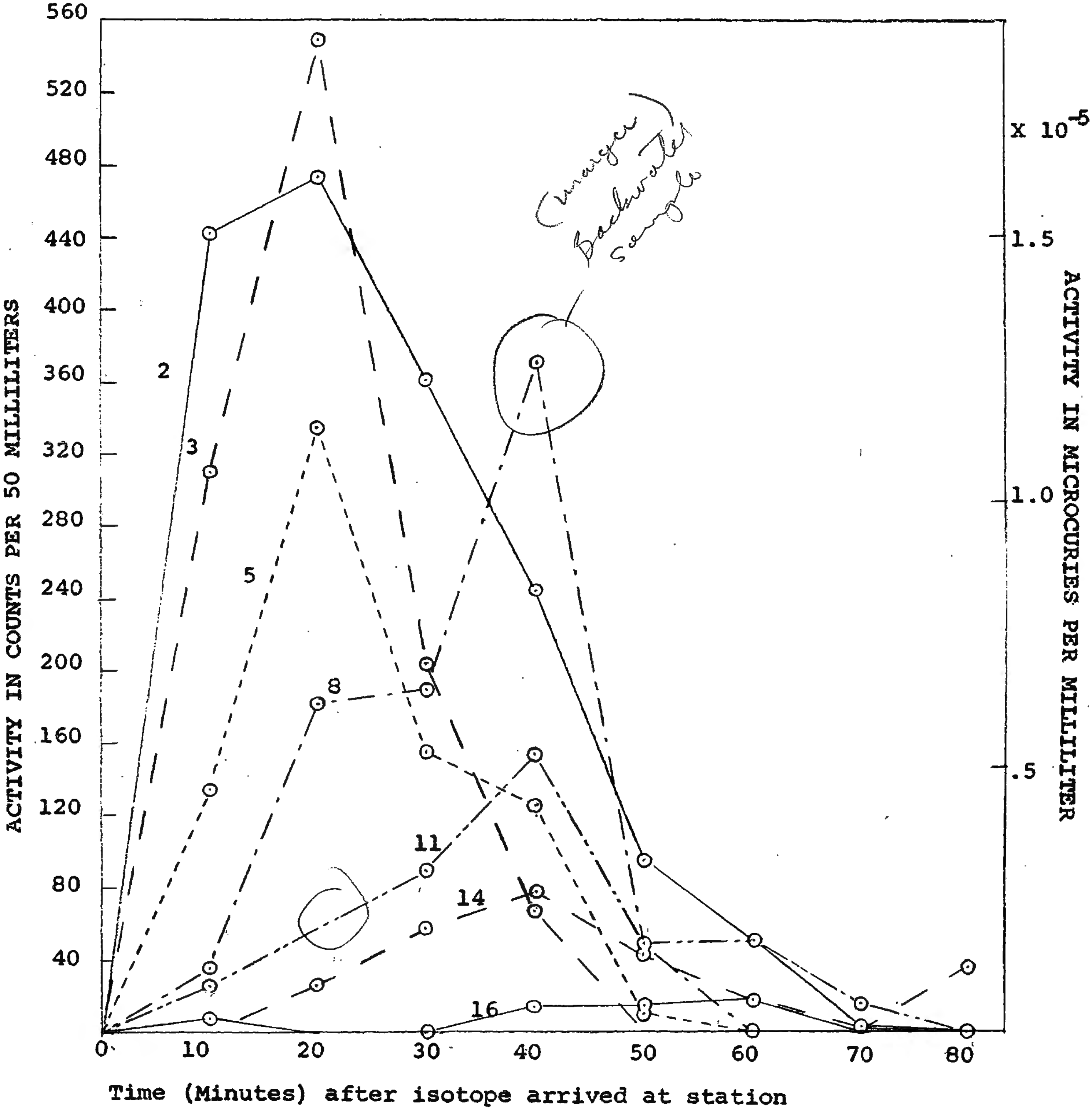
Water

As would be expected, and as figures 4 and 5 show, the P^{32} was rapidly taken up by the stream's primary producers and its inanimate bottom complex. Only 3 per cent of the isotope passed directly through the study area and only 30 per cent remained after 1000 yards. A rapid uptake took place in the first 500 yards of stream. The figures show that more isotope passed station 8 than station 5 which, of course, is impossible. It is, however, probable that very little more P^{32} passed 5 than did 8, considering the paucity of aquatic vegetation and the stream's rather direct flow between these two stations. A more intensive sampling would almost certainly have shown the activity at station 5 to be higher than station 8. The physical nature of the stream's flow is such as to make such errors possible. Of the isotope that was added, a small portion was carried downstream in the fastest, most direct route; another small portion took the most devious route, lingering in eddies, log jams, and embayments; but most of the isotope followed a route intermediate between these two extremes. (Note the two-tailed nature of the curves in Figure 4). The fast portion was diluted by the slower eddies and embayments of the stream whereas the slow portion was diluted by the faster inactive water moving down after the isotope had been cut off. The sampling of water that had just entered the main current from an embayment or eddy and consequently had not completely mixed could easily result in readings not representative of the stream's activity at that time. The fewer the samples taken, the greater the error resulting from such an unrepresentative sample is likely to be.

It would seem likely that a constant percentage of the isotope present in the stream would be taken up in any given length of stream, i.e. 10 per cent taken up in the first 100 yds., 10% of that remaining taken up in the second 100 yards, etc., but because of the variability in the stream from section to section this relation does not hold. There is, however, a linear relationship on a semi-logarithmic scale between the amount of P^{32} entering the stream and the amount passing stations 8, 11, 14, and 16. Stations 2, 3, and 5 fall considerably below this line indicating that a higher percentage of P^{32} was taken up in the upstream area.

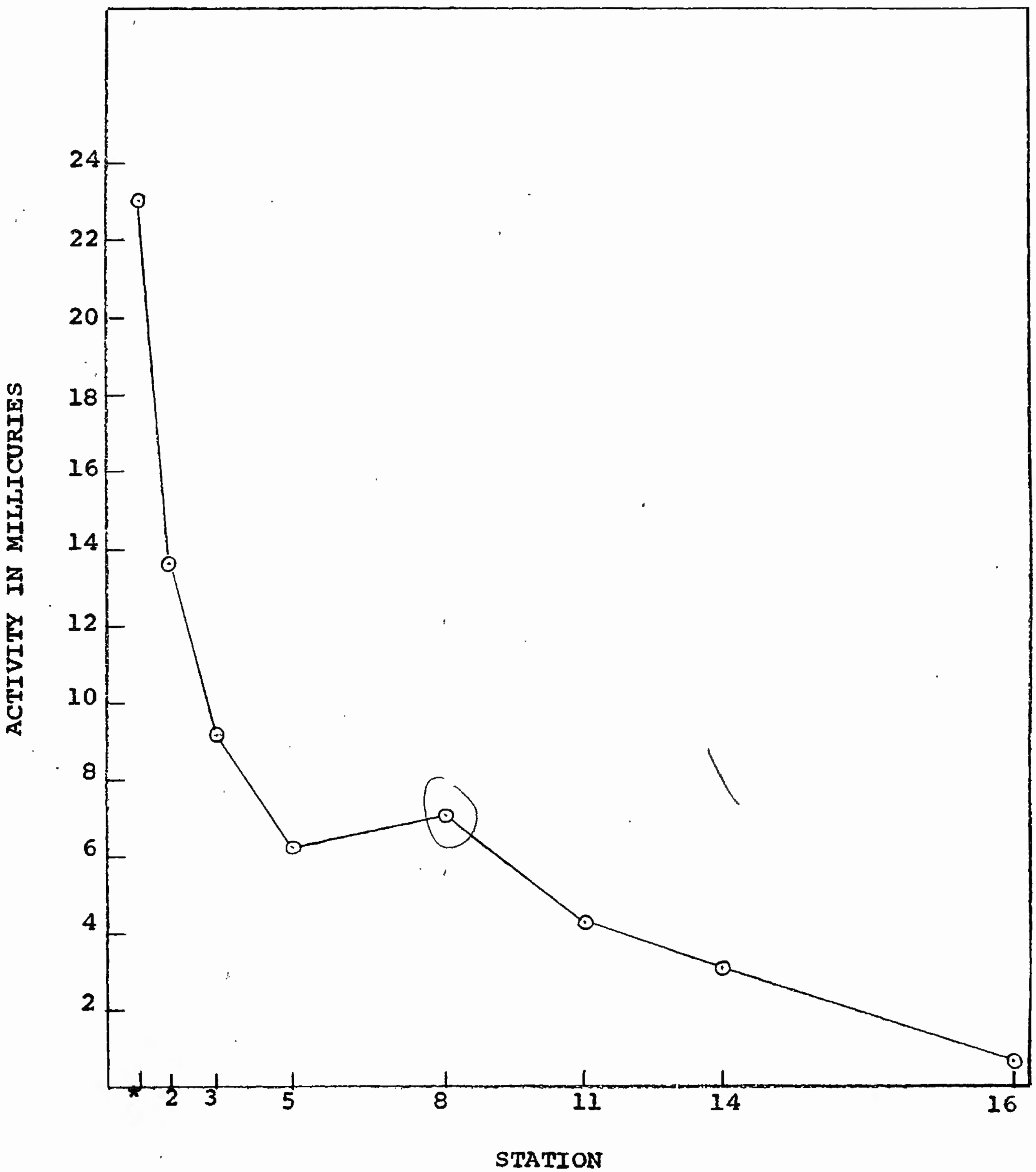
500 cc. water samples taken after August 5 failed to show any significant activity.

