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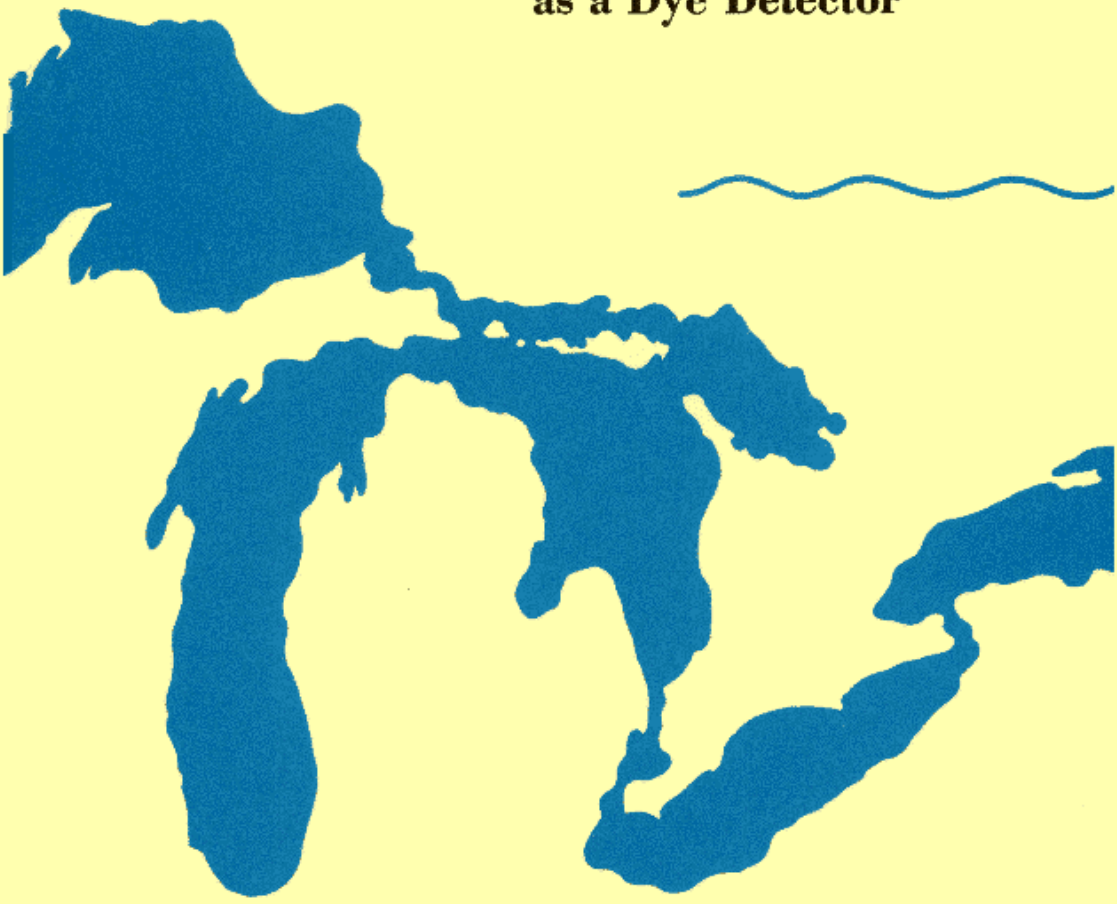

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by

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A PHOTOELECTRIC AMPLIFIER AS A DYE DETECTOR

by

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UNIVERSITY OF MICHIGAN
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ABSTRACT

Marking experiments on three streams in the Upper Peninsula of Michigan yielded quantitative estimates of populations of larval and transforming lampreys. The estimates not only gave an idea as to the numbers of ammocetes in the streams, but also confirmed the judgments of abundance based on earlier surveys with electric-shocking equipment and provided valuable information on the movement of larvae during chemical treatment. The estimated numbers of ammocetes in the three streams were 4,300 in Furnace Creek, 30,600 in Snyder Creek, and 336,700 in the Ogontz River.

Introduction

The Bureau of Commercial Fisheries and the Fisheries Research Board of Canada, under contract with the Great Lakes Fishery Commission, have been using specific lamprey larvicides to control sea lampreys *(Petromyzon marinus)* in streams tributary to the Great Lakes since 1958 (Applegate, Howell, Moffett, Johnson, and Smith, 1961). In the course of stream treatments with these larvicides, it has been visually apparent that large numbers of lamprey larvae of various species were destroyed. Collections taken by fyke nets and dip nets during and after treatment revealed the larval composition by species. These samples provided no estimates, however, of the total number of lamprey larvae destroyed. Since most treatments are almost completely effective the number destroyed would approximate the original population.

The first attempt to estimate the size of the ammocete population in a stream tributary to the Great Lakes was made by Hansen and Hayne (1962) in the Ogontz River. Collections on which they based their estimate were made in the shallower areas by the introduction of larvicide into a circular enclosure 2.5 feet in diameter and in deeper water by orange-peel dredge. The study area was divided into 100-yard sections in which sampling stations were randomly placed. The estimate of larval population was the product of the mean number of ammocetes collected per square

foot and the total area. The estimate of the ammocete stock in the same stream, made one year later in the present study, makes possible a useful comparison of results obtained by two different procedures.

The present study, based on recoveries of ammocetes marked by subcutaneous injection of insoluble dyes, was carried out in 1960 to obtain quantitative estimates of population from the ratio of marked to unmarked individuals in samples collected during a chemical treatment. Theresulting estimates not only gave an idea as to the actual numbers of ammocetes in the populations, but also provided a valuable check against the dependability of judgments of ammocete abundance based on our surveys. These surveys, conducted by electric-shocking equipment (Braem and Ebel, 1961), have been intended primarily to establish the limits of distribution of sea lamprey ammocetes in streams, but stocks have been classified in such broad terms as extremely abundant, moderately plentiful, or very sparse. These categories, roughly quantitative as they are, may be used to rank streams in the order of need for chemical treatment.

The planning of the experiment included the establishment of distinctive marks, through the use of different colors injected in different locations on the ammocetes' bodies, for each of the several areas into which the streams and tributaries were divided. Subsequent recoveries yielded information on the extent of downstream drift--a point on which we previously lacked accurate information.

All three streams studied are in Michigan's Upper Peninsula: Furnace Creek, Alger County; Snyder Creek, Schoolcraft County; and the Ogontz River, Delta County, (Fig. 1).

Methods

Methods of obtaining andmarking individuals were similar for all three streams. Ammocetes were collected with a back-pack shocker, anesthetized in a 75 p.p.m. solution of M.S. 222 (tricaine methane-sulfonate), identified, marked by injection with insoluble dye, and placed in "live cages" to recover before return to the streams. Ammocetes were collected as widely as possible in all sample areas to assure representative coverage of the stream.

The method of marking has been described by Wigley (1952). Four water-insoluble dyes were used: cadmium sulfide (yellow); brilliant orange S.W. (orange)'; chrome green (green)[1]; and

[1] Obtained as samples from Mr. John F. Les Veaux, Niagara Chemical Company, Middleport, New York.

