POPULATIONS, ECOLOGY, AND
MANAGEMENT OF MARGINAL
TROUT STREAMS IN SOUTHERN MICHIGAN

By

VIRGIL S. PRATT

DOCTORATE THESIS
UNIVERSITY OF MICHIGAN
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Institute for Fisheries Research

Report No. 1383

Doctor Cooper

I appreciate your help very much. The material in Dr. Pratt's Thesis was very helpful. Sincere thanks,

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Pratt's thesis
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Longer version of abstract than copy issued with Report 1383. Graduate School wanted a shorter version and this was revised.

ABSTRACT

POPULATIONS, ECOLOGY, AND MANAGEMENT OF MARGINAL TROUT STREAMS IN SOUTHERN MICHIGAN

by Virgil S. Pratt

The trout-stocking programs for four southern Michigan streams and the influences of certain environmental features on the capacity of these waters to support and produce trout are evaluated. The importance of these southern trout streams in the total recreational facilities of the State lies in their proximity to highly concentrated centers of population.

Equipment and methods of censusing stream fishes are developed and evaluated. Electrical shocking was found to be of greatest utility. Configurations of electrical fields in water produced by two A. C. generators and hand-held electrodes of various shapes and sizes are measured, and lines of equipotential are plotted with apparatus consisting of voltmeter, ammeter, 10 equal resistors in series, radio earphones, and wire probe. D. C. fields cannot be measured with this equipment but are similar under like conditions. Effective fields are plotted by measuring distances from electrodes to points at which test fish become paralyzed. The following characteristics are based on 500-watt, 110-volt A. C. power supply of 60 cycles.

Two wire-wound elliptical electrodes, 12 inches high by 26 inches long, produce a field with comparatively uniform voltage gradient and are effective in paralyzing fish (3.6 inches, average length) at an

average distance of 36 inches from the electrodes. Addition of a third electrode in line with the others increases the size of the effective field but decreases the average paralysis-distance to 32 inches with fish averaging 6.7 inches in length.

Two cylindrical brass-screen electrodes, 5 inches in diameter and 18 inches in height, produce a small horizontal field characterized by an abrupt voltage drop near the electrodes. Fish averaging 5.4 inches in length are paralyzed 35 inches from the electrodes. Wire-wound rectangular electrodes, 8 inches wide and 32 inches high, also create a small horizontal field and a very quick drop in potential with distance from electrodes. Rectangular electrodes of brass screen, 10 inches high by 22 inches long, and wire-wound electrodes, 10 inches high by 18 inches long, under like conditions, produce fields almost identical to that of the 12-inch by 26-inch elliptical electrodes.

The largest effective field is produced by electrodes long in the horizontal dimension yet not so large in area that the power unit is overloaded. A 60-cycle, 110-volt generator of 500-watt capacity is satisfactory for stunning fish with two electrodes in waters of moderate resistivity (1000 to 3500 ohms per cc.), moderate depth (up to 3 feet), and moderate width (up to 20 feet). In deeper waters of low resistivity, or with three electrodes for greater stream coverage, a generator of larger capacity is required.

Because a D. C. shocker attracts fish to the positive electrode, it is favored over the A. C. unit. However, its superiority in collecting fishes is unquestionable only in swift and/or muddy waters. The D. C. shocker used consists of a 230-volt, 2500-watt, direct-current generator and three electrodes. The negative electrode is a 14-inch by

8-foot copper sheet attached to the bottom of the shocker boat. The two hand-held positive electrodes are 9-inch by 12-inch, wire-wound rackets of copper tubing mounted on long wooden handles.

In comparatively still, clear water of Spring Brook, recovery with A. C. was 35.1 percent of the marked fish present, whereas that with D. C. was 41.2 percent. A. C. recovery in a swifter section of Spring Brook was only 28.8 percent, yet 44.8 percent were recaptured with direct current. In Wilder Creek, where extremely muddy water made the use of alternating current impracticable, 16.4 percent of the marked fish were recovered with the D. C. unit. Larger fish are more easily captured than fish of smaller sizes (less than three inches in length) with both shockers in all situations. Repeated experimental electro-narcosis of legal-sized trout with A. C. caused 11.2 percent fish mortality whereas mortality from D. C. was only 2.0 percent.

In blocked-off stream sections, fish are marked by fin-clipping, recaptured, and populations are estimated by the Petersen method. The reliability of estimates increases as the proportion of marked fish recovered to total fish recovered increases.

Quality of pools, extent of shade and cover, mean summer water temperatures, extent of floods and siltation, quantity of bottom food organisms, and other selected ecological factors are related to kinds and abundance of fish. All factors show considerable variation among the streams studied. The variability in numbers and volume of bottom organisms, even in samples taken entirely within one bottom type in each stream, is so great that reliable estimates of food production cannot be made. Analyses of stomach contents of predominant species indicate that trout consume greater numbers and kinds of bottom organisms than do other species.

There is considerable seasonal variation in the size of standing crops, both of trout and of other fish species. Generally, populations are smallest (in numbers of fish per acre) in early spring but increase in size during the summer as a result of recruitment by naturally reproduced young of all species and by hatchery-planted trout. Those waters which support large numbers and weights of non-trout species carry few trout. Average standing fish crops range from 96.2 pounds per acre in Wilder Creek to 302.7 pounds per acre in the North Branch of the Saline River. The average percentage of trout, by number, in these estimates ranges from 3.4 in the North Branch to 72.0 percent in Spring Brook. Size of the trout population appears to be limited in Paint Creek by shifting of bottom materials and scarcity of spawning areas; in the North Branch of the Saline River by floods, siltation and shifting of the bottom and by competition for food and space; in Wilder Creek by fishing pressure and dredge-caused turbidity; and in Spring Brook by fishing pressure.

Survival of legal-sized hatchery-reared trout is low in all waters, yet they do contribute substantially to the early-season catch. Brook and rainbow trouts disappear within four to five weeks following planting. Brown trout survive for longer periods, particularly in Paint Creek and Spring Brook. Over-winter survival rates of advanced fingerlings is also low, although there is variation with streams and with species. The greatest mortality was suffered by brook trout, many of which were of legal size at the opening of the 1950 trout season.

Fishing pressure is heavy on all streams during the first few weeks of the season, but it declines rapidly on Paint Creek and the North Branch. Fishing success, based on random creel checks, is low:

Paint Creek, 0.54; North Branch of the Saline River, 0.11; Wilder Creek, 0.31; and Spring Brook, 0.44 trout per hour.

Observations fail to reveal evidence of rainbow trout spawning in any of the streams. Brook trout spawn to a limited extent in Spring Brook. Brown trout reproduce in all of the streams, although in large numbers only in Spring Brook and Wilder Creek. A small percentage of hatchery-reared brown trout spawn the same year they are stocked in these streams. Partial excavation of five redds indicates an average egg survival of 78.1 percent one month after spawning. Success of natural reproduction, measured by the percentage of wild trout in the total trout population, ranges from 0.0 in the North Branch to 72.1 percent in Spring Brook.

Two general conclusions on the management of trout streams are drawn from the study: (1) The success of the stocking program in certain southern Michigan streams approaches that of more northern waters of the State. (2) Future stocking of these streams just prior to the opening of the fishing season, and again during the season if fishing pressure continues, is justifiable.

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June, 1953

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A dissertation submitted in partial fulfillment
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Committee in charge:
Associate Professor Karl F. Lagler, Chairman
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INTRODUCTION

During the past century, the course of agricultural and industrial progress has wrought drastic changes in the original environmental conditions of southern Michigan. Road nets, agricultural drains, erosion, domestic sewage and toxic industrial wastes have all left their marks on the originally more clear and cool waters of the region.

Although brook trout[1] were probably never endemic to these waters, they have been stocked widely since 1879. It might be inferred that before the lumbering era these southern Michigan streams were suitable for trout; but at an early date, the deleterious effects of the current agricultural and industrial practices were already manifest, for in 1888 it was reported (Michigan State Board of Fish Commissioners, 1888) that "nine-tenths, or over, of the streams which this board has stocked, or is now stocking with brook trout, never were trout streams before they were made such by the State."

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[1] Insofar as possible, fish names are those recommended in Special Publication No. 1 of the American Fisheries Society, 1948. Technical equivalents of common names are given in Appendix I.

The introductions of rainbow trout in 1880 and of browns in 1889 were followed by increasingly heavy plantings of these species up to the present, apparently with only slightly greater success. When it became evident to fishery officials of the State that only a few of the southern streams were actually suitable for trout, the trend in stocking salmonids shifted gradually to the north. In more recent times, however, the economic growth of the State, resulting in highly concentrated centers of population, created a demand for ample recreational facilities near metropolitan areas, where persons with limited leisure time might find sport and healthful diversion without the necessity of driving prohibitive distances. One important need was for trout fishing. Recognizing the desirability for the maintenance of cold-water angling in urban southern Michigan, the Conservation Department expanded its trout stocking program in the southern counties until by the end of the 1948 season, 127 streams south of Highway M-46 were receiving 8.0 percent of the total annual plants of brook, brown, and rainbow trouts made throughout the entire state.

Over a hundred thousand trout are being planted annually in these southern streams with little factual information on the success of such plantings. It has been suspected that at least some of the waters so stocked are incapable of maintaining sizable trout populations, whereas others are considered excellent trout streams. In order to justify its continued stocking of these waters, the Department of

Conservation directed that a study be made of several southern streams to determine, if possible, why some appear to be excellent trout producers and others, while apparently suitable, seem to be incapable of satisfactory trout production. The investigation reported in this thesis resulted from the foregoing directive.