Figure 4: Activity of water at each station as primary isotope mass moved past on August 5, 1958.



560
520
480
440
400
360
320
280
240
200
160
120
80
40
0
10
20
30
40
50
60
70
80
2
3
5
8
11
14
16
x 10^-5
1.5
1.0
.5
ACTIVITY IN COUNTS PER 50 MILLILITERS
ACTIVITY IN MICROCURIES PER MILLILITER
Time (Minutes) after isotope arrived at station

Figure 5: Total Activity of water passing each station on August 5, 1958.



* isotope entry

At station 8 the activity dropped to 0 c.p.m. at 3:25 P.M., 46 minutes after the isotope had ceased entering the stream. At 4:25 the activity rose again to 38 c.p.m. and the next sample at 4:45 P.M. showed 32 c.p.m. (Table II). This secondary "pulse" may be due to a sudden "feeding back" of P^{32} by primary producers to the stream. Possibly a physical uptake by a primary producer was followed by an appreciable loss of P^{32} an hour later. Coffin et al (1949) discussed this possibility for a small bog lake in which sphagnum moss showed a rapid uptake of P^{32} immediately following its introduction, followed by a sudden drop in activity after 8 to 10 hours. This was then followed by a gradual, more permanent uptake which peaked in 3 weeks. Coffin and his co-workers postulated that the first uptake was a physical one of some kind and the second a biological and permanent incorporation into the plant cells. Unfortunately, too few samples were taken late in the day on August 5 to form any conclusions on this point.

TABLE II

ACTIVITY OF WATER FROM WEST BRANCH OF STURGEON RIVER AFTER ADDITION OF P^{32} AT 2:01 P.M., AUGUST 5, 1958

Station Collected	Time Collected (Aug. 5)	Activity in Corrected c.p.m/50ml	Station Collected	Time Collected	Activity in Corrected c.p.m/50 ml.
2	2:04	14.3	5	4:05	0.0
2	2:14	442.6	5	4:23	0.0
2	2:24	474.3	8	2:25	0.0
2	2:34	361.2	8	2:35	36.6
2	2:44	244.8	8	2:45	182.7
2	2:54	95.7	8	2:55	191.1
2	3:14	4.3	8	3:05	370.6
2	3:34	7.6	8	3:15	49.0
2	3:54	4.3	8	3:25	0.0
3	2:01	0.0	8	3:35	4.3
3	2:11	5.5	8	3:45	0.0
3	2:21	309.7	8	4:05	4.3
3	2:31	549.6	8	4:25	37.9
3	2:41	204.1	8	4:45	31.8
3	2:51	67.6	8	5:25	7.2
3	3:01	0.0	8	6:05	19.6
3	3:21	0.0	11	2:49	0.0
3	3:41	0.0	11	2:59	25.6
3	4:01	0.0	11	3:09	56.5
3	4:41	0.0	11	3:19	89.6
5	2:13	0.0	11	3:29	153.5
5	2:23	132.9	11	3:39	49.9
5	2:33	334.8	11	3:49	51.1
5	2:43	155.3	11	3:59	15.1
5	2:53	125.8	11	4:09	2.3
5	3:03	10.6	11	4:19	8.5
5	3:13	0.0	11	4:29	0.0
5	3:23	0.0	11	4:39	0.0

TABLE II (Continued)

Station Collected	Time Collected (Aug. 5)	Activity in Corrected c.p.m/50 ml.	
11	4:59	0.0	
11	5:19	0.0	
11	5:39	0.0	
11	5:59	0.0	
11	6:39	0.0	
14	3:28	0.0	
14	3:38	0.0	
14	3:48	25.8	0.516
14	3:58	57.6	1.15
14	4:08	78.4	1.57
14	4:18	42.2	0.844
14	4:28	17.8	0.556
14	4:38	1.0	0.02
14	4:48	36.7	0.73
14	5:08	9.7	0.19
14	5:18	0.0	
14	5:38	12.0	
14	5:58	3.5	
14	6:18	0.0	
14	6:38	0.0	
16	4:30	8.1	
16	4:40	0.0	
16	4:40	0.0	
16	5:00	0.0	
16	5:20	14.0	3.28
16	5:30	14.0	.35
16	5:40	17.5	
16	5:50	0.0	
16	6:15	0.0	

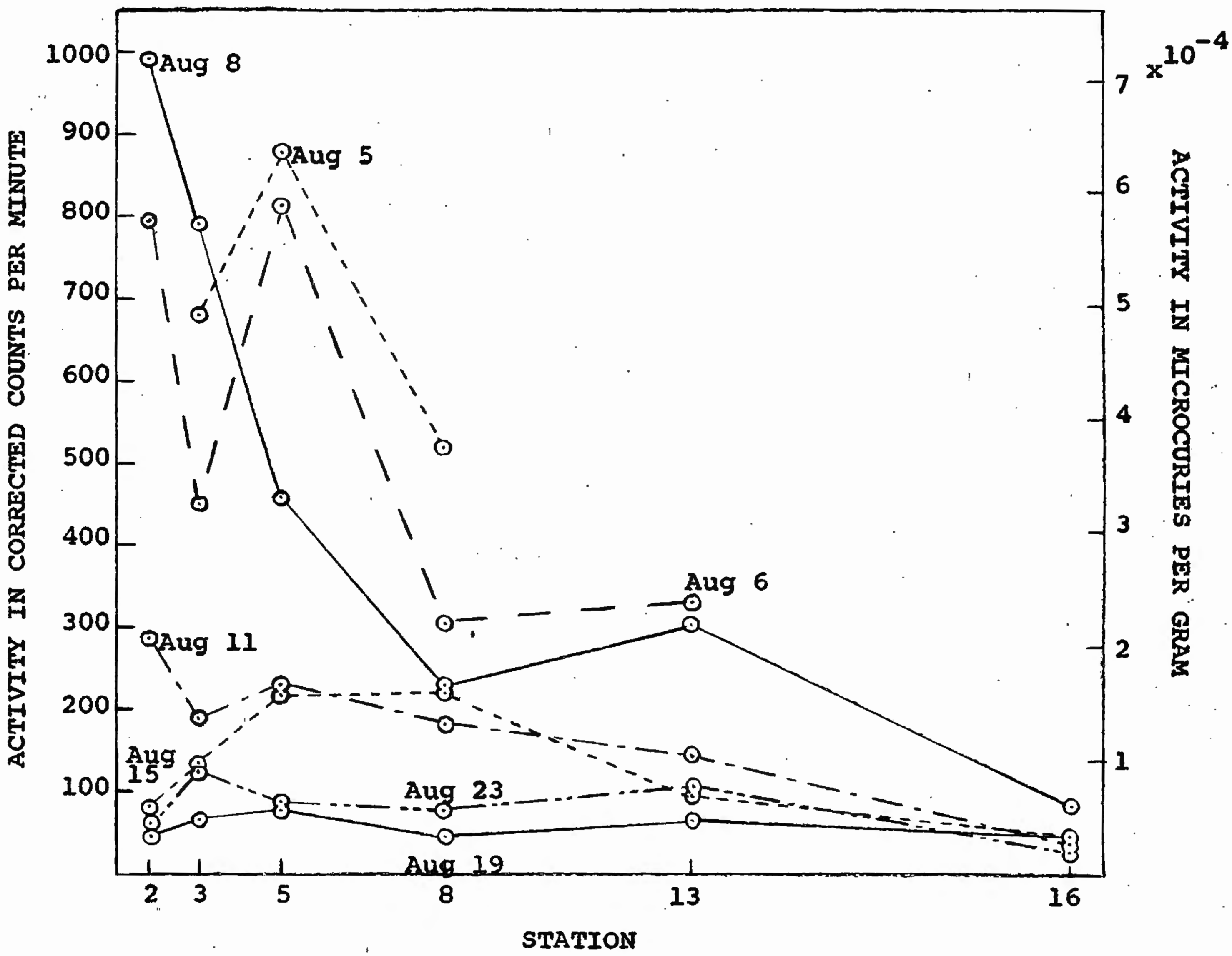
Aquatic Plants

Activity levels in *Chara* and *Potamogeton* are very similar in many respects. *Fontinalis*, however, differs quite strikingly from these two (see Figures 6-10). The average activity of *Chara* and *Potamogeton* in the first 1000 yards below the isotope entry remained high until August 8 and then dropped rapidly to reach a stable level of between 50 and 100 counts per minute. The activity curves of these two plants (Figures 6 and 8) for the various stations remained high until August 8 and then flattened rapidly until August 19 when all stations exhibited a consistently low activity. After August 19 all stations remained at this low level. This constantly low activity probably indicates that the P^{32} remaining in the plants is incorporated into the cell structure.