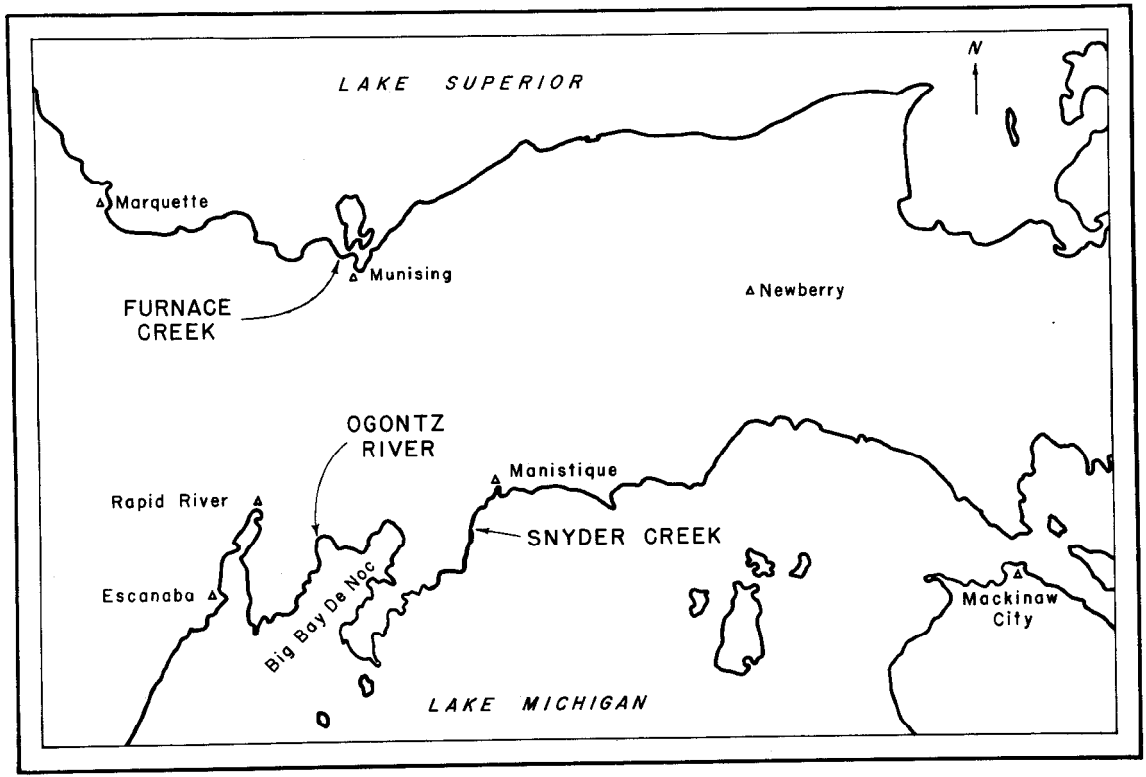

Figure 1. - Map of a portion of the Upper Peninsula of Michigan showing location of the three study streams.

mercuric sulfide (red). The dyes were injected subcutaneously with a 1 C.C. hypodermic syringe and No. 22 needles. A single line, 1/4 to 1/2 inch long, was positioned on one of thefollowing locations (anterior and posterior apply to position in relation to the anus): right anterior; left anterior; right posterior; left posterior; and dorsal in the head area. The combination of four colors and five positions gave 20 identifiable combinations. Actually the greatest number needed in any one stream was eight (Ogontz River). Only ammocetes longer than 1-1/2 inches could be marked.

Larval lampreys recovered rapidly from the anesthetic and marking. Marked animals were held in cages until they had recovered completely and only lively, healthy individuals were returned to the stream. Ammocetes were released in three different ways: in Furnace Creek, they were placed in the upper portion of each area; in Snyder Creek, the marked larvae were artificially redistributed throughout each area; and in the Ogontz River, the marked collections were returned to the location of capture.

An estimate of post-marking mortality was obtained only in the Ogontz River where in late June 150 larvae were marked and placed, with 100 unmarked animals as controls, in a large live box in the lower portion of the main stream. At the conclusion of the experiment 2 months later, 147 of the 150 marked individuals and all of the unmarked ammocetes had survived; mortality then was 2 percent for marked and nil for unmarked ammocetes. The 2-percent figure was used to correct the counts of individuals released in the Ogontz River; no correction was applied to the records for the other two streams. The time between marking and treatment was more than 2 weeks in Furnace Creek and 1-2 days in Snyder Creek.

During the chemical treatment, samples of marked and unmarked ammocetes were collected in riffle fyke nets of 1/Z-inch-mesh (extension measure) netting lined with bobbinet in the cod end. The mouth of each net was 52 by 24 inches. Additional samples were obtained by dip netting. Collections were preserved in a 5-percent solution of formalin.

Populations were estimated from the formula $N = \frac{nT}{t}$, where N equals total population, T the total number of individuals marked originally, n the number (marked and unmarked) in the sample, and t the number of marked individuals in the sample. Schaefer (1951) gave an excellent review of the literature on this method of estimating the size of animal populations. We realized the limitations of the method, as described by Schaefer, but

estimates derived were sufficiently accurate to meet the needs of the present study.

Furnace Creek

Furnace Creek, a small tributary to Lake Superior in Alger County, Michigan, originates at Bay Furnace Lake and flows northward about 1/2 mile (2,500 feet) to Lake Superior (Fig. 1). The width varies from 10 to 30 feet and midstream depth is usually between 1 and 3 feet. Three small tributaries above Bay Furnace Lake are not infected with sea lamprey ammocetes (Stauffer and Hansen, 1958). Good lamprey spawning gravel, well interspersed with larval habitat, was present throughout the infected area.

An electromechanical weir and trap operated near the mouth of the stream since 1953 has greatly limited the opportunity for adults to enter the stream and spawn (Erkkila, Smith, and McLain, 1956). Pre-treatment surveys in the spring of 1960 indicated a very small population of sea lamprey larvae and a moderate population of American brooklamprey *(Lampetra lamottei)* ammocetes.

The infected portion of Furnace Creek was divided into six areas, each approximately 400 feet long (Fig. 2). A different mark was assigned for ammocetes in each area. Collections totaling 461 brook lamprey and 17 sea lamprey larvae were obtained by shocking on April 28 and 29. These specimens were marked and returned to the stream in the uppermost portion of the area of capture (Table 1).

Chemical treatment of Furnace Creek was scheduled for May 2, but severe rains and flood forced postponement until May 14. The stream discharge on this date was 35 c.f.s. Six riffle fyke nets were set, one at the lower extremity of each area (Fig. 2). These nets were removed from the water after all swimming activity of the larvae had ceased, Additional samples of dead larvae were collected with dip nets from each section of the stream and from Lake Superior beyond the mouth of the creek.