The primary purpose of the investigation was to identify the factors influencing and, in many instances, limiting trout production in representative southern Michigan streams. It was suspected that some of the undesirable features of certain of these waters, once recognized, might be so altered as to improve conditions for trout. For this study, 13 watercourses, believed to be representative of southern Michigan trout streams, were chosen. Following a superficial examination of these streams, four were selected for intensive study. Because it was impracticable to conduct a complete creel census on all of these widely scattered waters, most of the information on production was obtained through periodical estimates of the standing crop. The trout-producing capacity of each stream was estimated on the basis of data obtained on physical, chemical, and biological factors known to influence, or suspected of influencing, production. The electrical fish shocker was chosen for obtaining specimens for the population estimates because of its apparent advantages over the seine. However, when it appeared that little was actually known of the capabilities and limitations of electrical shockers, a critical study of existing techniques and available equipment was first made.

The results of the investigations on these southern Michigan streams are presented as two major parts of this paper. The first includes the results of the experimental studies on electrical fish shockers conducted to develop a population-census method for stream fish; the second deals with the fish populations and their ecology with special reference to factors of the environment which appear to influence trout production.

DEVELOPMENT OF A CENSUS METHOD UTILIZING THE ELECTRICAL FISH SHOCKER

A reliable evaluation of the factors influencing trout production in streams depends first on a knowledge of production per se. Production of aquatic organisms, as defined by Clarke (1946), is the net increase in the size of the standing crop at the end of a stated period of time, plus the yield which includes that amount harvested by man and that permanently removed from the area by other causes. Such a measure, then, necessitates a knowledge of the weight or number of the population at the beginning and at the end of the study period, and, in addition, the weight or number of the fish removed permanently from the area by fishermen, natural mortality, and emigration.

Determination of the size of the fish populations in the various sections of the study streams was made by the "mark-and-recovery" method as described by Ricker (1948). This method has become widely used in fishery management in recent years; its reliability depends on the assumption that handling and marking do not change the rates of capture, recapture, or mortality of the fish. The assays obtained by the procedure apparently are much more reliable when a comparatively large proportion of the total population is marked and returned to the water and when a large proportion of the marked fish present is recovered. The limits of reliability to be expected with varying levels of marked-fish release were measured. Furthermore, my needs were to determine with highest possible accuracy the standing crop of fish of all sizes and species with different habits and in various habitats.

Of the number of devices used in the past with varying degrees of success and selectivity, only two, the seine and the electrical fish shocker, were considered of adequate promise for use in the present study. Shetter and Hazzard (1939) reported that, even under the most difficult seining conditions, they were able to recover 89.1 percent of the population of all species and sizes in a blocked-off section of a Michigan trout stream. Greeley (1935) estimated that in selected study sections of New York streams, at least 90 percent of the fish present were caught with seines. Trippensee (1937) on New Hampshire trout streams reported 70 to 80 percent recovery in situations difficult to seine, 80 to 90 percent in waters of moderately difficult seining, and over 90 percent efficiency in streams well adapted to the use of seines. Gerking (1949a) estimated a recovery rate of 88 percent in one Indiana stream in which debris had been removed prior to seining. Shetter and Leonard (1943), on the other hand, showed that intensive seining even under the best of conditions would not result in an efficiency of over 90 percent, and that fishes not captured were in the smaller size groups. In view of these reported variations in the efficiency of seining, and the fact that each stream would have had to be seined very intensively (requiring many man-hours of effort) for recovery of a large proportion of the population, seining was discarded as the method to be used in the present investigations. Instead, the electrical fish shocker was chosen on the basis of existing reports concerning its excellence as a collecting device.

A review of the literature on the shocker revealed that, in North America at least, little was actually known about the application of electricity to the field of fishery management. Because of the confusion and uncertainty which apparently existed in nearly every aspect of the subject, experimentation with electrical fish-collecting devices was undertaken to develop a census method suitable for the streams under study. In this phase of the study, an attempt was made to:

1. Assemble much of the pertinent literature on the use of electricity in fish collecting and in fishery management.
2. Measure the characteristics of electrical fields produced in water by electrodes of a variety of shapes and sizes.
3. Determine the magnitude of voltage gradient necessary to produce paralysis.
4. Compare the efficiency of alternating- and direct-current units under various conditions.
5. Measure the instantaneous and delayed mortality resulting from electrical shock.

Following these measurements, the mark-and-recovery method, as employed by me for estimating population sizes, was tested for reliability. The results of this phase of the investigation are presented in the following sections.

History of the Use of Electricity in Aquatic Situations

Although the first practical application of electricity to the field of fishery management apparently came quite recently, studies of the physiological effects of electricity on aquatic animals began much earlier. Hermann (1885), for example, found that fish and other aquatic animals, when placed in a direct-current field, orient themselves parallel to the current lines with their heads toward the anode. The assumption of such a position has been termed "galvanotropism." Van Harreveld (1938), who studied the reactions of fishes in direct-current fields, also noted that in a weak alternating-current field the animals moved into a position at right angles to the current lines. Numerous other investigators have studied the effects of electrical stimuli on aquatic organisms from a purely academic viewpoint. The works of a few of these will be considered later.

What appears to be the first reported use of electricity in fishery management occurred in 1917 when Burkey applied for a patent on an electrical screen designed to prevent fish from entering irrigation ditches (Holmes, 1948a). Further noteworthy experiments on the fish screen have been carried out by McMillan (1930), by McMillan, Holmes, and Everest (1937), and more recently by Applegate and colleagues at the Hammond Bay Fish Laboratory of the U. S. Fish and Wildlife Service (Unpublished).

According to Schiemenz and Humburg (1939), Schönfelder in 1924 was one of the first to report the use of electricity in collecting fish. Following the work of Schönfelder, there appeared many technical reports on the application of both alternating and direct currents in Germany for commercial as well as scientific purposes. The use of electrical shocking devices in North America apparently began with Haskell's (1940) experiments in New York and has been confined largely to scientific studies. In the decade following 1940, numerous workers, both in the United States and Canada, have produced a variety of modifications in techniques and equipment.

Until Rayner (1949) described the results of work with direct current on fish in Oregon, the emphasis in North America had been on the use of alternating current. Since 1949, direct current has gradually assumed increased importance, until it is now favored for stream studies by many workers who have used both types.

Response to Electrical Stimuli

When two electrodes, each connected to a pole of an electric generator or other source of electricity, are placed in water, an electrical field is established which produces a response by the animal life present in that field. The nature of the response will depend on: (1) the strength or intensity of the field, (2) the type of current--alternating (A. C.) or direct (D. C.)--, and (3) the time of exposure in the field of given intensity.

Fish which encounter a weak field, either A. C. or D. C., appear to be irritated and attempt to avoid the source of stimulus. As the intensity of the field is increased beyond a certain level, the magnitude of which will vary with size and probably with species, narcosis or paralysis results. In a weak field of alternating current, fish align themselves at right angles to the current lines, a position called "oscillotaxis." In an intense field, the fish are completely paralyzed, the gill-covers and fins are stiff and erect, the gill action becomes greatly reduced or stops entirely, and the body surface becomes lighter in color. In a strong direct-current field, on the other hand, fish are only partially "narcotized." They become relaxed, and direct their heads toward the anode, a position termed "galvanotropism." They are capable of movement, which consists of swimming feebly toward the anode. Such movement has been designated "galvanotaxis." When removed from the direct-current field, fish recover almost immediately, while those shocked with alternating current remain unconscious for a varying period of time, depending on the severity of the shock. If the fish are left in an intense field long enough, mortality will result. Again, the length of time will vary with size and species of fish and intensity of the field. These factors are discussed in greater detail below.

Physiological Effects of Electrical Stimuli on Fish

Van Harreveld (1938) and subsequent workers have suggested various causes for the responses of fish to electrical currents. It has been postulated that: (1) with the head toward the anode in a direct-current field, the fish is least irritated; (2) direct current stimulates certain cells in the central nervous system and so causes the orientation of the animal, making it easy to move toward the anode but difficult to move toward the cathode; (3) tropisms or taxes are caused by electrical stimulation of the labyrinths of the ear since these responses are not seen in embryos in which the labyrinths have not yet formed; and (4) the reaction to a direct-current stimulus is a reflex, for by cutting the auditory, lateral, and facial nerves, van Harreveld (1938) found that galvanotropism occurs independently of the organs supplied by these nerves and that it occurs when the spinal cord is severed from the brain but not when the cord is destroyed.

Regnart (1931) believed that the lateral line plays an important part in the response of fishes to direct current. Cutting the nerves to the lateral line on the left side resulted in the fish's turning to the right when facing the anode. Cutting the corresponding nerves on the right side caused another fish to turn to the left under the same conditions. However, eliminating the nerves to both lateral line organs did not prevent galvanotropism entirely, although it did reduce the violence of the reaction. This led Regnart to believe that the very high electrical conductivity of the mucous canals conducted the stimulus, in the absence of the nerves.

The results of Regnart's study do not invalidate the findings of van Harreveld, for the destruction of the cranial nerves to the lateral line organs would not affect the path of a reflex. Fisher (1950) pointed out that the effects of the current are apparently not direct effects on the muscles, but are mediated by the central nervous system.

The Electrical Component Causing Paralysis

Much debate has centered around the question of which component of electricity--voltage or amperage--causes shock and paralysis. Although the general principles held true for both alternating- and direct-current electricity, the works cited were mostly concerned with the former.