Fontinalis acted quite differently. Its activity dropped abruptly from August 6 to August 8, especially at stations 2 and 3. Thereafter its activity dropped rather slowly and remained higher in activity (2 or 3 times) than *Chara* or *Potamogeton*. This may be due to metabolism differences between *Fontinalis* and the other plants or possibly to differences in their ability to hold P^{32} in some physical manner.

Note the tendency for the activity of plants at

Figure 6. Activity of Chara sp. during August, 1958.



1000
900
800
700
600
500
400
300
200
100
ACTIVITY IN CORRECTED COUNTS PER MINUTE
Aug 8
Aug 5
Aug 6
Aug 11
Aug 15
Aug 23
Aug 19
2
3
5
8
13
16
STATION
x10^-4
7
6
5
4
3
2
1
ACTIVITY IN MICROCURIES PER GRAM

Figure 7. Activity of Watermoss (*Fontinalis antipyretica*) during August, 1958.

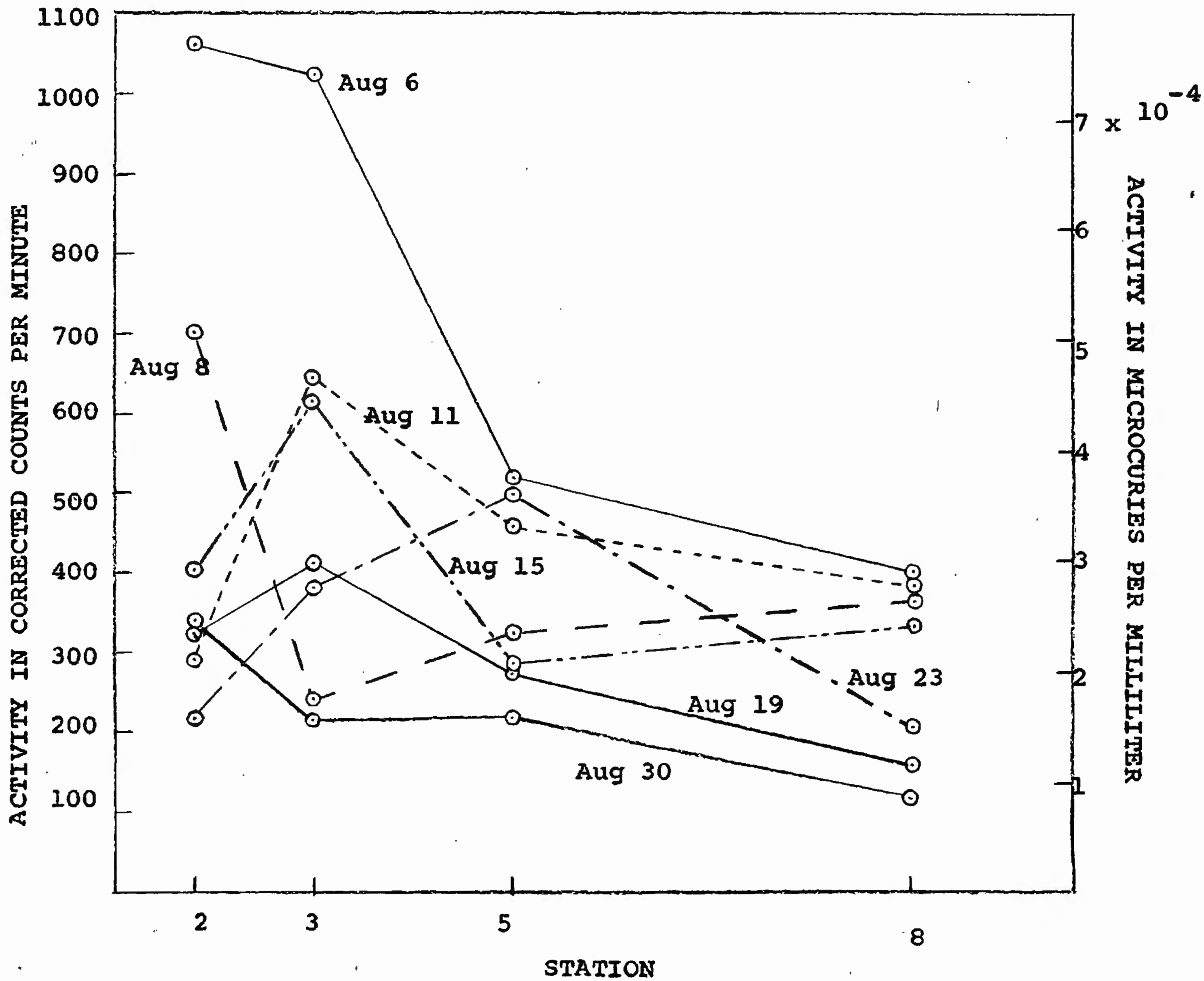
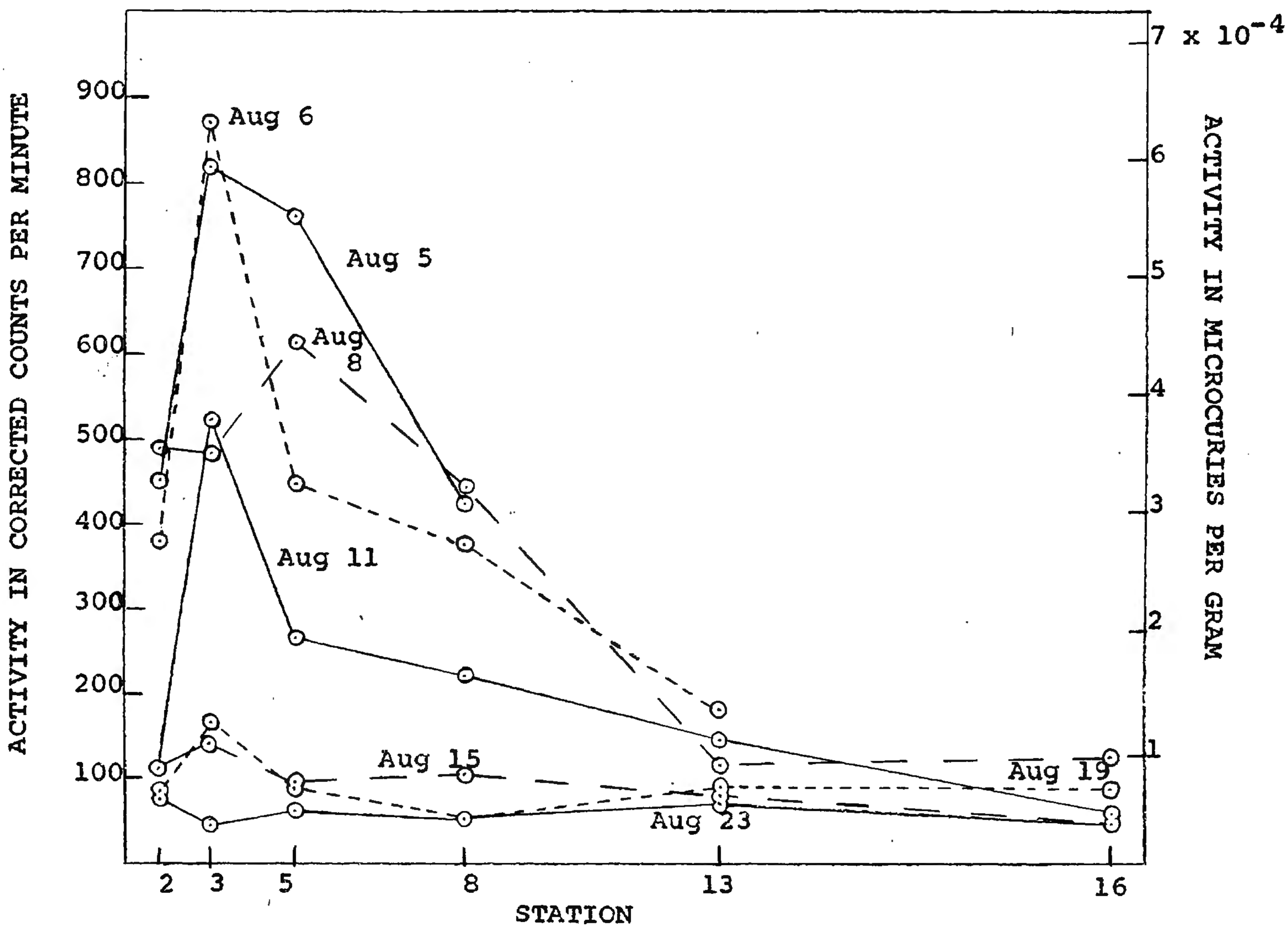
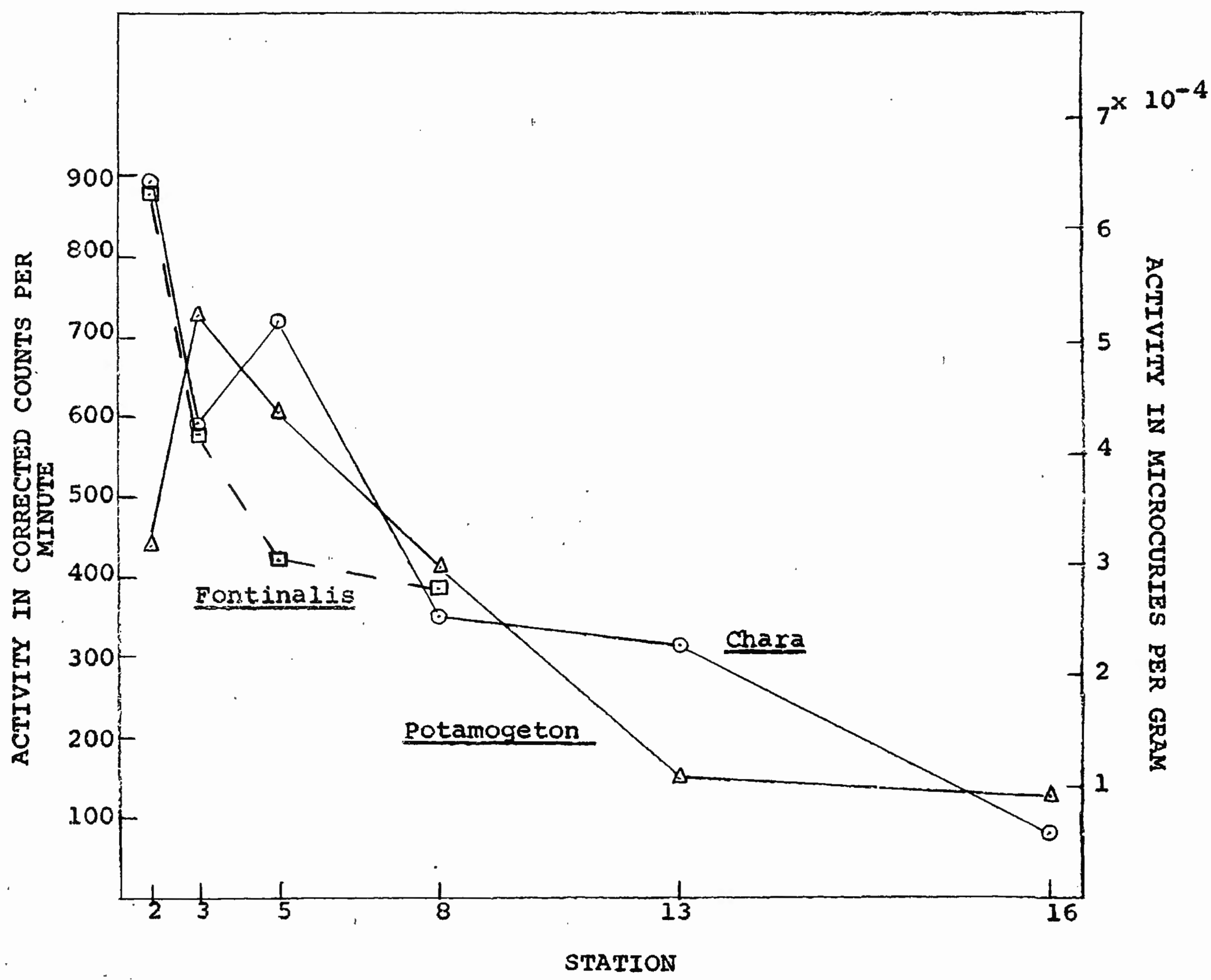