Collections by both methods totaled 1,458 specimens--493 from the fyke nets and 965 by dip netting. This sample contained 1,400 brook lamprey larvae and 58 sea lamprey ammocetes. The catch included 165 of the 478 marked individuals released.

Records on the locations of recapture disclosed considerable post-marking movement. Individuals from each area were recovered from lower areas, and 6 larval brook lampreys-were found in areas upstream from the point of release. Ammocetes are not active swimmers and hence could be expected to appear downstream after the floods and from the drift of dying individuals

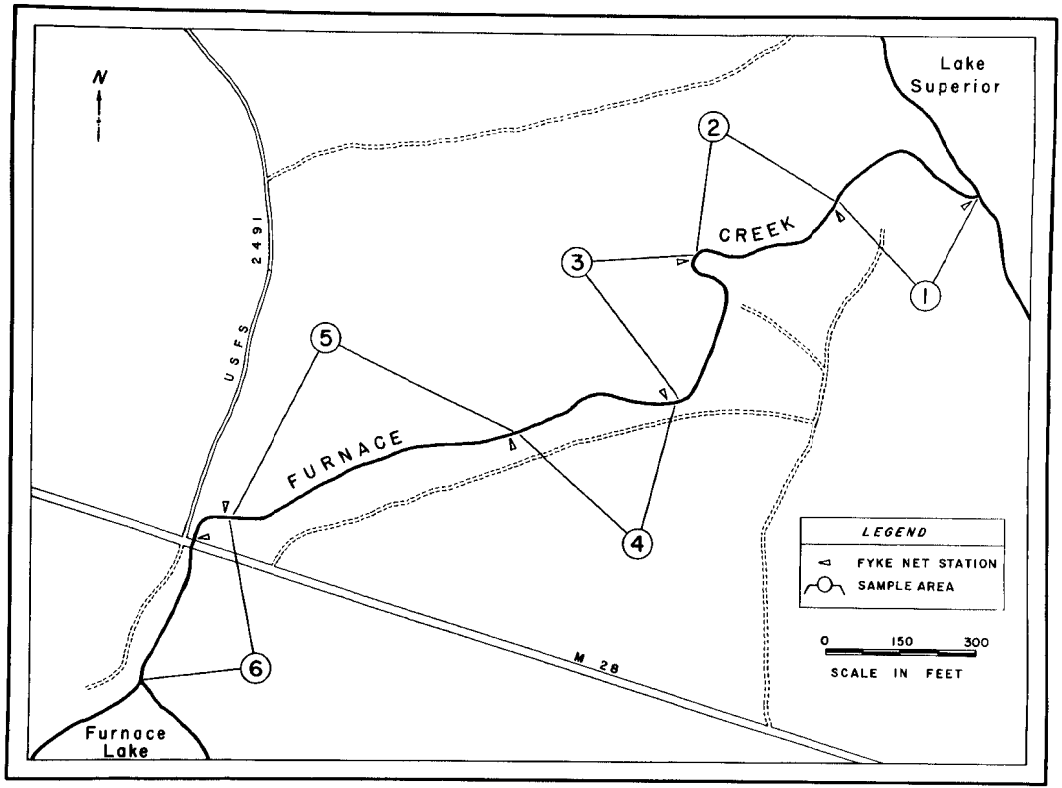

Figure 2.--Map of Furnace Creek showing study areas and fyke net stations.

Table 1. - Numbers of marked ammocetes released and recaptured in Furnace Creek

[‘See Figure 2 for location of the different areas.

Area of release	Number released	Number and area of recapture							Total recaptured	Percentage recaptured	Total in post-treatment collections
		1	2	3	4	5	6	Lake			
Brook lamprey											
1	91	26	2	0	0	0	0	0	28	30.8	190
2	23	1	4	2	0	0	1	0	8	34.8	78
3	7	0	0	2	0	0	2	0	4	57.0	66
4	107	0	0	1	17	5	20	1	44	41.1	86
5	58	0	0	0	4	5	17	1	27	46.6	103
6	175	0	0	0	0	0	46	5	51	29.1	768
Lake	0	...	...	...	...	...	...	...	...	...	109
Totals	461	27	6	5	21	10	86	7	162	35.1	1,400
Sea lamprey											
1	0	...	...	...	...	...	...	...	...	...	0
2	2	0	1	0	0	0	0	0	1	50.0	5
3	0	...	...	...	...	...	...	...	...	...	2
4	9	0	0	0	0	0	1	0	1	11.1	1
5	3	0	0	0	0	0	1	0	1	33.3	13
6	3	0	0	0	0	0	0	0	0	0.0	31
Lake	0	...	...	...	...	...	...	...	...	...	6
Totals	17	0	1	0	0	0	2	0	3	17.6	58

during treatment. The recovery of ammocetes upstream from point of release was not anticipated. Probably the upstream currents at the edges of the large pools formed during flood permitted some to move into the next upstream area.

The 165 marked individuals recovered included 162 brook lamprey ammocetes (35.1 percent of the number released) and 3 sea lamprey ammocetes (17.6 percent). The considerable amount of movement of the marked animals made it impractical to estimate original populations by area. The estimates are based, therefore, on combined data for the six areas. Recoveries of two species of marked ammocetes made it possible to compare population estimates of each from its own data with those obtained from pooling of both areas and species (Table 2).

Table 2. - Comparison of estimates of ammocete populations in Furnace Creek by individual groups and by pooling groups

Species	Basis of estimates		Difference of estimate	
	Data for individual groups	Pooled data for all groups[1]	Number	Percentage
Brook lamprey	3,984	4,055	71	1.8
Sea lamprey	329	169	-160	-48.6
Totals	4,313	4,224	-89	-2.1

[1] Numbers in the individual categories determined by application of percentage composition of the pooled post-treatment sample of 1,458 individuals to the estimate of 4,224 based on the pooled data.

The estimates for the lamprey groups were 3,984 brook lamprey ammocetes and 329 sea lamprey larvae. The sum of the individual estimates (4,313) was only 89 more than the estimate of 4,224 from the pooled data. Comparison of the preceding estimates for individual species, with those obtained from application of the percentage composition of the post-treatment samples of 1,458 individuals to the estimate of 4,224 from the pooled data, show a similar figure for brook lamprey larvae (a difference of ‘71 individuals) and a 49-percent discrepancy for sea lamprey larvae.

Both estimates for sea lampreys, 329 and 169, were very low and confirmed the judgments of a small population, based on the pre-treatment surveys with electric shockers.

The sample collected in Lake Superior near the mouth of the creek contained seven (4 percent) of the marked individuals recovered. Application of this percentage to estimates of total population indicated that approximately 170 individuals of both species drifted out of the stream during treatment. The relatively small number of these individuals was reassuring, in that the possibility of significant movement out of the stream into uncontaminated waters and eventual survival had caused concern as to the full effectiveness of treatment, Whether any ammocetes that drifted from Furnace Creek into Lake Superior actually survived is not known.