McMillan (1930), working with carefully controlled conditions, showed that the voltage gradient in water necessary to produce paralysis in rainbow trout and king (chinook) salmon was inversely proportional to the length of the fish and was further influenced by the resistivity of the water.

Schiemenz and Humburg (1939), and Holzer whose work they cited, have determined the magnitude of the potential difference from head to tail necessary to produce paralysis. They also recognized that the necessary gradient is influenced by water resistivity.

Smolian (condensation in English by Holmes, 1948b) believed that voltage generally has a greater effect than amperage, but that a certain minimum of each is necessary. He stated that in water of high resistivity (such as is found in mountain streams), although the voltage may be high, fish will be shocked with difficulty or not at all in the low amperages which normally pertain. Conversely, in water of low resistivity, amperage is increased and is usually accompanied by a decrease in voltage. Then, in contradiction, he stated that the resulting current density is greatly reduced, but that it is the current density which actually paralyzes the fish! This is evidence of one of the features of uncertainty which stimulated this aspect of my work.

Regnart (1931) was in agreement with Smolian's general and final contention when he proposed that the only standard way to measure the influence of electrical stimuli is to express current in terms of its density, or amperes per square inch (or per square centimeter). He expressed the relationship in the formula:

$$C = \frac{V}{R}$$

where C = Current (amperes per square inch)

V = Voltage (volts per inch)

R = Resistivity (ohms per cubic inch)

From Shetter's (1947a) statement that smaller fish are not so easily shocked as are larger fish because their bodies do not absorb so great a portion of the electrical current, it would appear that he agreed with those who support the current-density viewpoint.

Prevost (1945), reporting on the results of experiments in Quebec, stated that fish lying parallel to the lines of force (alternating current), receive a shock stronger than do fish lying perpendicular to these lines. Further, of two fish perpendicular to the lines of force, the smaller fish is struck by a smaller number of electrons and, therefore, a stronger current is required to cause paralysis.

Prevost's results were partly corroborated by the following experiment. Two groups of fish of uniform size were held in an alternating-current field of the minimum strength necessary to paralyze fish. Those fish which were held parallel to the lines of force were paralyzed; those perpendicular to these lines were irritated but not paralyzed. If current density is responsible for paralysis, the fish perpendicular to the lines of force should have intercepted more current and should have been shocked first. Since this was not the case, it would appear that the difference in potential from head to tail produces the effect. This view was further substantiated in that large fish were more quickly shocked in my experiments than small fish, when both were placed in the same location in the field and parallel to the lines of force. The longer fish may be presumed to have intercepted a greater linear distance and hence to have experienced a greater drop in potential over their total length.

On the other hand, when two groups of fish, unequal in size, were placed at right angles to the lines of force in a field just strong enough to paralyze the larger fish, the smaller ones were not overcome by shock. The larger fish by virtue of their size doubtless intercepted more lines of force. This condition has been noted by many of the workers cited above and has been the basis for the belief that current density is the component of electricity that results in shock. Two pieces of evidence oppose this view. (1) First, in water of low resistivity, it would be expected that the water would be at least as good a conductor of electrical current as are the fish and that relatively little current would flow through the body of the fish, resulting in a lowered efficiency of the shocker. Conversely, in water of high resistivity, it would be expected that more current would pass through the less-resistant fish than through the surrounding water and the efficiency of the shocker would be increased. Such is not true; the shocker is efficient in waters of moderately low resistivity but fails to function satisfactorily in water of high resistivity. (2) Secondly, since McMillan (1930) showed that the influence of resistivity on the voltage gradient required for paralysis was not constant but that it varied widely over the total range of water resistivities measured, it follows that current density, as expressed by Regnart's formula (q. v.), is not a better measure.

Considering all the evidence, it appears that both the drop in potential throughout the length of the fish and the current density in the water are involved in causing paralysis of fish. The exact relationship is unknown, but it is believed that the magnitude of the voltage gradient intercepted by the fish provides a better and more convenient measure of the effect as long as the influence of water resistivity is taken into consideration.

Configuration of Electrical Fields in Water

A great variety of electrode types and sizes have been used in electrofishing under an equally great variety of stream conditions, with both excellent and poor results. For example, Haskell (1940) used as one electrode one or more iron stakes driven into the stream bottom, and as the other a floating metal screen stretched between two poles. The screen strip varied from 4 to 6 inches wide and 10 to 15 feet long. A later improvement by Haskell and Zilliox (1941) consisted of substituting a bare wire dragged over the bottom in place of the iron stakes. This arrangement greatly increased the efficiency in hard water over bottom soil of high resistance. In both cases a vertical field was created, the efficiency of which varied with the relative resistance of the water and the bottom soil and with the greatest stream width encountered.

Prevost (1945) described a slightly different arrangement using a very large and powerful generator. His electrodes consisted of two bare copper wires, 20 to 25 gauge, and up to 75 feet in length. The wires were stretched parallel to the long axis of a blocked-off stream section at variable distances apart and at various depths from the surface to the bottom. One disadvantage of this method lies in the fact that when such a large area is electrified simultaneously many fish falling near the wires may be killed before they can be seen and removed from the field. Another undesirable feature is the relatively high source of power, and hence size of generator, required.

A series of vertical fields was set up by both Funk (1949) and Joeris (1949) with their modifications of an "electrical seine." The arrangement consisted of a number of floating electrodes of one polarity, spaced along a cable. Alternately spaced between these electrodes were hanging wire "drops" connected to the opposite pole of the generator. The major differences between their two units were the more numerous and more closely spaced electrodes used by Joeris, and therefore the heavier and more powerful generator needed.

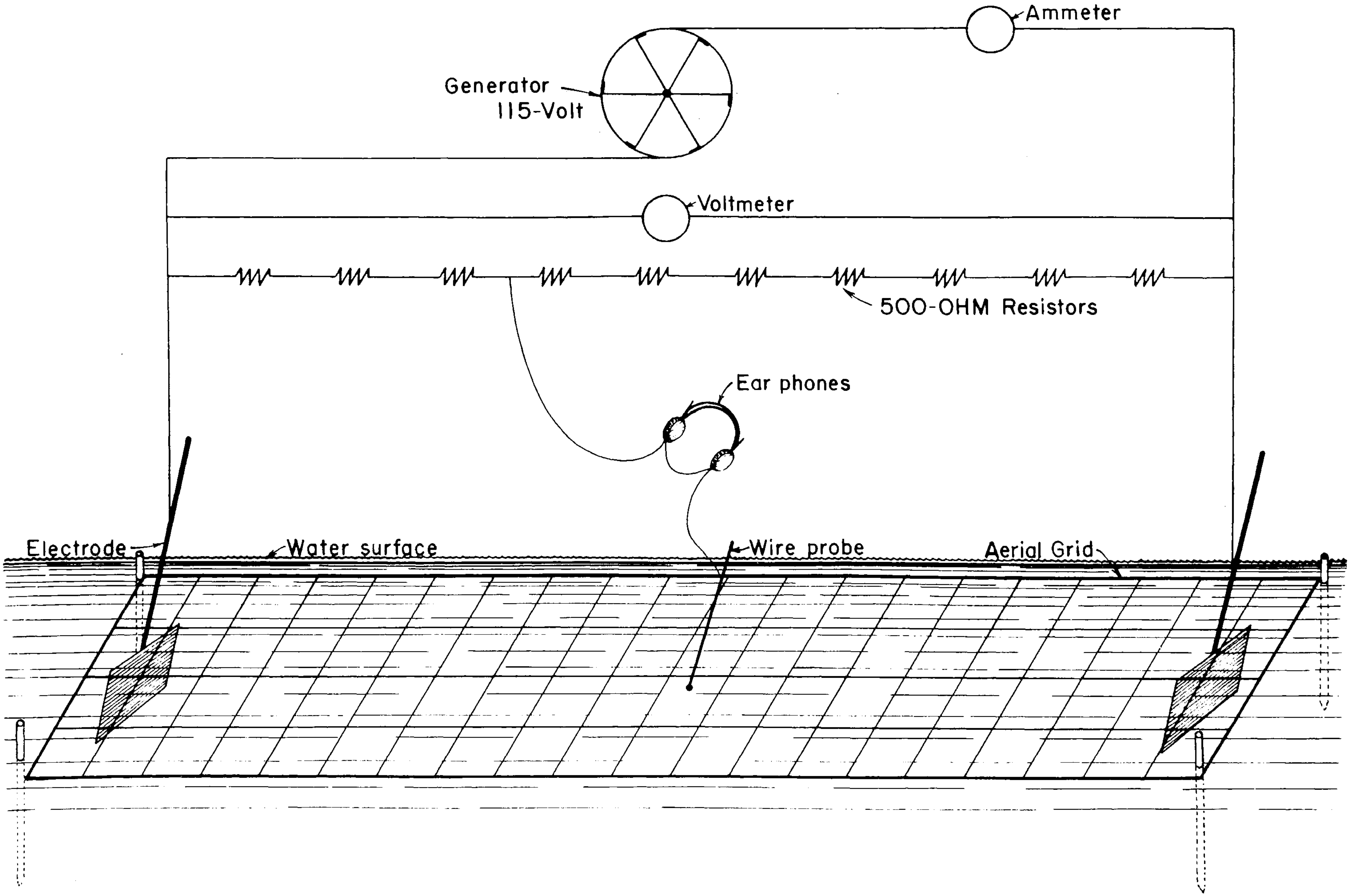
The arrangement developed by Hughes and Shetter in Michigan (Shetter, 1947a), as well as the modification of it used in Minnesota (personal communication from Dr. R. E. Johnson), consisted of two hand-held electrodes each connected to a pole of the generator. Use of this electrode design eliminated the problem of keeping the electrodes free of snags and obstructions in the water, a problem of considerable importance with floating electrodes. Another apparent advantage of this method was the possibility of adding a third electrode to the circuit in wide and shallow streams, provided the water depth and resistivity were such that the output of the generator was not exceeded. The factors determining the required power output will be discussed below.