1100
1000
900
800
700
600
500
400
300
200
100
ACTIVITY IN CORRECTED COUNTS PER MINUTE
Aug 6
Aug 8
Aug 11
Aug 15
Aug 19
Aug 23
Aug 30
2
3
5
8
STATION
7 x 10^{-4}
6
5
4
3
2
1
ACTIVITY IN MICROCURIES PER MILLILITER

Figure 8. Activity of *Potamogeton pectinatus* during August, 1958.



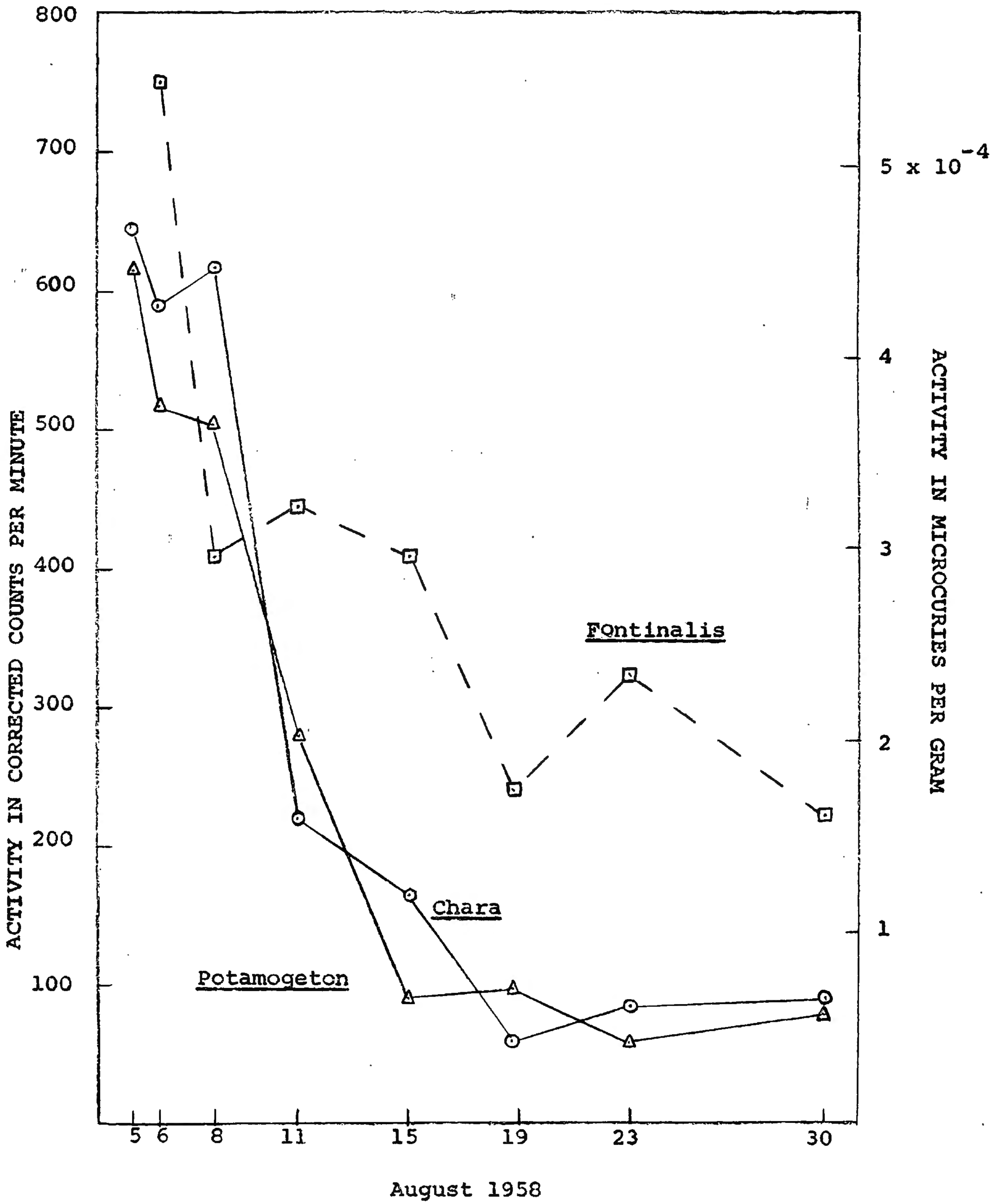
ACTIVITY IN CORRECTED COUNTS PER MINUTE
900
800
700
600
500
400
300
200
100
ACTIVITY IN MICROCURIES PER GRAM
7 x 10^-4
6
5
4
3
2
1
Aug 6
Aug 5
Aug 8
Aug 11
Aug 15
Aug 19
Aug 23
2
3
5
8
13
16
STATION

Figure 9. Mean activity in aquatic plants, August 5, 6, and 8, 1958.