Snyder Creek

Snyder Creek is a small stream originating in swamps on the Garden Peninsula and flowing into Lake Michigan southwest of Manistique, Michigan (Fig. 1). The width of the stream is 2 to 15 feet and mid-stream depth is 6 inches to 2 feet. A tributary, Deadhorse Creek, which enters the main stream approximately a mile above the mouth, has a flow slightly less than the main branch. Snyder Creek runs through two beaver flowages that contain excellent habitat for sea lampreys.

Distribution surveys prior to the experiment indicated that approximately 2.5 stream miles were inhabited by a very small population of sea lamprey larvae and a large population of American brook lamprey ammocetes. The heaviest concentration of ammocetes was in the lower third of the system. Snyder Creek was divided into three areas: Deadhorse Creek from County Road 435 to the junctionwith Snyder Creek; Snyder Creek from County Road 435 to the junction with Deadhorse Creek; and the main stream from the junction to the mouth (Fig. 3).

Electric shocking on May 20 and 21, yielded 383 lamprey ammocetes from the three areas. These larvae were identified, marked immediately, allowed to recover, and returned to the stream the next day. The marked individuals were redistributed evenly throughout each area.

The stream was treated on May 22, at a dischargeof 21 c.f.s., about double normal low flow. Six fyke net sites, two for each area, were established for recovery of a sample (Fig. 3). In addition, ammocetes were recovered from the entire treated area of the stream with dip nets.

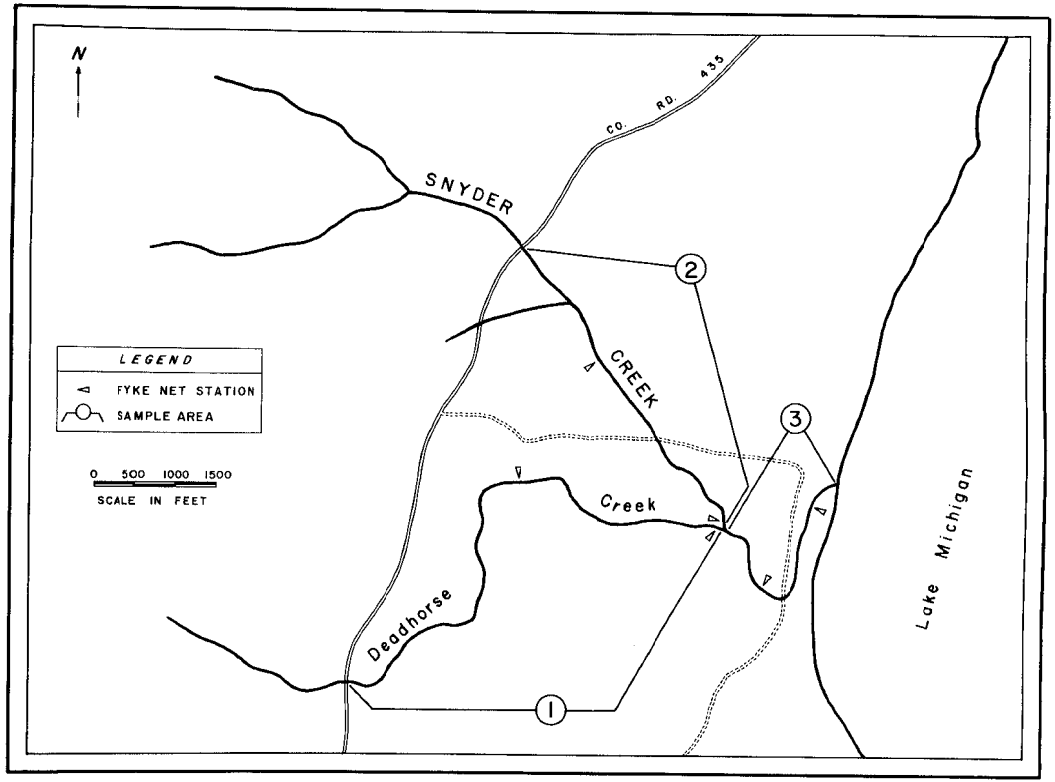

Figure 3.--Map of Snyder Creek showing study areas and fyke net locations.

Collections by both methods totaled 1,605 specimens--435 from the fyke nets and 1,170 by dip netting. The sample contained 1,591 brook lamprey ammocetes and 14 sea lamprey ammocetes. The catch included 20 (5.3 percent) of the 383 marked individuals released.

All marked animals recovered were brook lamprey ammocetes and were recaptured in the areas of release (Table 3). The low rate of flow, physical characteristics of the stream (many slow pools), and the short time between release and collection precluded redistribution of the population.

The recovery of only one kind of marked individual made it impossible to make estimates separately for individual species. Therefore, determinations of numbers in individual categories are based on percentage composition of the post-treatment sample of 1,605 specimens. The lack of movement within the stream did permit estimates by area. Comparison of these estimates with those from pooled data for all areas show a surprisingly close similarity (Table 4). The estimates by individual areas (30,586) and from the pooled data (30,736) differed by only 150 animals (0.5 percent). The number of sea lampreys by area was 269 compared to 277 from pooled data (a difference of 3.0 percent).

Estimates by both methods confirm the judgment, based on the pre-treatment surveys with electric shockers, of a very small population of sea lampreys and a large number of brook lampreys.

The post-treatment collections includedno lampreys from the mouth of the creek. The lower part of the stream runs parallel to the shore of Lake Michigan for several hundred feet. The slow rate of flow in this stretch prevented dying individuals from reaching the lake.

Ogontz River

The Ogontz River is a small spring-fed tributary to northern Lake Michigan in Delta County, Michigan (Fig. 1). Stream flow at the mouth is 10 to 50 c.f.s. The river has four large and two small tributaries in a watershed of about 30 square miles. Pre-treatment surveys indicated that approximately 9 miles of the river and its tributaries were infected by a large population of sea lamprey and American brook lamprey ammocetes. An electromechanical weir and trap for adult sea lampreys had been operated near the mouth of the stream in 1958 and 1959. Approximately 500 individuals were captured each year.

Distinctive marks were assigned for ammocetes in eight areas of the stream--three on the main stem and one each on

Table 3.--Numbers of marked ammocetes released and recaptured in Snyder Creek

[See Figure 3 for location of the different areas.]

Area of release	Number released	Number and area of recapture			Total recaptured	Percentage recaptured	Total in post-treatment collections
		1	2	3			
Brook lamprey							
1	111	5	0	0	5	4.5	430
2	104	0	6	0	6	5.8	189
3	162	0	0	9	9	5.6	972
Totals	377	5	6	9	20	5.3	1,591
Sea lamprey							
1	0	...	...	...	...	...	4
2	2	0	0	0	0	0.0	2
3	4	0	0	0	0	0.0	8
Totals	6	0	0	0	0	0.0	14

Table 4. - Comparison of estimates of ammocete populations in Snyder Creek by individual areas and by pooling areas

Stream area	Estimated stock of ammocetes		
	Total	Brook lamprey[1]	Sea lamprey[1]
1	9,635	9,546	89
2	3,311	3,276	35
3	17,640	17,495	145
Total			
Sum for areas	30,586	30,317	269
Pooled data for areas	30,736	30,459	277
Difference			
Number	+150	+142	+8
Percentage	+0.5	+0.5	+3.0

1 Numbers estimated from species composition of post-treatment sample.

Johnson Creek, East Branch, West Branch, North Branch, and Tributary No. 1 (Fig. 4). These areas were selected to conform partially with the divisions of Hansen and Hayne (1962) and partially with the physical characteristics of the river.