As Elsen (1950) pointed out, the information on the field characteristics produced by the various electrode designs has been obtained largely from the observed effects on fish rather than from quantitative measurements of the field themselves. This seems to be true in North America, but the fields of practically all the modifications described above were carefully measured and evaluated in Germany by Schiemenz and Humburg (1939). They did not, however, test a variety of the portable hand-held electrodes described by Shetter (1947a).

For this reason, the fields produced by a limited number of electrodes of different designs and sizes were measured and plotted, during the summer of 1948, in an attempt to determine the desired characteristics of an all-purpose electrode for use in streams varying in width, depth, and resistivity. These were assayed with each of two A. C. generators of different but commonly employed capacities.

The equipment for measuring the field characteristics was set up as shown in Figure 1. It consisted of ten 500-ohm resistors in series, a pair of radio earphones, and an

Figure 1. Equipment for locating lines of equipotential in water.


Ammeter
Generator
115-Volt
Voltmeter
500-OHM Resistors
Ear phones
Electrode
Water surface
Wire probe
Aerial Grid

insulated wire probe with an exposed tip. An ammeter with a range of 0 to 5 amperes and a voltmeter with a range of 0 to 150 volts were wired into the circuit. The two electrodes to be tested were securely fixed to the bottom over a non-conducting grid marked off in one-foot squares to assist in plotting.

The resistance of the individual resistors was found to change from their original measured values after they had been receiving current for some time. In order to eliminate sources of error introduced by such changes, the resistance of each was measured after it had "warmed up" and again at the end of the test.

It was assumed that the voltage difference in the water between the electrodes was the same as that across the circuit indicated by the voltmeter, but, as pointed out by Holmes (1948a), precise measurements of voltage gradients in water cannot be made with instruments which draw current from the circuit and, therefore, distort the field. For this reason, the voltmeter and ammeter were switched off after the original readings had been made and were turned on again only periodically to check the power source for constant output.

In operation, the total resistance, and hence the total potential across the circuit was divided into 10 equal parts by the 10 resistors, assuming the resistors to be of equal value and the water resistivity to be uniform.

One lead from the earphones was plugged into the circuit between the first and second resistors at a point 1/10 of the total resistance, and similarly 1/10 of the total voltage, across the circuit. The other lead from the earphones was attached to the probe which was placed in the water near the closer electrode. In operation, a hum could be heard, indicating that current was flowing through the earphones. As long as there was a difference in potential between the point of attachment of the earphone lead and the location of the probe in the water, a flow of current resulted. However, as the probe was moved, the hum became fainter and finally ceased. The point of no current flow, or null point, indicated that the potential difference from the electrode to the null point was the same as that through the first resistor, or 1/10 of the total voltage across the field. A series of null points located around the electrode gave an equipotential line, all points on which are of the same potential from the electrode. Similarly, a vertical series of these lines gave a three-dimensional delineation of all points an equal number of volts distant from the electrode.

By plugging the earphone lead into the circuit between the second and third, and again between the third and fourth resistors, and so on, the location of all points 2/10, and 3/10, of the total potential from the first electrode could be plotted to scale, both in plan and profile, as shown in Figure 2. The gradients in volts per foot were obtained by measuring the plotted distances between adjacent lines of equipotential. These figures were converted to volts per inch by means of proportional distances.

The accuracy of these calculations is dependent on the accuracy with which the equipotential lines could be plotted with respect to the grid lines on the bottom. The magnitude of error introduced by plotting is directly proportional to the magnitude of the gradient per inch. Since plotting was probably accurate to the nearest inch, the error introduced did not exceed 0.5 volt per inch except in areas of very rapid potential drop, and here it was probably only slightly above that figure.

After the field had been plotted and before the electrodes had been moved, an attempt was made to determine the extent of the effective field and to measure the voltage gradient necessary for paralysis by introducing fish of different sizes and species. The fish were placed singly in a non-conducting scap net in the water outside the field and moved slowly toward the center. The direction of the fish and the point at which body movements ceased were observed and recorded. The paralysis-gradient was determined from a knowledge of the size of the fish and the gradient in volts per inch at the point where paralysis occurred. In spite of the difficulty encountered in keeping the fish oriented in a constant direction and in determining when it became paralyzed, the results of this experiment are considered to be within the same limits of accuracy obtained in the determination of voltage gradient in water.

The several species employed in the experiments were taken by seining and electrofishing. Those collected electrically were allowed at least 24 hours to recover from the effects of shock before being used in the tests. The following species, with their size ranges (total length), were employed:

Brown trout	11.0 to 16.5 inches
Common shiner	3.5 to 5.4 inches
Bluegill	2.5 to 6.0 inches
Pumpkinseed	4.2 to 5.6 inches
Largemouth black bass	3.5 to 10.2 inches

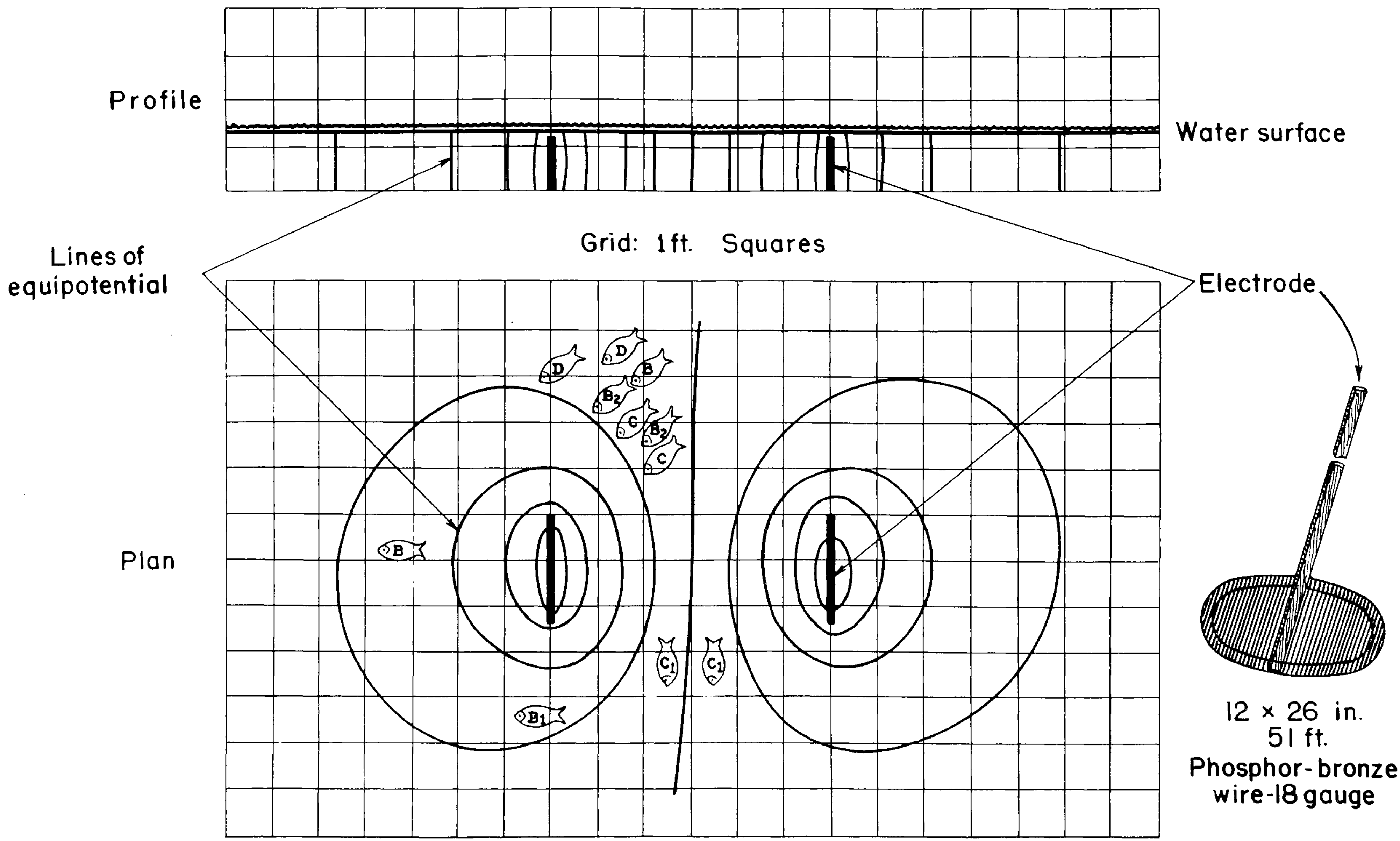
Since Shetter (1947a) had already shown that floating grids were unsatisfactory for general use as electrodes in Michigan trout streams, I did not plot the electrical fields produced by them but confined my trials to hand-held types. Furthermore, no attempt was made to measure the influence of bottom-soil resistivity on the distortion of fields in water.

The experimental-field analyses were made in the Clinton River where it flows through the State Fish Hatchery grounds at Drayton Plains, Oakland County, Michigan. Here, the stream varies in width approximately from twenty to sixty feet and in depth from one foot to at least eight or nine feet. The resistivity of the water during the period of the tests fluctuated from 2860 ohms to 3110 ohms per cubic centimeter, corrected to 25°C. During this time the water temperature ranged from 72°F. to 79°F.