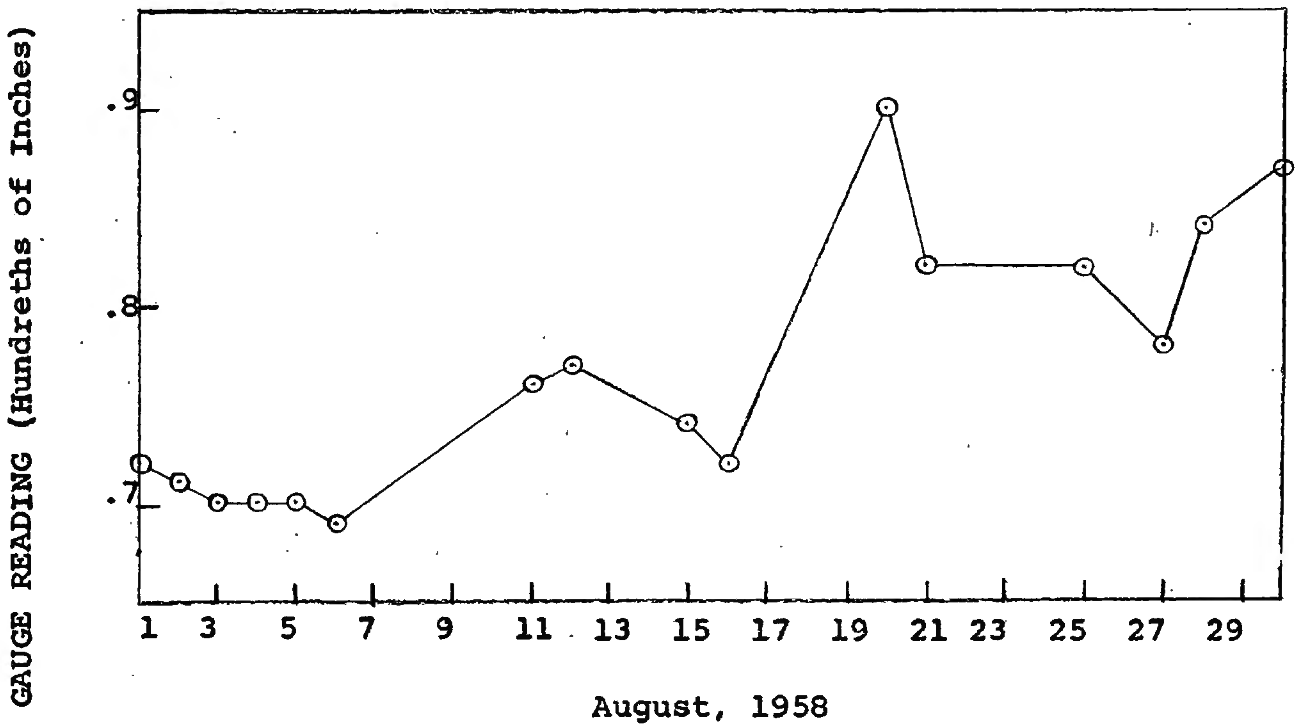
ACTIVITY IN CORRECTED COUNTS PER MINUTE
900
800
700
600
500
400
300
200
100
7 x 10-4
6
5
4
3
2
1
ACTIVITY IN MICROCURIES PER GRAM
Fontinalis
Chara
Potamogeton
2
3
5
8
13
16
STATION

Figure 10. Mean activity of aquatic plants from stations 2, 3, 5, and 8 during August, 1958.



800
700
600
500
400
300
200
100
ACTIVITY IN CORRECTED COUNTS PER MINUTE
5 x 10-4
4
3
2
1
ACTIVITY IN MICROCURIES PER GRAM
Fontinalis
Chara
Potamogeton
5
6
8
11
15
19
23
30
August 1958

Figure 11. Water fluctuation of West Branch of Sturgeon River during August, 1958.


GAUGE READING (Hundreths of Inches)
.9
.8
.7
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
August, 1958

station 2, the station nearest the isotope entry, to be lower than the activity of those from stations 3 and 5. This is especially noticeable in potamogeton for August 6 through August 11 and in Fontinalis after August 8. Clifford (unpublished) found that periphyton growing on plastic shingles showed much higher activity at stations 3 and 4 than at station 2. This was true for the shingles collected two hours after the isotope mass had passed as well as those collected 3 days later. Intuitively this seems incompatible with the water data, however the explanation may be simple. After the primary source of the P^{32} had been exhausted and the activity in the water was not detectible, the gradual "feeding back" of P^{32} from extremely slow backwaters, log jams, and Chara beds continued. "Feedback" of P^{32} through the metabolism of primary producers also would have begun to occur. Foster (1958) states that "Plankton and algae exchange phosphorus very rapidly with the water" in reference to his Columbia River studies. A large proportion of this "feedback" P^{32} is again taken up by the biota. Through this cycle the P^{32} would gradually move downstream through the system. Station 2, however, is in a poor position to receive this "feedback" phosphorus. Between the isotope entry and station 2 there is 100 yards of stream. The first 50 yards of this is a straight, swift, gravelly stretch in which the isotope would contact a relatively small area of stream bottom due to incomplete mixing. Station two would then have only 50 yards of stream from which it could receive "feedback" phosphorus. The advantage that the more downstream stations have in this respect is an obvious one. This advantage would be even greater if the plants' ability to take up phosphorus is greater for a low concentration over a longer period than for a higher concentration over a shorter period of time.

Although the stream system is an open one, complete loss of the P^{32} (into a lake) is very gradual.

TABLE III

ACTIVITY OF *CHARA SP*. FROM WEST BRANCH OF STURGEON RIVER AFTER ADDITION OF P^{32}

Station Collected	Date Collected	Activity in Corrected c.p.m.	Station Collected	Date Collected	Activity in Corrected c.p.m.
2	8-5-58	0.0	3	8-15-58	136.4
3	"	682.6	5	"	218.0
4	"	502.6	8	"	225.2
5	"	878.4	13	"	96.8
8	"	519.7	16	"	36.4
2	8-6-58	794.1	2	8-19-58	47.4
3	"	449.1	3	"	68.0
5	"	813.8	5	"	79.3
8	"	305.6	8	"	46.9
13	"	330.6	13	"	64.8
2	8-8-58	992.4	16	"	43.6
3	"	789.9	2	8-23-58	59.8
5	"	459.3	3	"	124.9
8	"	230.0	5	"	85.1
13	"	302.0	8	"	77.1
16	"	82.5	13	"	103.1
2	8-11-58	287.3	16	"	25.8
3	"	188.8	2	8-30-58	89.5
5	"	230.6	3	"	86.4
8	"	182.7	5	"	107.7
13	"	144.0	8	"	86.4
16	"	36.6	13	"	73.0
2	8-15-58	82.9	16	"	107.9

TABLE IV

ACTIVITY OF <u>POTAMOGETON</u> <u>PECTINATUS</u> FROM WEST BRANCH OF STURGEON RIVER AFTER ADDITION OF P^{32}

Station Collected	Date Collected	Activity in Corrected c.p.m.	Station Collected	Date Collected	Activity in Corrected c.p.m.
2	8-5-58	451.7	3	8-15-58	140.8
3	"	819.1	5	"	94.0
4	"	819.0	8	"	103.5
5	"	760.1	13	"	82.0
8	"	422.0	27	"	48.5
2	8-6-58	378.3	2	8-19-58	85.3
3	"	870.0	3	"	168.2
5	"	445.6	5	"	88.0
8	"	374.2	8	"	53.5
13	"	183.7	13	"	84.9
2	8-8-58	488.8	27	"	90.0
3	"	482.2	2	8-23-58	76.1
5	"	610.6	3	"	44.6
8	"	441.5	5	"	60.7
13	"	113.5	8	"	53.1
27	"	127.2	13	"	72.7
2	8-11-58	112.7	27	"	45.0
3	"	520.8	2	8-30-58	64.1
5	"	265.9	3	"	61.9
8	"	219.7	5	"	128.1
13	"	143.7	8	"	78.0
27	"	59.5	13	"	84.0
2	8-15-58	112.5	27	"	60.5

TABLE V

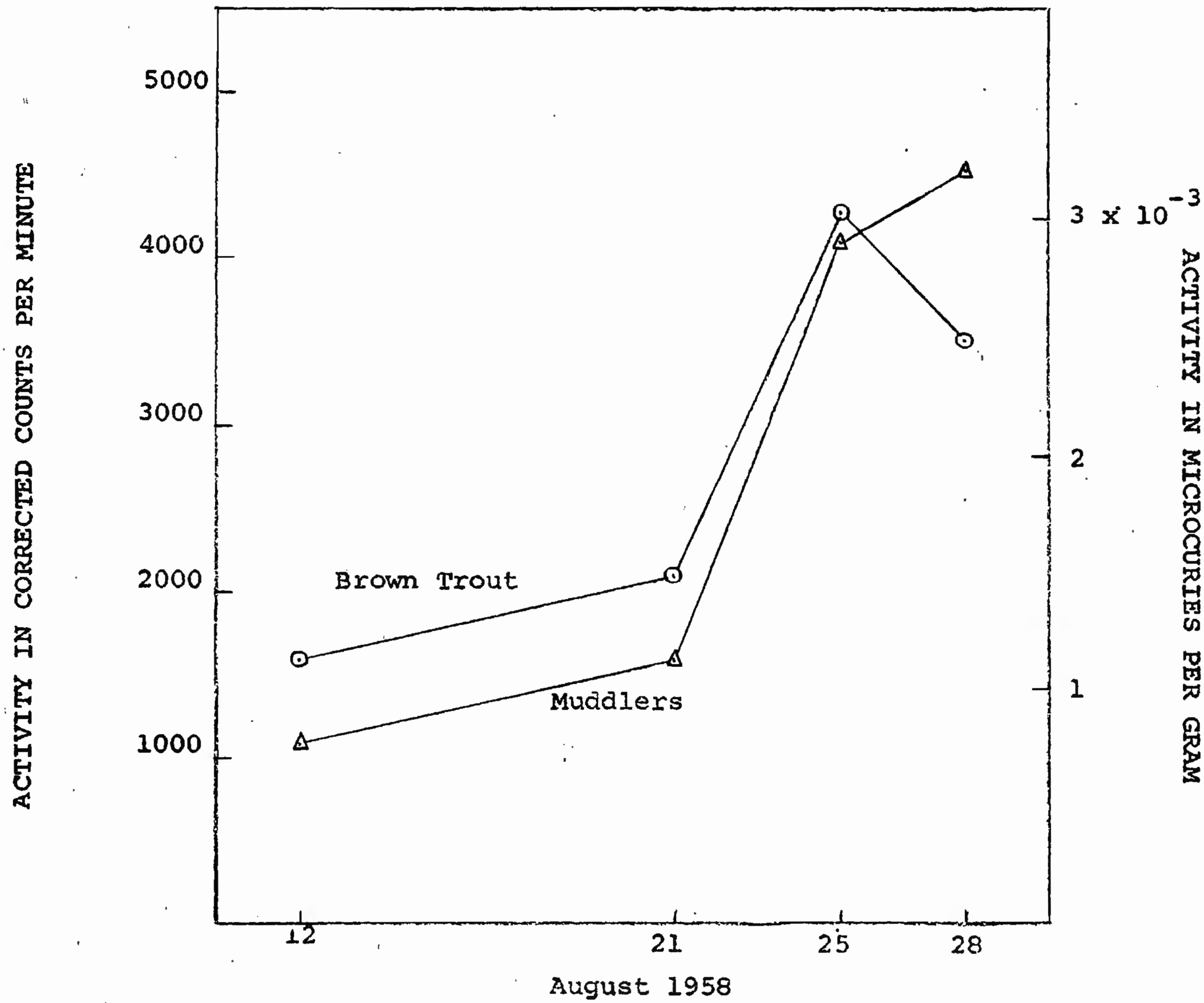
ACTIVITY OF *FONTINALIS ANTIPYRETICA* FROM WEST BRANCH OF STURGEON RIVER AFTER ADDITION OF P^{32}