Electrical shocking in the various areas, June 7 to July 1, 1960, produced 4,579 ammocetes--3,212 American brook lampreys and 1,367 sea lampreys. The collection stations were distributed to give coverage in each of the various areas. The ammocetes were anesthetized, identified to species, marked, and returned as near as possible to the location of capture (Table 5).

The Ogontz River was treated chemically on August 31-September 1 at which time stream flow was 28 c.f.s., slightly above low-water stage. The first of seven feeders was started at 4:30 a.m. on August 31, and the chemical reached the mouth of the river 36 hours later. Visual observations during treatment and the post-treatment surveys indicated practically complete extermination of both species of lamprey.

Ammocetes were collected during treatment at 24 stations with riffle fyke nets (Fig. 4) and at 12 locations with dip nets. These collections totaled 12,154 individuals--5,605 sea lampreys and 6,549 brook lampreys (Table 5). The fyke *nets* accounted for 9,620 specimens and 2,534 were collected by dip netting. The sea lamprey collection contained 576 individuals in the process of

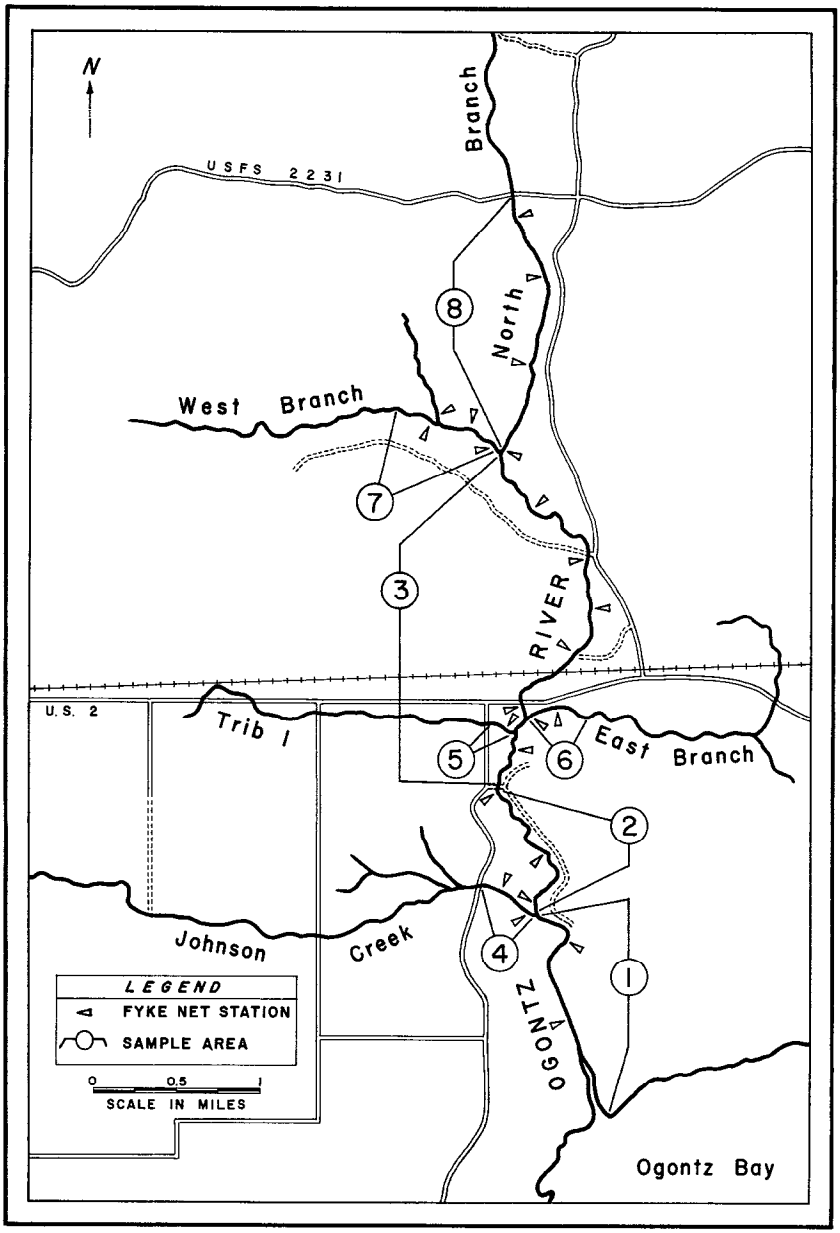

Figure 4. - Map of Ogontz River showing study areas and fyke net locations.

Table 5. - Numbers of marked ammocetes released and recaptured in the Ogontz River

[See Figure 4 for location of the different areas.]

Area of release	Number released[1]	Number and area of recapture								Total recaptured	Percentage recaptured	Total in post-treatment collections
		1	2	3	4	5	6	7	8			
Brook lamprey												
1	852	1a	0	0	0	0	0	0	0	18	2.1	867
2	57	0	1	0	0	0	0	0	0	1	1.8	333
3	1,415	0	0	47	0	1	0	0	0	48	3.4	3,526
4	38	0	0	0	4	0	0	0	0	4	10.5	330
5	25	0	0	0	0	3	0	0	0	3	12.0	74
6	7	0	0	0	0	0	1	0	0	1	14.3	95
7	274	0	0	0	0	0	0	13	0	13	4.7	432
a	478	0	0	0	0	0	0	0	36	36	7.5	892
Totals	3,146	1a	1	47	4	4	1	13	36	124	3.9	6,549
Sea lamprey												
1	418	3	0	0	0	0	0	0	0	3	0.7	1,346
2	41	1	0	0	0	0	0	0	0	1	2.4	249
3	614	0	1	25	0	0	2	0	0	28	4.6	3,119
4	6	0	0	0	2	0	0	0	0	2	33.3	21
5	41	0	0	0	0	4	0	0	0	4	9.8	88
6	6	0	0	0	0	0	0	0	0	0	0.0	154
7	148	0	0	0	0	0	0	4	0	4	2.7	471
a	65	0	0	0	0	0	0	0	2	2	3.1	157
Totals	1,339	4	1	2 5		2	4	2	4	2	44	3.3	5,605

1 The original release number was adjusted on the assumption of 2-percent mortality of marked ammocetes. See section on Methods.

transformation; the brook lamprey sample had 726 transforming specimens. Ammocetes collected in June had given no indication of transformation.