Two sources of power were used to energize the electrodes. One was a 500-watt, 115-volt, 60-cycle, single-phase, alternating-current generator; and the other, a 1400-watt, 120-volt, 400-cycle, single-phase, alternating-current unit with a built-in voltage regulator. Both units were manufactured by the Homelite Corporation, Port Chester, New York. Direct-current fields cannot be plotted with the above equipment, but the writer was assured by several physicists that the two fields are identical under like conditions. Resistivities were measured with a variable-scale resistivity bridge and dip-cell. This instrument was accurate to within 1.0 percent at the range covered in the study.

The first electrode which was evaluated consisted of a 12-inch by 26-inch elliptical framework of brass tubing. Over this tubing was placed a piece of rubber garden hose for insulation. The hose was later discarded when it was found that it had no value but actually hindered facile movement of the instrument in the water. Approximately 50 feet of 18-gauge phosphor-bronze wire were wound in vertical coils around each frame. The coils were spaced one inch apart and one end of the wire was soldered to the insulated lead running up the handle. In water 14 inches deep and with the electrodes six feet apart, the field which was produced appeared as in Figure 2. Since the total voltage

Figure 2. Configuration of the alternating-current field produced by elliptical electrodes of the type shown. Water depth 14 inches, resistivity 2890 ohms, line voltage 125, amperage 1.7. Letters indicate points in the field where various fish became paralyzed. See text.


Profile
Water surface
Grid: 1 ft. Squares
Lines of equipotential
Electrode
Plan
12 × 26 in.
51 ft.
Phosphor-bronze wire-18 gauge

was 125, the drop in potential between adjacent lines of equipotential was 12.5 volts. With the knowledge that the divisions of the grid are 12 inches, it was then possible to express the potential difference between lines as the drop in volts per foot. The total current flowing in the circuit was 1.7 amperes.

The voltage drop between electrodes, though less abrupt than it was to the sides, still was not the uniform quantity stated by Fisher (1950), but decreased with distance in all directions from the electrodes. On a line between centers, the magnitude of the gradient varied from approximately 3.1 to 1.3 volts per inch; and on an extension of the line beyond the electrodes, it decreased from 2.5 volts to less than 0.3 volt per inch at a distance of 5 feet.

A measure of the effective field was obtained when a number of fish were introduced into the field in the manner previously described. The species of fish, their numbers and sizes, and the distance from the electrodes at which each was paralyzed are given in Table 1. All specimens were approximately at right angles to the lines of equipotential when paralyzed, with the exception of one common shiner, 4.5 inches in length, designated as B_1, and two bluegills, 2.5 inches in length, designated as C_1, which were parallel to the line.

It appears from an examination of Table 1 and Figure 2 that large fish are shocked at greater distances from the electrodes than are small fish of the same or different species. Similarly, it appears that those individuals lying perpendicular to the lines of equipotential are shocked at greater distances than are those parallel to these lines.

TABLE 1. SPECIES, SIZES, AND DISTANCES FROM TWO ELLIPTICAL ELECTRODES AT WHICH PARALYSIS OCCURRED

Resistivity 2890 ohms, line voltage 125, amperage 1.7

Species		Number of fish	Total length (inches)	Distance from electrode (inches)
B	Common shiner	2	4.5	42 (39-45)
B_1	Common shiner[1]	1	4.5	24 (...)
B_2	Common shiner	2	3.5	36 (...)
C	Bluegill	2	2.5	34 (...)
C_1	Bluegill[1]	2	2.5	32 (...)
D	Pumpkinseed	2	4.3	43 (41-45)
	Average		3.6 inches	36.2 inches

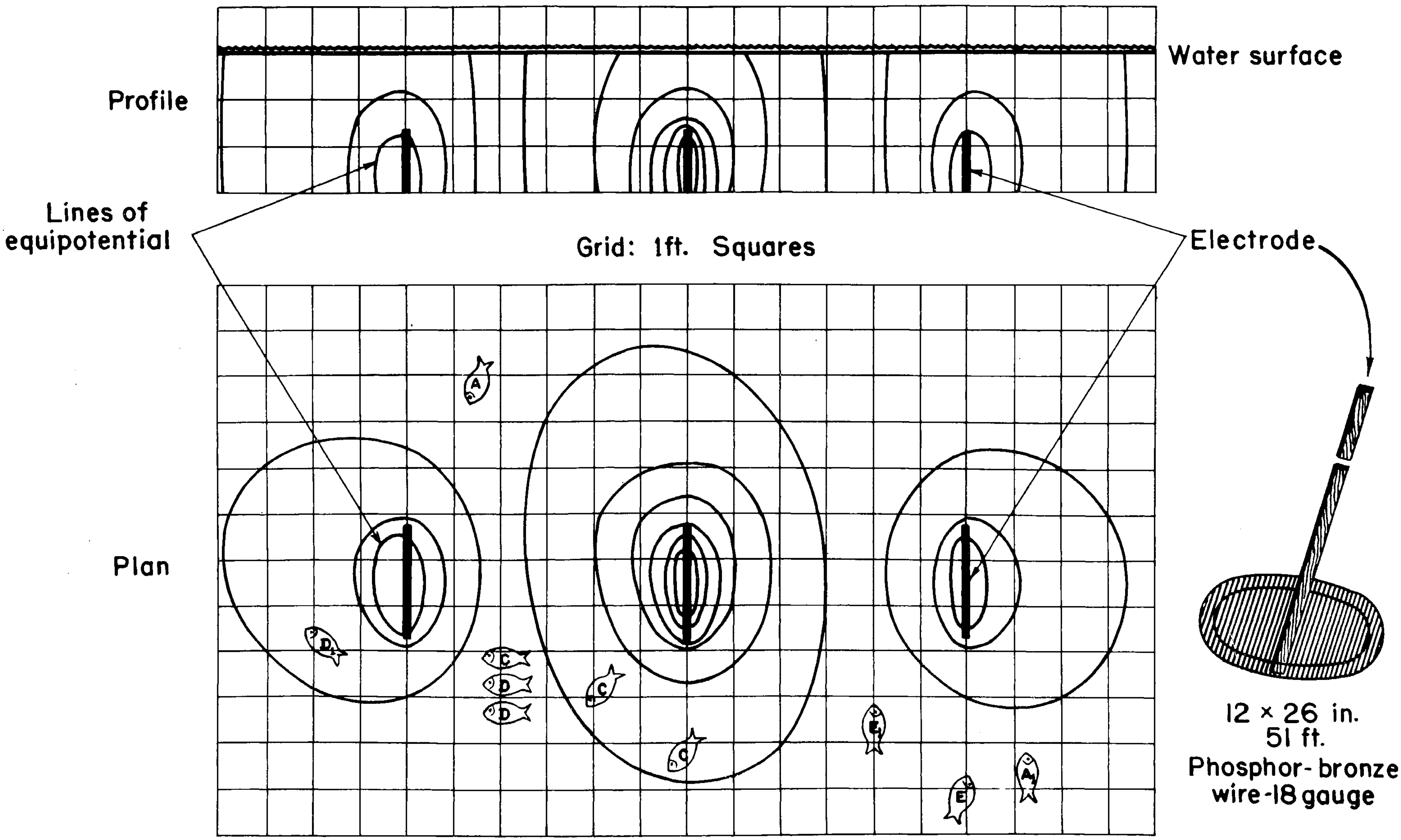
[1] Parallel to lines of equipotential

The average length of the fish employed in the assay being considered was 3.6 inches; the average distance from the electrodes at which paralysis occurred was 36 inches. These figures indicate that, under similar conditions, the above electrodes would be effective in taking fish 3.6 inches in length and longer, from a field approximately 12 feet square. However, in ordinary stream work, this field would actually be slightly smaller, since a large proportion of the fish tend to enter between the electrodes in a direction parallel to the lines of equipotential. As it was shown above, such orientation requires that the fish be closer to the electrodes than when perpendicular.

When the same electrodes were placed 12 feet apart in water 36 inches deep, the resulting field showed a region near each electrode in which the voltage gradient exceeded 6 volts per inch and another region about 4 feet wide in which the gradient was less than 0.2 volt per inch. To increase the low gradient in the center, a third electrode of the same type was added at this point. It was connected to one pole of the generator while the two outside electrodes were connected to the opposite pole. The addition of the third electrode caused the current to increase beyond the capacity of the 500-watt unit with a resulting drop in the circuit voltage. The 1400-watt power plant was then substituted. It was able to provide the 4.5 amps required and still maintain the total potential at 135 volts.

The field produced by the three electrodes appeared as shown in Figure 3. There was a continuous zone 16 feet long and 3 feet wide through the electrodes in which the gradient did not drop below 0.5 volt per inch. On the other hand, the drop in potential near the central electrode did exceed 5 volts per inch which appears much higher than needed to shock very small fish. The bending of the field

Figure 3. Configuration of the alternating-current field produced by three elliptical electrodes of the type shown in water 36 inches deep. Resistivity 2890 ohms, line voltage 135, amperage 4.5. Letters refer to points in the field where fish became paralyzed. See text.


Profile
Water surface
Lines of equipotential
Grid: 1ft. Squares
Electrode
Plan
12 × 26 in.
51 ft.
Phosphor-bronze wire-18 gauge

to the left was caused by the left electrode being in water 2 inches shallower (34 inches) than that at the other electrodes.