Station Collected	Date Collected	Activity in Corrected c.p.m.	Station Collected	Date Collected	Activity in Corrected c.p.m.
2	8-6-58	1061.5	5	8-15-58	287.9
3	"	1623.1	8	"	332.8
5	"	519.2	2	8-19-58	321.7
8	"	402.5	3	"	410.7
2	8-8-58	702.9	5	"	274.4
3	"	241.7	8	"	160.9
5	"	326.8	2	8-23-58	217.4
8	"	367.3	3	"	380.3
2	8-11-58	292.5	5	"	499.2
3	"	645.8	8	"	208.1
5	"	459.4	2	8-30-58	340.0
8	"	388.7	3	"	215.5
2	8-15-58	403.8	5	"	219.6
3	"	615.2	8	"	118.3

Fish

As Figure 12 shows, both species of fish increased slowly in activity until August 21 and then rapidly to August 25. The activity in brown trout dropped by August 28 while the muddlers continued to increase, but at a reduced rate. This sudden rise may be partially due to the fact that prior to the August 25 sampling the stream was swollen from rain (Figure 14) and the fish were feeding. The sampling was made while shocking the stream for the population estimate and most of the fish handled had noticeably bulging sides from full stomachs. As fish get virtually all their phosphorus from their food (Coffin et al, 1949) (Olson, 1952), one would expect that an extended feeding spree would result in a rapid increase in the activity of the fish, provided their food was high in activity. Referring back to the aquatic plants Chara and Potamogeton, recall that they maintained a high level of activity until August 8 after which the activity dropped rapidly to a "base level" by August 19. Although some of this activity was lost, most of it continued to move through the food chain. One would expect, then, a substantial increase in another part or parts of the food chain following the drastic decrease in the "pool" of P^{32} in the higher aquatics. Clifford, (op. cit) found a higher mean activity in periphyton on August 18 than on

Figure 12. Mean activity of all fish from Stations 2, 3, 5, and 8 during August, 1958.

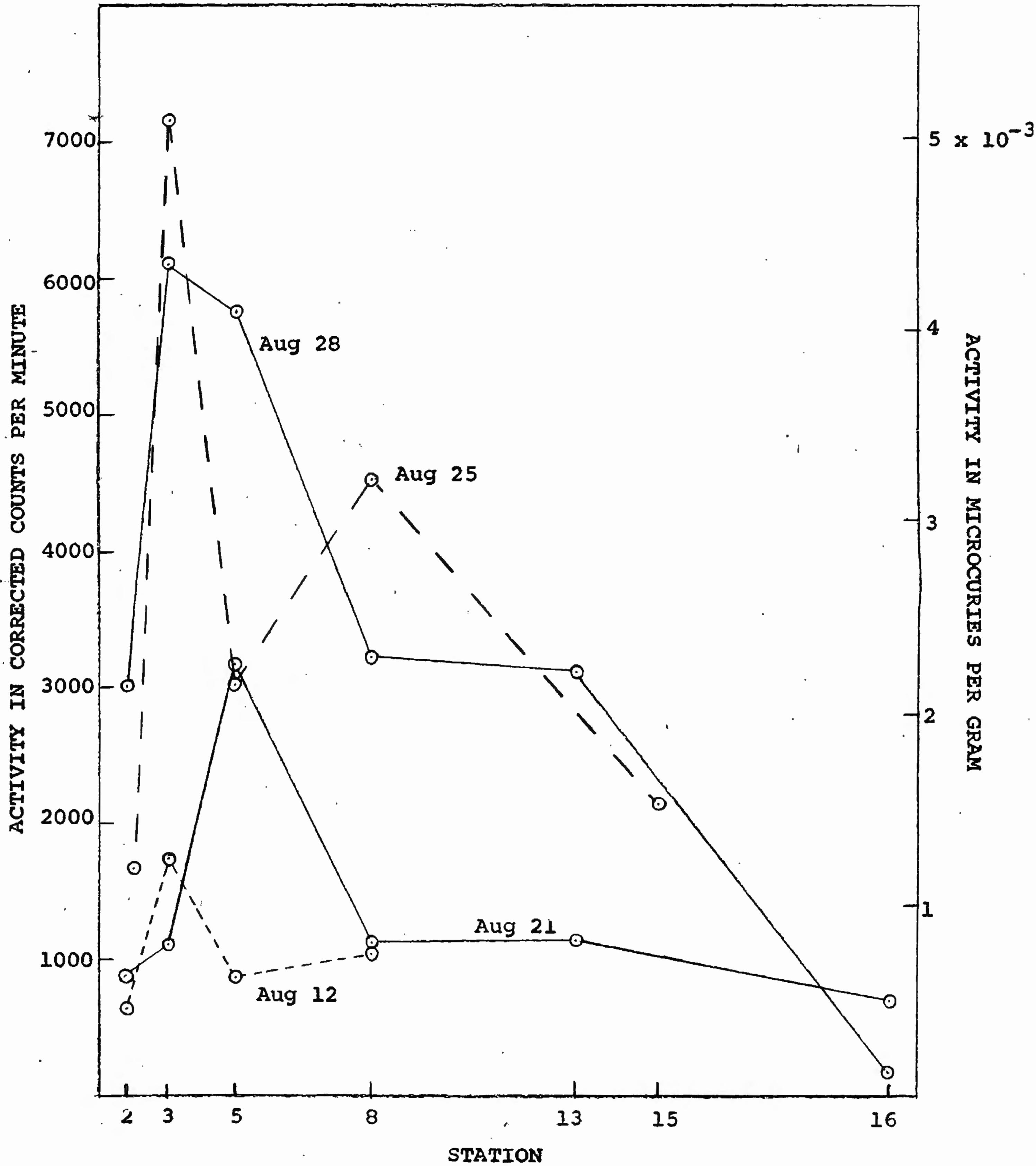

ACTIVITY IN CORRECTED COUNTS PER MINUTE
5000
4000
3000
2000
1000
Brown Trout
Muddlers
12
21
25
28
August 1958
3 x 10-3
2
1
ACTIVITY IN MICROCURIES PER GRAM

August 12, the mean activity on August 18 being more than 50 per cent of the mean activity on August 5, the day the isotope was added. This indicates that a considerable amount of the "feedback" P^{32} from the aquatic plants was being taken up by the periphyton. Clifford also found that the activity in the periphyton dropped sharply from August 18 to August 24, the period in which Chara and Potamogeton reached their base level. Foster (1958), in his work on the Columbia River, considered the turnover rate of P^{32} in the plankton and algae to be so rapid that its "age" can be considered the same as the water from which it came. Foster also calculated the lag between plankton and the caddisfly, Hydropsyche. "The average 'age'", he states, "of P^{32} in the caddis larvae must be about one week". Assuming that these data are roughly applicable to the West Branch of the Sturgeon, the invertebrates should show an increase in activity corresponding to the aquatic plants' decrease, followed by a decrease after the aquatic plants had reached "base level". The lag separating these two occurances can be set at about one week. In agreement with this scheme, Bryant (unpublished) found that the average activity in the caddisfly larvae, Brachycentridae, from stations 2 and 8 to be 2650 c.p.m. on August 8, 3023 c.p.m. on August 16, and 2172 c.p.m. on August 30. The fish, therefore, would have fed on invertebrates which were at a high level of activity between August 21 and August 25, and possibly at their peak level.