Post-marking movement in the stream was slight, although from 2 to almost 3 months elapsed between the release of marked individuals and chemical treatment. Only five ammocetes were recovered outside the area of marking. Two of them--one from Area 2 recovered in Area 1, and one from Area 3 recovered in Area 2 - had moved downstream just below the lower limits of the release areas. The other three individuals were recovered in the mouths of the tributaries where they possibly had moved to avoid the chemical.

The limited numbers of marked animals recaptured in some areas and movement (although not extensive) between areas, made it undesirable to estimate original populations by area. Therefore, the estimates are based on the combined data for the eight areas. Recoveries of both species of marked lampreys made it possible to estimate populations of each from its own data and compare totals with figures obtained from the pooled data for the species (Table 6).

The population estimates for the species individually were 170,570 sea lampreys and 166,154 brook lampreys--a total of 336,724 (Table 6). This sum of the individual estimates was 12,256 more than the estimate of 324,468 from the pooled data. Estimates for individual species, from application of the percentage composition of the post-treatment sample of 12,154 individuals to the figure 324,468 gave values of 174,888 for brook lamprey larvae and 149,580 for sea lampreys. These estimates are, respectively, 5.3 percent above and 12.3 percent below those obtained from data for the individual species. Both methods of estimation confirm the judgment of large populations of the two species, based on the pre-treatment surveys with electric shockers.

The estimates of Hansen and Hayne (1962) of ammocete populations in the Ogontz River were: sea lamprey, 136,800; brook lamprey, 138,700; both species 275,500. These values were respectively 19.8, 16.5, and 18.2 percent below our figures of 170,600 sea lampreys, 166,200 brook lampreys, and 336,700 for the species combined. The disagreements were substantial, but in view of the fact that the estimates were made a year apart and the procedures were altogether different, they cannot be termed excessive.

In contrast to Furnace Creek, the Ogontz River is slow-moving and deep near its mouth. Observations during treatment revealed no movement from the river into the bay. Actually, collection of the post-treatment sample in the lower portion of this area

Table 6. - Comparison of estimates of ammocete populations in Ogontz River by individual groups and by pooling groups

Species	Basis of estimates		Difference of estimate	
	Data for individual groups	Pooled data for all groups [1]	Number	Percentage
Brook lamprey	166,154	174,888	8,734	5.3
Sea lamprey	170,570	149,580	-20,990	-12.3
Totals	336,724	324,468	-12,256	-3.7

1 Numbers in the individual categories determined by application of percentage composition of the pooled post-treatment sample of 12,154 individuals to the estimate of 324,468 based on the pooled data.

was difficult because of limited numbers of ammocetes. Larvae near the mouth of a stream of this type are not likely to escape into the open lake and thus avoid the action of the chemical.

Acknowledgments

We wish to acknowledge the assistance of all staff members who participated in the work on these streams. James W. Moffett, Director, and Leo F. Erkkila, Assistant Director for Sea Lamprey Control, Bureau of Commercial Fisheries Biological Laboratory, Ann Arbor, Michigan, provided guidance and help. Martin J. Hansen, Institute for Fisheries Research, Michigan Department of Conservation, Marquette, Michigan, supplied information on his original population study of ammocetes in the Ogontz River. Ralph Hile advised in the preparation of the manuscript.

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A PHOTOELECTRIC AMPLIFIER AS A DYE DETECTOR

Wesley J. Ebel

ABSTRACT

A dye detector, based on a modified photoelectric amplifier, has been planned, built, and tested. It was designed to record automatically the time of arrival of fluorescein dye at predetermined points in a stream system. Laboratory tests and stream trials proved the instrument to be efficient. Small changes in color can be detected in turbid or clear water. The unit has been used successfully for timing intervals of more than 17 hours; significant savings of time and manpower have resulted.

Replacement of the clock, included in the original device, with a recording milliammeter increases the efficiency of the unit by continuously recording changes in turbidity. The addition of this component would increase the cost from $75 to approximately $105.

Introduction

Development of new equipment and techniques has contributed greatly to the progress of the sea lamprey *(Petromyzon marinus)* control program of the Great Lakes Laboratory, Bureau of Commercial Fisheries.[1] An important problem in the use of chemicals in lamprey control has been the development of an efficient method of timing water movement. The start of chemical metering must be on a time schedule that allows treated water masses to reach the confluence of tributaries simultaneously. The most effective means of determining the correct time is to introduce fluorescein dye at the application points and record time of arrival at predetermined locations (Applegate, Howell, Moffett, Johnson, and Smith, 1961). This process usually required a large amount of staff time and the extensive use of vehicles. A photoelectric *am*plifier, modified for use as a dye detector, has been developed to increase the efficiency of this operation.

An instrument for timing water movement had to fulfill the following requirements: simple and durable design to limit mechanical failure; portability, for movement to difficult access

1 This study is part of a program conducted by the Bureau of Commercial Fisheries under contract with the Great Lakes Fishery Commission.

locations; automatic recording of the arrival time of dyes; sensitivity to small amounts of dye in streams of various colors (turbidities); and, low cost.

Chemical and electrical methods of detection were considered. No suitable chemical system of detection was found since fluorescein is a relatively inert compound that does not enter into chemical reactions easily (Gould, 1955). On the other hand, electrical circuits that can be used to detect variations in water color are readily available. Several of these circuits were investigated and their adaptability studied. All of this equipment contained various light-sensitive elements and had varying degrees of sensitivity to different portions of the light spectrum.

Requirements were best met by modifying a circuit containing a 1P39 phototube (Whitmer, 1960). This phototube has a maximum response between 3,000 and 7,000 angstroms (Bukstein, 1961). Since plate current is linearly related to illumination, it allows the tube to have adequate sensitivity to varying degrees of light intensity and hence to light altered by water color.

Description and Circuitry

The dye detector designed for the sea lamprey program consists of three basic components--a photoelectric amplifier, a waterproof sensing unit, and a power supply (Fig. 1). The power supply is a 12-volt, 72-ampere-hour battery equipped with a 265-volt converter. A 12-volt D.C. electric clock is included in the circuit to permit the recording of time. The complete unit weighs about 20 pounds and can be carried by one man. Cost of all parts and materials is approximately $75.

The amplifier, converter, and clock are all contained in a case constructed of marine plywood. The sensing unit, including a light source to minimize the effects of sunlight and darkness, is contained in a galvanized sheet-metal housing (Fig. 2). This housing is painted black to minimize light reflections. The light in the sensing unit is directed at the phototube at a distance (6 inches) which allows water to circulate freely. The openings to the water space are screened with hardware cloth to prevent activation of the mechanism by floating or suspended objects, One-pint, wide-mouth jars, neoprene tubing and tubing fittings provide waterproof containers for the phototubes, light source and wires. The fragile components are padded with sponge rubber.