Fish introduced into the field as described previously were shocked at the points indicated in Figure 3. For this field Table 2 shows the species, their numbers and sizes, and the distance from the electrodes where each was paralyzed. Again all fish were perpendicular to the lines of equipotential except one pumpkinseed designated as D_1, and one bass, designated as E_1.

TABLE 2. SPECIES, SIZES, AND DISTANCES FROM THREE ELLIPTICAL ELECTRODES AT WHICH PARALYSIS OCCURRED

Resistivity 2890 ohms, line voltage 135, amperage 4.5

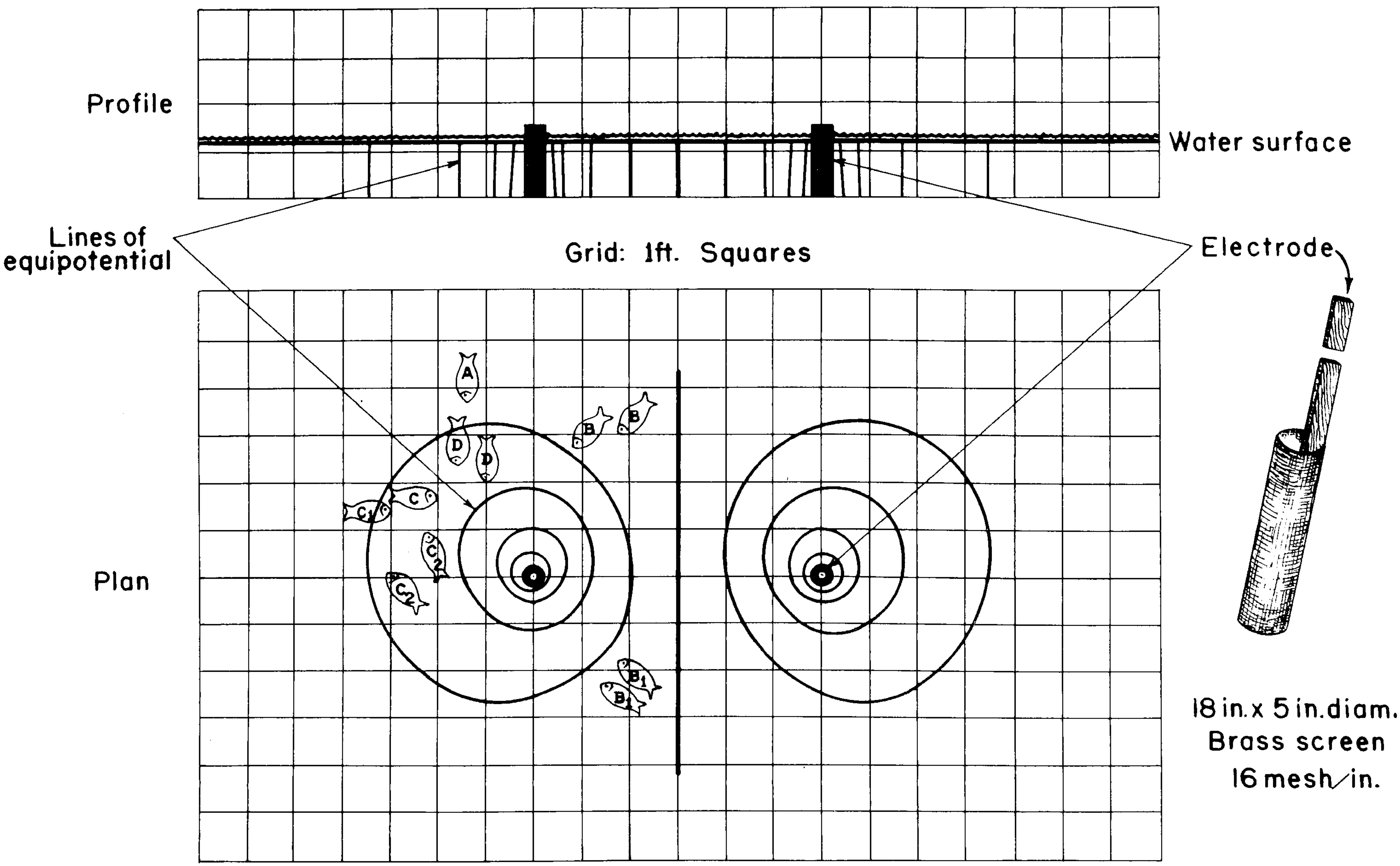
Species		Number of fish	Total length (inches)	Distance from electrode (inches)
A	Brown trout	1	11.0	41 (...)
A_1	Brown trout	1	14.2	38 (...)
C	Bluegill	3	3.0	28 (27-29)
D	Pumpkinseed	2	4.2	31 (29-33)
D_1	Pumpkinseed[1]	1	5.6	22 (...)
E	Largemouth bass	1	9.5	40 (...)
E_1	Largemouth bass[1]	1	9.5	34 (...)
	Average		6.7	32.1

[1] Parallel to lines of equipotential

In spite of the fact that a much larger effective field resulted from the use of the third electrode, the larger fish (6.7 inches, average length) had to be brought closer to the electrodes before they were immobilized. The average distance from the electrodes was 32 inches, which indicated that the effective field was approximately 18 feet wide. In field use, this apparent advantage would be offset by the need of an additional crew member and a generator of greater current capacity, and thus, usually greater weight. The additional man would be needed to handle the third electrode.

In the search for an electrode which would provide a wide field with comparatively uniform gradients in water of varying depths, two cylinders of brass screen, 5 inches in diameter by 18 inches in length, were tested. When placed 6 feet apart in water 14 inches deep, they produced a field as shown in Figure 4. The total voltage was 130 volts and the amperage 1.3, amps., resulting in a power demand that could be supplied by the small generator. It may be seen that the field was far from uniform in the distribution of the equipotential lines. Near the electrodes the gradient reached a high of about 9 volts per inch; while midway between them the voltage drop was still approximately one volt per inch. To the sides the drop was much more rapid, decreasing from about 5 volts per inch to less than 0.2 volt per inch at a distance of about 3 feet from the electrode.

Figure 4. Configuration of the alternating-current field produced by the cylindrical electrodes shown. Water depth 14 inches, resistivity 2950 ohms, line voltage 130, amperage 1.3. Letters indicate points at which individual fish were paralyzed. See text.


Profile
Water surface
Lines of equipotential
Grid: 1ft. Squares
Electrode
Plan
A
D
D
B
B
C
C_1
C_2
C_2
B_1
B_1
18 in. x 5 in. diam.
Brass screen
16 mesh/in.

The fish used to test the effective strength of the field are described in Table 3. Except for the two bluegills designated as C_2, all fish were as nearly perpendicular to the lines of equipotential as it was possible to hold them.

TABLE 3. SPECIES, SIZES, AND DISTANCES AT WHICH PARALYSIS OCCURRED IN THE FIELD PRODUCED BY CYLINDRICAL BRASS ELECTRODES

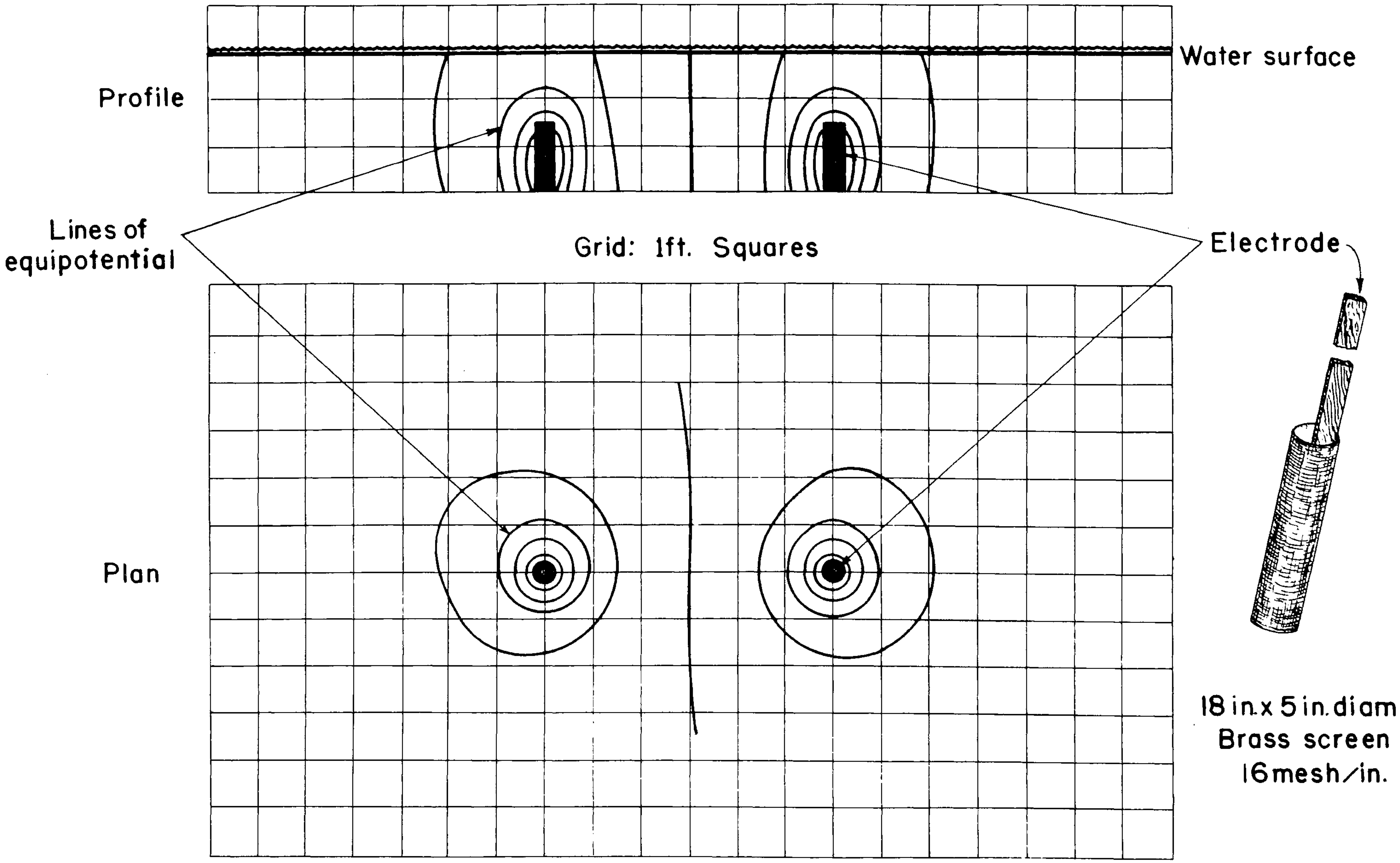
Resistivity 2950 ohms, line voltage 130, amperage 1.3