The drop in activity in brown trout by August 28 may be due partly to inadequacy of sampling and partly to the loss of P^{32} by way of the digestive tract. Watson (1957) found that adult trout retain only about 54 per cent of the P^{32} that they ingest. If the trout fed very little between August 25 and August 28 they would have lost a considerable amount of P^{32} from their digestive tract.

The curves in Figures 13-15 show that brown trout reach their highest activity at station 5 and muddlers at station 3. Brown trout maintain a higher activity at the more downstream stations. These data indicate that brown trout feed more on drifting organisms than do muddlers. Because they are not strong swimmers, muddlers do not forage freely in the heavy currents. They move about the stream bottom with the aid of their large, hand-like pectorals, feeding among the _Chara_ beds and debris. Brown trout are found in the deeper areas in the main current where they feed primarily on organisms drifting down from upstream areas.

Figure 13. Activity of muddlers during August, 1958.



ACTIVITY IN CORRECTED COUNTS PER MINUTE
7000
6000
5000
4000
3000
2000
1000
5 x 10^{-3}
4
3
2
1
ACTIVITY IN MICROCURIES PER GRAM
Aug 28
Aug 25
Aug 21
Aug 12
2
3
5
8
13
15
16
STATION

Figure 14. Activity of brown trout during August, 1958.

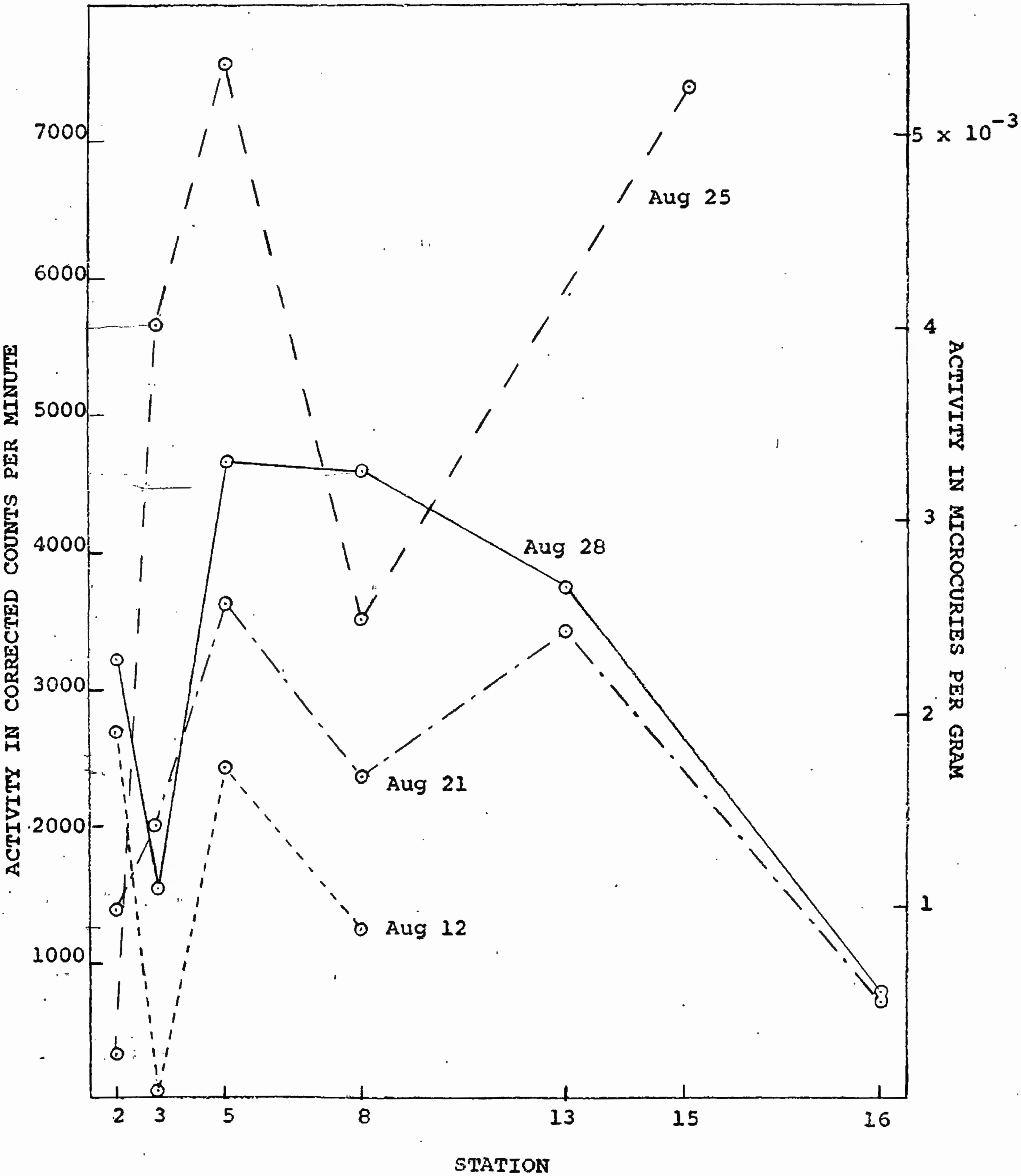
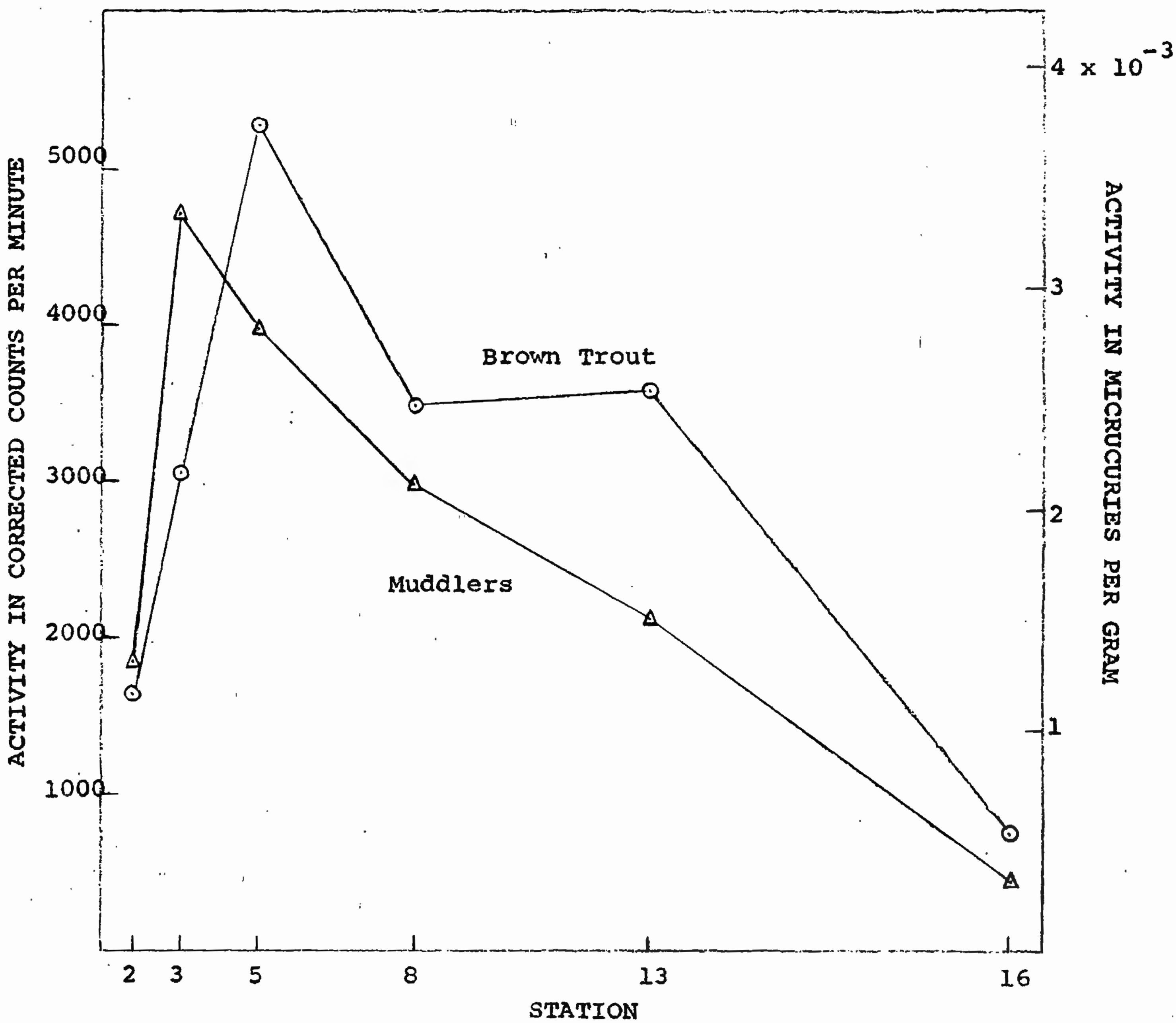

7000
6000
5000
4000
3000
2000
1000
ACTIVITY IN CORRECTED COUNTS PER MINUTE
5 x 10-3
4
3
2
1
ACTIVITY IN MICROCURIES PER GRAM
Aug 25
Aug 28
Aug 21
Aug 12
2
3
5
8
13
15
16
STATION

Figure 15. Mean activity of fish collected August 21, 25, and 28 at stations shown.