The description of the circuit can be followed most easily through reference to the schematic diagram of the detector in Figure 3. The 265-volt A.C. source is coupled to the amplifier

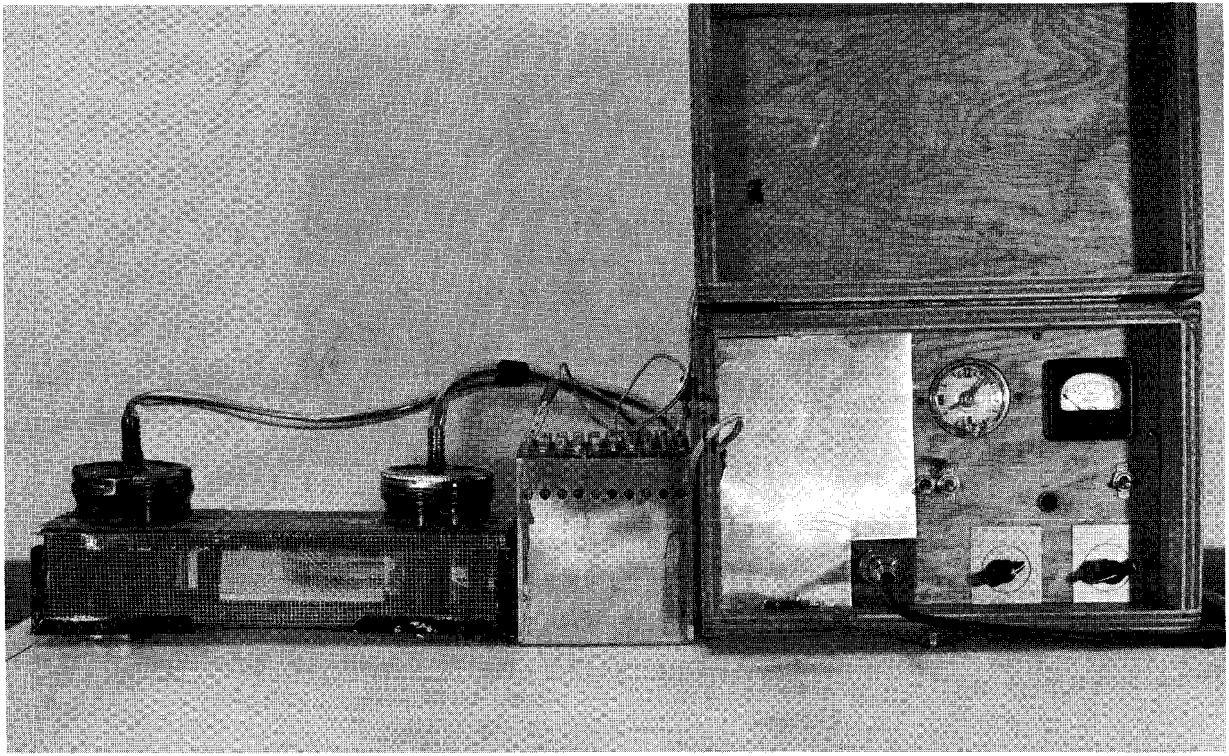

Figure 1.--Dye detector showing sensing unit, photoelectric amplifier, and power supply.

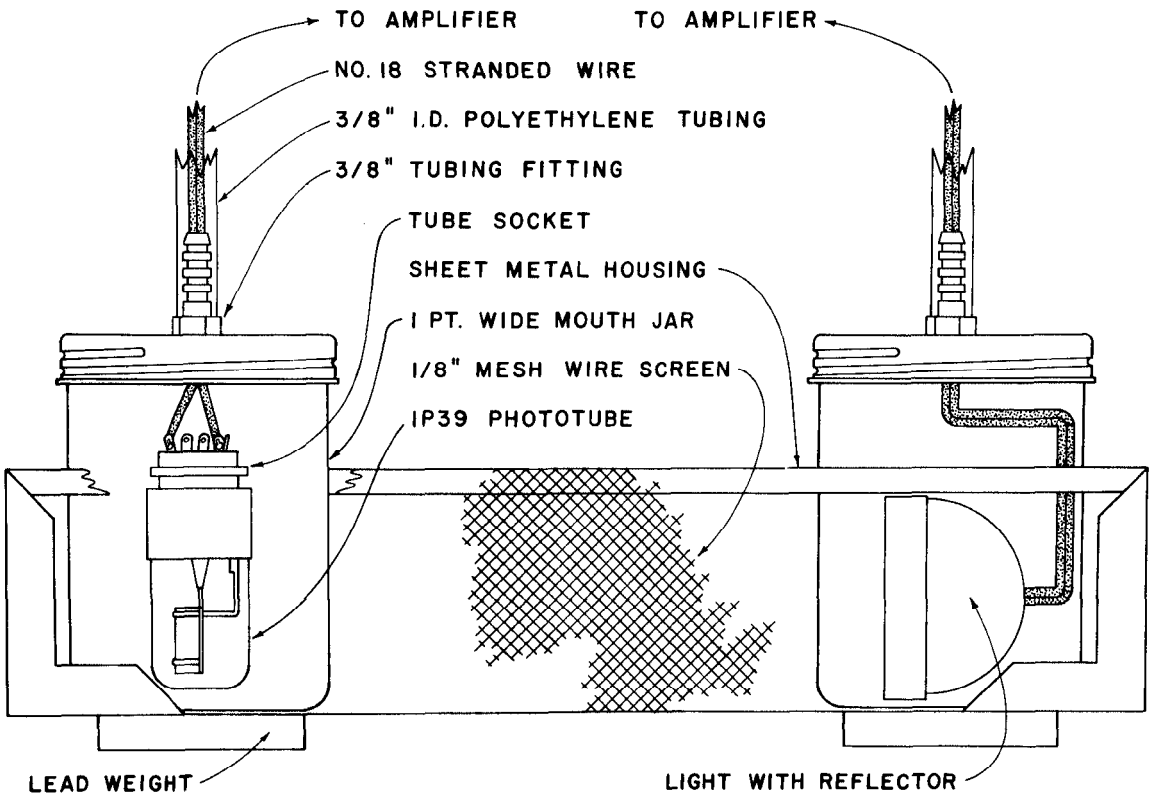

Figure 2.--Diagram showing sensing unit with light source and phototube.