	Species	Number fish	Total length (inches)	Distance from electrode (inches)
A	Brown trout	1	12.0	50 (...)
B	Common shiner	2	4.8	39 (36-42)
B_1	Common shiner	2	3.9	33 (32-34)
C	Bluegill	1	5.8	34 (...)
C_1	Bluegill	1	5.5	40 (...)
C_2	Bluegill[1]	2	5.0	26 (22-30)
D	Pumpkinseed	2	4.4	33 (28-38)
	Average		5.4	35.1

[1] Parallel to lines of equipotential

The effective field measured with the test fish seemed to be larger than that indicated by the plotted lines. Fish

Figure 5. Configuration of the alternating-current field produced by cylindrical electrodes the same as shown in Figure 4 but placed in water 36 inches deep. Resistivity 2860 ohms, line voltage 130, amperage 2.7.

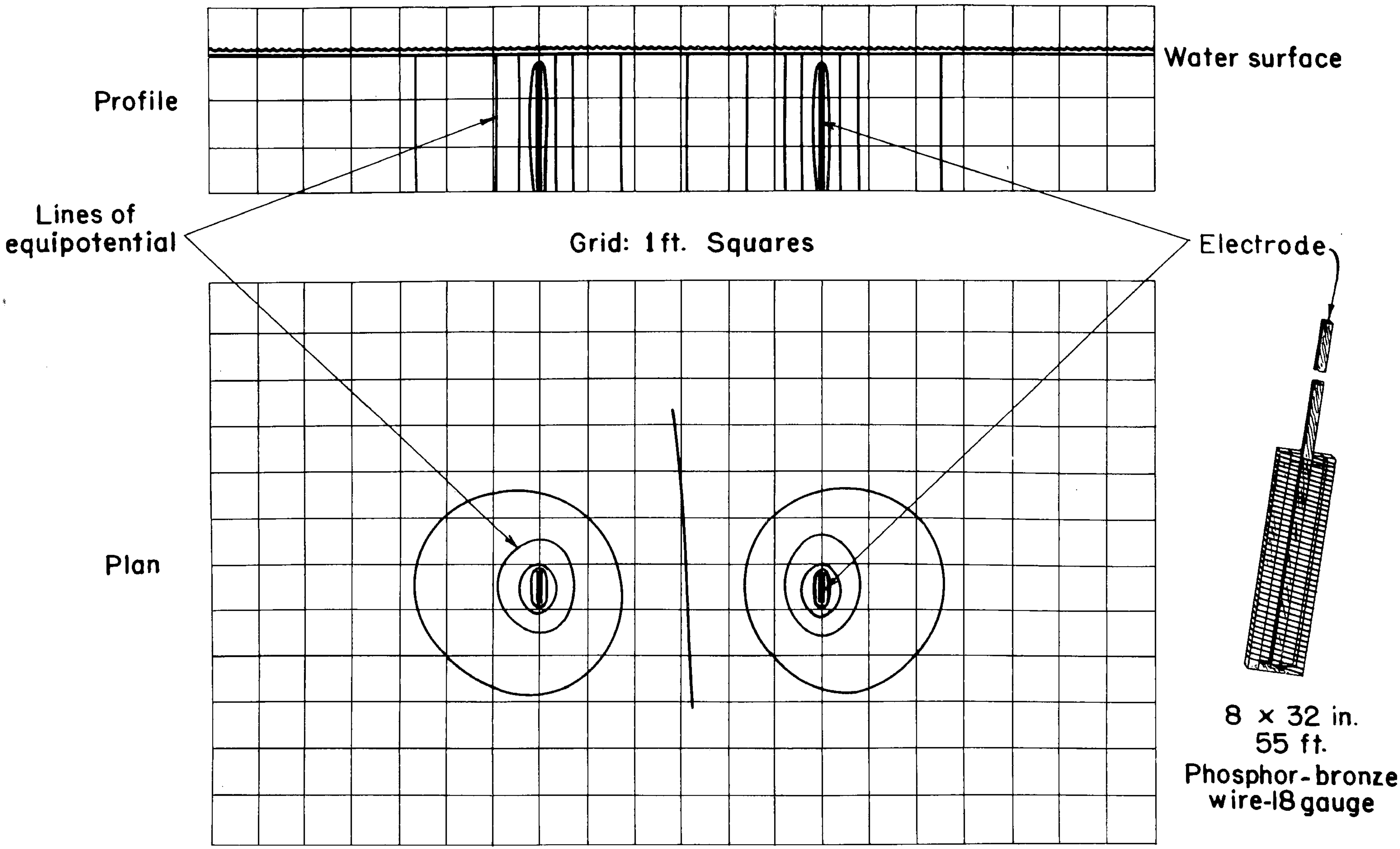

Water surface
Profile
Lines of equipotential
Grid: 1ft. Squares
Electrode
Plan
18 in.x 5 in. diam.
Brass screen
16 mesh/in.

averaging 5.4 inches in length were paralyzed at an average distance of 35 inches from the electrodes. Yet when compared with the figures presented in Table 1, the effective field does not seem unreasonably large, for the fish which were used in testing the first electrodes averaged only 3.6 inches in length and were shocked at an average distance of 36 inches.

As a further test, the cylindrical brass screen electrodes were placed 6 feet apart in water 36 inches deep. The potential remained at 130 volts, while the current increased to 2.7 amps. These values represented a power load of 251 watts, again within the limits of the 500-watt unit. The resulting field shown in Figure 5 was much smaller than that produced by the same electrodes in shallow water. Because there seemed to be such a good correlation between the plotted and observed effective fields, no further attempts were made to plot points at which fish became paralyzed.

The third electrode tested was made on wooden frames 8 inches by 32 inches. Around each frame was wound 55 feet of 18-gauge phosphor-bronze wire. In 36 inches of water they created a field (Figure 6) of approximately the same size as that of the cylindrical model. The gradient varied from about 9 volts per inch at the electrode to approximately 0.2 volt per inch at a distance of 2.5 feet to the sides. This type would appear to be effective only in extremely narrow streams approximately two to four feet deep.

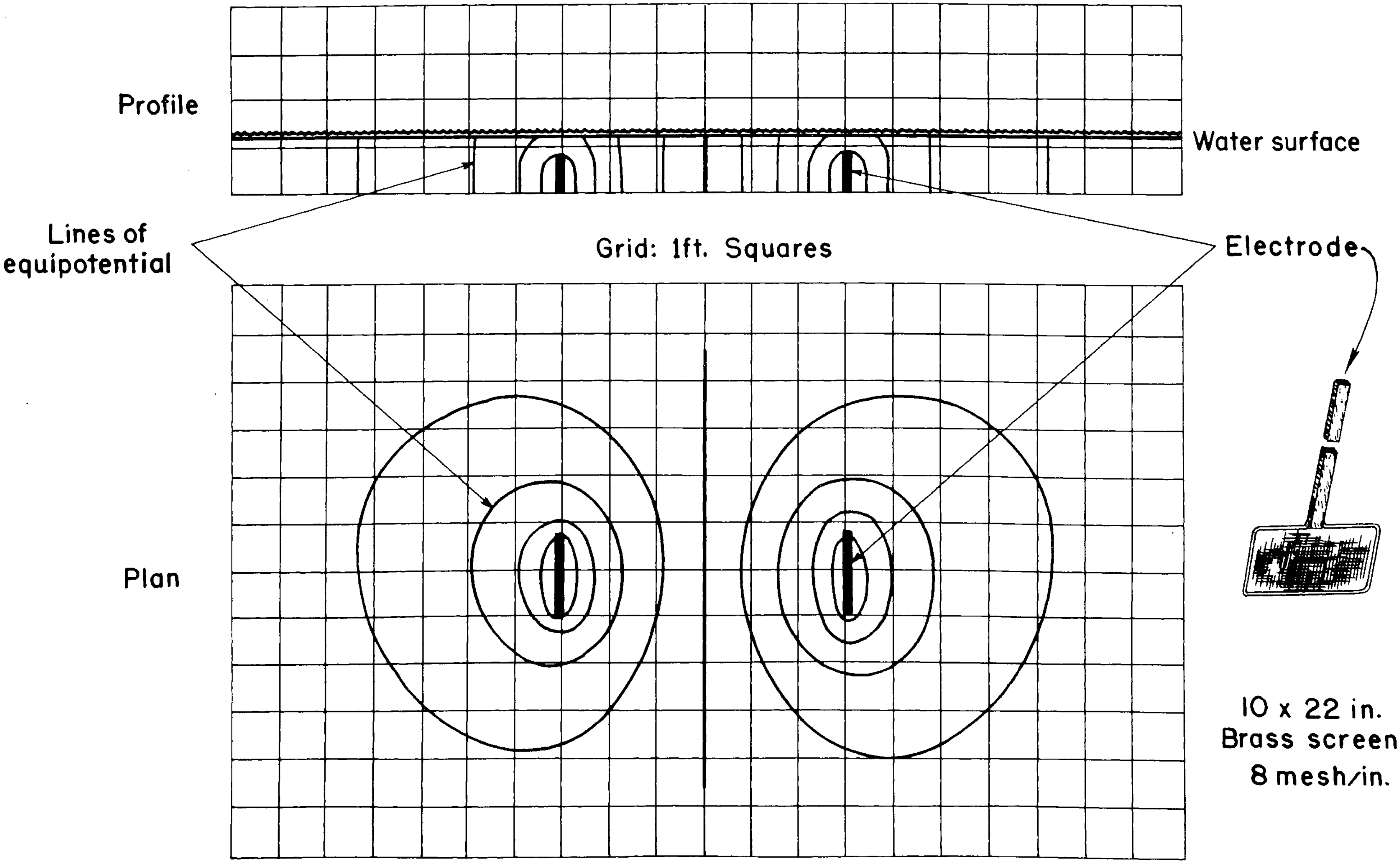
Figure 6. Configuration of the alternating-current field produced by the tall, rectangular electrodes illustrated. Water depth 36 inches, resistivity 3110 ohms, line voltage 130, amperage 3.0.