ACTIVITY IN CORRECTED COUNTS PER MINUTE
5000
4000
3000
2000
1000
ACTIVITY IN MICRUCURIES PER GRAM
4 x 10^{-3}
3
2
1
Brown Trout
Muddlers
2
3
5
8
13
16
STATION

TABLE VI

ACTIVITY OF BROWN TROUT FROM WEST BRANCH OF STURGEON RIVER AFTER ADDITION OF P^{32}

Station Collected	Date Collected	Activity in Corrected c.p.m.	Station Collected	Date Collected	Activity in Corrected c.p.m.
2	8-12-58	4648.0	2	8-25-58	337.4
2	"	734.4	3	"	5665.9
3	"	120.9	5	"	6344.4
3	"	4.3	5	"	8805.5
4	"	196.2	8	"	3514.4
4	"	207.3	15	"	7440.0
5	"	2435.8	15	"	7401.2
8	"	2256.5	2	8-28-58	1962.0
8	"	244.8	2	"	4481.3
2	8-21-58	1231.2	3	"	1813.0
2	"	1548.6	3	"	1277.0
3	"	1648.8	5	"	1041.5
3	"	2363.2	5	"	8283.4
5	"	4838.1	8	"	8436.9
5	"	2434.5	8	"	751.2
8	"	392.1	13	"	5964.8
8	"	4329.9	13	"	1436.1
13	"	2429.5	13	"	3857.4
13	"	4423.4	16	"	411.8
16	"	156.6	16	"	1138.8
16	"	1260.3			

TABLE VII

ACTIVITY IN MUDDLERS FROM WEST BRANCH OF STURGEON RIVER AFTER ADDITION OF P^{32}

Station Collected	Date Collected	Activity in Corrected c.p.m.	Station Collected	Date Collected	Activity in Corrected c.p.m.
2	8-12-58	784.6	16	8-21-58	483.8
2	"	525.2	2	8-25-58	1661.2
3	"	3438.7	3	"	7161.6
3	"	47.0	5	"	3024.3
5	"	1569.8	8	"	4530.6
5	"	176.0	15	"	909.2
8	"	59.8	15	"	3407.6
8	"	2027.8	2	8-28-58	1226.2
2	8-21-58	1110.7	2	"	4972.5
2	"	687.1	3	"	5927.2
3	"	1105.1	3	"	6280.8
3	"	1123.1	5	"	1976.1
5	"	5545.7	5	"	9558.5
5	"	808.4	8	"	2265.5
8	"	1239.4	8	"	4218.9
8	"	1031.9	13	"	2980.7
13	"	1680.4	13	"	3249.5
13	"	620.6	16	"	148.6
16	"	920.0	16	"	220.6

Individual Parts of Brown Trout

Table 8 shows the activity in the various parts of the brown trout. From a public health standpoint it is significant to note that the edible portion of the fish contained the lowest activity. The ribs and vertebra concentrated 5.35 times more P^{32} than the flesh, the viscera 2.85 times more, and the head and gills 2.63 times more than the flesh. A good deal of other work has been done on the concentration of phosphorus in the various parts of fish. Krumholtz (1954, 1956), working with mixed isotopes in White Oak Creek and Lake, Tennessee, found that hard bone and scales concentrated the largest amounts of radioactivity followed by the soft bone, liver, and other internal organs. Flesh concentrated very little radioactivity. Robeck *et al*, (*op. cit.*) found the highest activities in Columbia River fish to be in the bone, scales, stomachs, liver, sex organs and kidneys, with much lower activity (4 to 10 times) in the flesh and skin.

Population Estimate

The population estimate yielded the following data:

Total Fish Biomass:

Brown trout 44.137 Kg.

Brook trout	5.206 Kg.
Rainbow trout	19.780 "
Muddlers	67.181 "
Total	136.304 Kg.

Through a random sample of 100 stream widths (and actual measurement of the length) the surface area of the stream between the isotope entry and station 8 was calculated to be 1.77 acres. The standing crop, then, for this part of the stream is 170 pounds per acre which is comparable to that of Michigan's best eutrophic lakes. According to the system of classifying streams as to productivity of bottom fauna proposed by Hazzard (1935) and modified by Davis (1938) whereby streams with more than two grams of organisms per $ft.^2$ of bottom are considered rich, those with 1-2 grams per $ft.^2$ are average, and those with less than 1 gram per $ft.^2$ are poor. The West Branch, with less than .5 grams per $ft.^2$ (Keup, 1958), is a very unproductive stream. This indicates that our poorest streams produce as well as our best lakes.

Assuming an equal activity in all species of fish, an estimate of the total activity in the fish between the isotope entry and station 8 can be made for a given date. This is done by multiplying the mean activity per gram of fish in that area at that date by the total number of grams of fish (136,304). Using 400 c.p.m. as the mean activity

TABLE VIII

ACTIVITY IN VARIOUS PARTS OF BROWN TROUT FROM WEST BRANCH OF STURGEON RIVER AFTER ADDITION OF P^{32}

Sample Number	Station Collected	Date Collected	ACTIVITY IN CORRECTED C.P.M.			
			Head and Gills	Viscera	Flesh	Ribs and Vertebrae
1	8	8-21-58	217.0	128.7	96.7	315.0
2	3	"	1954.9	4642.8	608.1	2983.2
3	2	"	1599.1	1287.6	574.4	3312.5
4	3	8-25-58	3869.3	4672.7	1530.1	7153.6
5	5	"	2528.1	1821.4	931.8	5049.2
6	15	"	358.5	437.5	108.9	350.2
7	8	9-2-58	1152.1	619.8	504.5	2817.1
8	8	"	1544.2	1086.0	497.9	4228.9
9	8	"	742.0	528.0	456.8	1966.2
10	8	"	144.0	137.4	109.3	402.6
11	8	"	465.9	437.9	121.6	1051.4

of fish on August 25, the total activity in the fish was estimated at 0.4 millicuries. Assuming that 70 per cent of the isotope was taken up between the isotope entry and Station 8 (from Figure 4) the percentage of isotope which had been taken up by all fish in the stream can be estimated at 2.5 per cent (.57 millicuries). Applying this to phosphorus fertilization of streams, one could say that 2.5 per cent of the phosphorus added would find its way into the fish about three weeks after fertilization.

SUMMARY

Twenty-three (23) millicuries of radioactive phosphorus were added to the West Branch of the Sturgeon River near Wolverine, Michigan, on August 5, 1958. The movement of the P^{32} through the stream's ecosystem was traced by radioactive counting of samples of water, aquatic plants, and fish.

The P^{32} was siphoned into the stream at a constant rate of 1.116×10^{-5} microcuries per milliliter of stream water over a period of 37.5 minutes. The stream was sampled at 7 different stations as it carried the isotope downstream. The results showed that only 3 per cent of the P^{32} passed directly through the 3000 yard experimental area and that only 30 per cent remained after 1000 yards.

Differences were observed in the manner in which the P^{32} passed through the aquatic plants _Chara_ _sp_., _Potamogeton_ _sp_., and _Fontinalis_ _sp_. _Chara_ and _Potamogeton_ lost activity rapidly after August 8, and reached a low "base level" of of activity in about 2 weeks. During this period a large amount of "feedback" P^{32} entered the stream. The highest activity in these plants was not observed immediately below

the isotope entry but at Station number 3, 250 yards downstream. This was attributed to the "feeding back" of P^{32} into the stream followed by uptake farther downstream. Through a cycle of uptake, "feedback", and uptake the P^{32} moved gradually downstream through the system.

The levels of activity reached in the brown trout and muddlers were very similar. Both species increased slowly in activity until August 21, and rapidly between August 21 and August 25. The activity in brown trout dropped by August 28, while muddlers continued to increase in activity but at a reduced rate. It was postulated that these fluctuations were caused by variability in feeding, changes in activity of invertebrates, and loss of P^{32} from the digestive tract.

Brown trout were found to reach a higher activity farther downstream than did the muddlers. From this it was postulated that the brown trout fed more on drifting organisms than did muddlers.

Of the various parts of the brown trout, ribs and vertebrae showed the highest activity, followed by viscera and head and gills. The lowest concentration of P^{32} was found in the flesh. The non-edible parts of the fish concentrated from 2 to 5 times more P^{32} than the edible portion.

A population estimate of all fish species was made for a 1000 yard section of stream immediately below the isotope entry. The results showed that the West Branch of the Sturgeon, though very unproductive, compared favorably in standing crop with Michigan's good eutrophic lakes (170 pounds per acre).

By using the population estimate data and the activity levels in the fish, an estimate of the total amount of P^{32} which had been taken up by the fish was made. It was calculated that 2.5 per cent (.57 millicuries) of the P^{32} was in the fish on August 25, three weeks after its introduction.

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