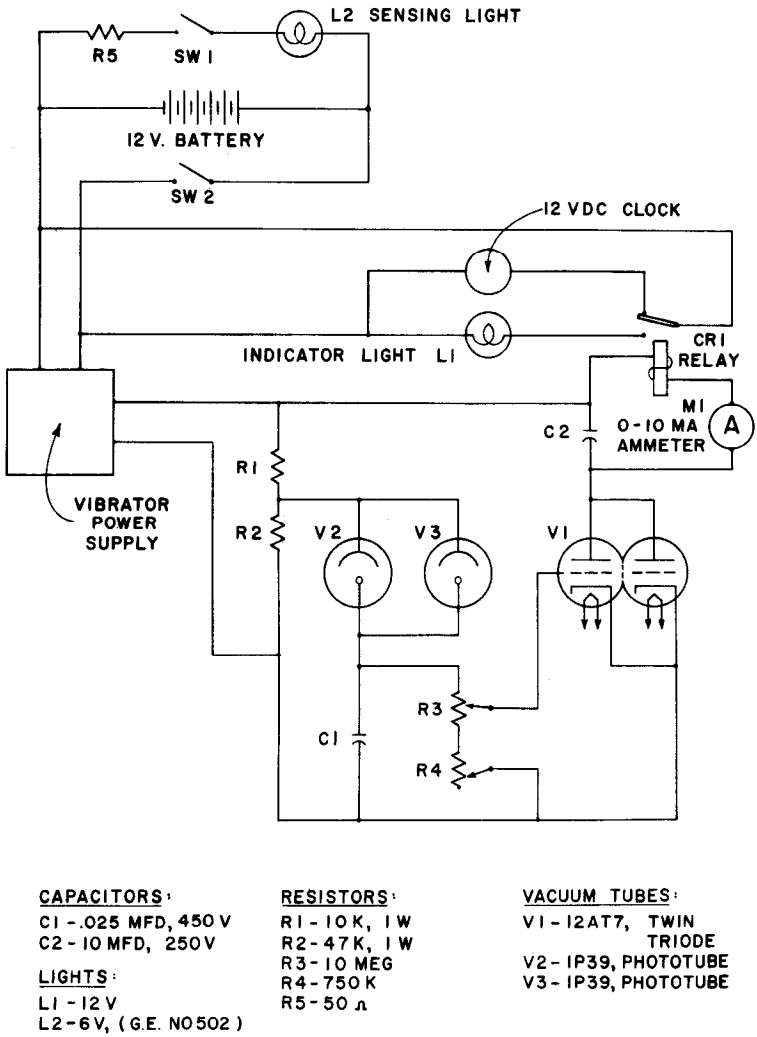

Figure 3. - Schematic diagram of dye detector.

circuit from the vibrator power supply. Cathode voltage at pin 8 of V2 and V3 is obtained from a voltage divider consisting of R1 and R2. When A. C. power is applied, the photoelectric tubes conduct during the half cycle when pin 5 is positive with respect to pin 8 - provided the light source is energizing the photocathode. Capacitor Cl and resistor R3 and R4 provide both coupling and time delay. Conduction of V2 and V3 causes Cl to charge. On the

next half cycle, Cl attempts to discharge through R3 and R4. Because the slider arm of R3 is connected to the grid of V1, this tube is biased in accordance with the charge on Cl and the setting of R3 and R4. The polarity of supply voltage applied between plate and cathode of V1 is 180° out of phase with the voltage across V2 and V3, so their conduction periods will occur during opposite half cycles. As long as light energizes the photocathode, the discharge current of Cl through R3 and R4 will be sufficient to keep V1 cut off. When light does not fall on the photocathode, Cl will complete its discharge cycle to the point where V1 can conduct. At this time, current through V1 energizes relay CR1, opening the normally closed contacts and closing the normally open contacts (relay de-energized is considered normal). The current through V1 also charges C2 during this half-cycle conduction period. During the next half cycle when the supply voltage across V1 is such that the tube cannot conduct, C2 discharges through contact relay CR and keeps it energized. The contacts of relay CR1 form a single-pole, double-throw switch. When relay CR1 is closed or activated, indicator light L1 operates and the clock stops, thereby recording the arrival time of the dye.

The sensing light L2 is connected through switch SW1 and resistor R5. R5 reduces current and voltage to the desired level for maximum life of the sensing light. R3, R4, and meter Ml are used to adjust to water color and to control sensitivity. Meter Ml measures current through CR1. Since CR1 activates at 4.6 milliamps and de-energizes at approximately 3.0 milliamps, R3 and R4 can be used to keep amplifier tube V1 operating between 3.0 and 4.6 milliamps output regardless of water turbidity. R3, 10 megohms, provides coarse adjustment and R4, 750K, may be used as fine adjustment. Two phototubes in parallel are used to increase reliability and the 12AT7 is wired in parallel to increase current output.

Because the value selected for Cl is greater than is needed for half-cycle coupling, the time delay will be such that the light to the photocathode must be interrupted for more than one-half cycle before V1 can conduct. This arrangement prevents a momentary cloud of silt from activating the relay. The value which gave satisfactory time delay was 0.025 MFD. A larger value for Cl may be used if more time delay is desired. The closer V1 is adjusted to 4.6 milliamps, the greater the sensitivity of the unit. The greater the sensitivity, the shorter the time delay.

The efficiency and value of the detector can be increased by installing a recording milliammeter to measure continually the flow of current through V1. This record has the advantage of

providing a means of detecting any natural change in water turbidity and provides, not only the arrival time of the dye, but a measure of its duration. It also eliminates the possibility of error from a silt cloud which may last long enough to cause relay CR1 to operate and stop the clock.

Testing and Operation

The detector was tested in the laboratory to determine: correct spacing between light sources and phototubes; optimum milliamp setting; and relative efficiency of one or two phototubes. These points were tested at various turbidity readings from 0 to 400 on a Klett Summerson colorimeter scale and with fluorescein dye concentrations from 0.1 to 3.5 p.p.m. The range of turbidity corresponded with the minimum and maximum values encountered in streams treated in previous years. Water samples of seven different turbidities and with colorimeter readings from 0 to 400 were prepared with tap water.

Two sensing units were constructed, one with a single phototube and one with two phototubes. Both units contained a GE502 bulb with flashlight reflector for the light source. The phototubes and light were tested at several spacings until an optimum distance of 6 inches was determined. A spacing of less than 6 inches gave slightly better results at higher turbidities, but poor results at lower readings. This relation was reversed at a spacing of over 6 inches.

The sensitivity of the units was tested by placing each in the samples of various turbidities and adjusting to five different predetermined milliamp readings on the meter scale. Settings of 3.0, 3.4, 3.8, 4.0, and 4.2 were selected because relay CR1 closes at 4.6 milliamps and reopens at 3.0. (The closing point did not change significantly from 4.6 milliamps in tests at ambient temperatures from 20° to 80° F.) The minimum concentration of dye that would cause operation of the relay was recorded for each of the five settings. The optimum setting derived was 4.0 milliamps. At this setting, 0.4 p.p.m. of dye activated the relay throughout the range of turbidity; the time delay was kept sufficiently large to prevent possible voltage surges from accidentally activating the relay. Comparisons of the two sensing units for relative efficiency throughout the tests disclosed no significant difference.

The dye detector was used successfully during preparations for several treatments of streams with larvicide. These field tests did result in a few failures which can be avoided by heeding the following precautions for efficient operation: the battery

should be fully charged and the milliamp setting should be adjusted after 12 hours of operation; the sensing unit must be waterproof; enough dye should be used to give a concentration at the timing point high enough to activate the unit (a minimum of 0.4 p.p.m.); sensitivity must be checked and necessary adjustments made after 5 minutes of operation (capacitors in circuit must be allowed to stabilize); and the sensing unit should be so placed that neither direct nor reflected sunlight strikes the phototube.

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