Profile
Water surface
Lines of equipotential
Grid: 1 ft. Squares
Electrode
Plan
8 x 32 in.
55 ft.
Phosphor-bronze
wire-18 gauge

Electrodes consisting of brass screen, 8 meshes per inch, were tested next. Each was made by soldering the screen to a 10-inch by 22-inch frame of bronze tubing. The electrodes and the resulting field are shown in Figure 7. The field produced by these electrodes appeared almost identical to that created by the 12-inch by 26-inch wire-wound electrodes under similar conditions.

The tests of the various electrodes indicated that the largest effective fields are those with the more uniformly spaced lines of equipotential. To produce such fields, the electrodes should be longer in a horizontal direction than they are high, and should be as large as can be conveniently handled by the operators. They should not be so large that, at ordinary working distances, they draw more current than the generator can supply and still maintain the rated voltage. It may be remembered that the maximum power output (watts) of a given generator is a constant, equal to the rated voltage (volts) times the maximum amperage (amperes). If the amperage is increased beyond the capacity of the generator, the voltage drops proportionately. The maximum size appears, then, to be limited by (1) the maneuverability of the electrodes, (2) the output (watts) of the generator, (3) the electrical conductivity of the water, (4) the depth, and (5) the width of the stream. In narrow, deep streams of relatively low resistivity, smaller electrodes will be required than those needed in wide, shallow streams of high resistivity.

Figure 7. Configuration of the alternating-current field produced by the more or less rectangular electrodes shown. Water depth 14 inches, resistivity 2950 ohms, line voltage 120, amperage 1.7.


Profile
Water surface
Lines of equipotential
Grid: 1ft. Squares
Electrode
Plan
10 x 22 in.
Brass screen
8 mesh/in.

Based on the information obtained in this study, electrodes for general stream use were constructed. They consisted of 18-inch by 10-inch bronze-tubing frames around each of which were wound approximately 60 feet of 12-gauge copper wire in vertical coils (Figure 8). In subsequent trials these electrodes proved to be entirely satisfactory. They were light and easy to manipulate, yet the field was of sufficient size and strength to paralyze a vast majority of the fish encountered.

Magnitude of Voltage Gradient Required for Paralysis

It was pointed out in the previous section that an approximate measure of the voltage difference necessary for paralysis might be obtained from the determination of the potential drop per inch at the points where paralysis occurred. Several investigators have determined this quantity for fish of various sizes and species under different stream conditions.

The results of two studies are worthy of note. Holzer, cited by Schiemenz and Humburg (1939), stated that a head-to-tail difference of 2.0 volts A. C. would paralyze most salmonids and 1.4 volts A. C. would immobilize most other species in water at a resistivity of 14 ohms per centimeter cube at 9°C.

McMillan (1930) realized that the effect of resistivity was not constant throughout a wide range of water resistivities and proposed the following formula to obtain the

Figure 8. Alternating-current shocker in plywood boat.
Note all-purpose electrodes.

minimum paralysis gradient for rainbow trout and king salmon:

$$g = \frac{3.70\ W}{L}$$

where g = voltage drop necessary for paralysis expressed as volts per inch of water

W = a correction factor for water resistivity

L = fork length in inches

The values of W at various resistivities presented in Table 4 have been modified from the data of McMillan who expressed resistivities in ohms per cubic inch at 55°F. From the figures in Table 4, it is possible to express the voltage gradient per inch in the water and the head-to-tail voltage necessary for paralysis of fish by substitution in the previous formula.

TABLE 4. CORRECTION FACTOR, W, FOR VARIOUS WATER RESISTIVITIES

Modified from McMillan (1930)

Water resistivity[1]	Correction factor, W
25	0.22
120	.27
240	.30
480	.34
720	.37
1200	.40
2400	.48
4600	.56
7200	.61
8825	.65

[1] Resistivity expressed as ohms per cubic centimeter and corrected to 25°C.

The results of the measurements of the voltage gradient necessary for paralysis made with the three electrode arrangements are presented in Tables 5 to 7. Although the conditions could not be as carefully controlled and the measurements are probably not so precise as in McMillan's laboratory experiments, I believe the values to be reasonably accurate.

TABLE 5. APPARENT PARALYSIS GRADIENT WITH THE TWO ELLIPTICAL ELECTRODES SHOWN IN FIGURE 2

Resistivity 2890 ohms, line voltage 125, amperage 1.7

(Range of values given in parentheses)

Species		Number of fish	Total length (inches)	Paralysis gradient (volts)	
				Per inch	Head-to-tail
B	Common shiner	2	4.5	0.4 (...)	1.8 (...)
B_1	Common shiner[1]	1	4.5	0.7 (...)	3.2 (...)
B_2	Common shiner	2	3.5	0.5 (0.4-0.6)	1.8 (1.4-2.1)
C	Bluegill	2	2.5	0.7 (0.5-0.8)	1.7 (1.3-2.0)
C_1	Bluegill[1]	2	2.5	0.9 (...)	2.3 (...)
D	Pumpkinseed	2	4.3	0.3 (0.2-0.4)	1.3 (0.9-1.7)
	Average		3.6	0.56	1.89

[1] Parallel to the lines of equipotential

The gradients in volts per inch were determined from the total voltage drop between adjacent lines of equipotential and from these figures the head-to-tail paralysis voltage was calculated. The paralysis gradients in volt per inch varied from 0.38 to 0.56. Such variation is to be expected since the magnitude of this value is determined by the size and orientation of the fish with respect to the lines of equipotential. The head-to-tail paralysis gradient may vary considerably with individuals, species, and water resistivity. The variation in the average values obtained, 1.89 to 2.09 volts, may have been influenced by one or more of the following conditions: (1) the accuracy of the measured gradients is known to vary indirectly with the magnitude of the gradient. (2) All fish were not exposed to given gradients for a uniform length of time before paralysis occurred. (3) The direction of the fish with respect to the lines of equipotential was not always constant. (4) Individuals and species may vary greatly in their susceptibility, or resistance, to electrical shock.

In spite of their variation, the paralysis gradients which I determined compare favorably with results obtained by McMillan. He showed that in water of approximately equal resistivity (2400 ohms per cubic centimeter, converted to 25°C) a head-to-tail (fork length) difference of 1.8 volts was required to immobilize rainbow trout and king salmon, although he failed to mention the orientation of the fish with respect to the equipotential lines as a factor in determining the magnitude of the required gradient.

TABLE 6. APPARENT PARALYSIS GRADIENT OF FISHES IN THE ELECTRICAL FIELD OF THE THREE ELLIPTICAL ELECTRODES SHOWN IN FIGURE 3

Resistivity 2890 ohms, line voltage 135, amperage 4.5

(Range of values given in parentheses)

Species		Number of fish	Total length (inches)	Paralysis gradient (volts) Per inch	Paralysis gradient (volts) Head-to-tail
A	Brown trout	1	11.0	0.2[1] (...)	2.2[1] (...)
A_1	Brown trout	1	14.2	0.2[1] (...)	2.8[1] (...)
C	Bluegill	3	3.0	0.5 (0.4-0.5)	1.5 (1.4-1.6)
D	Pumpkinseed	2	4.2	0.4 (0.3-0.4)	1.6 (1.5-1.7)
D_1	Pumpkinseed[2]	1	5.6	0.6 (...)	3.4 (...)
E	Largemouth bass	1	9.5	0.2[1] (...)	1.9[1] (...)
E_1	Largemouth bass[2]	1	9.5	0.3 (...)	2.9 (...)
	Average		6.7	0.38	2.09

[1] Estimated values since the fish were outside the plotted lines.

[2] Parallel to the lines of equipotential; all others perpendicular.

TABLE 7. APPARENT PARALYSIS GRADIENT WITH CYLINDRICAL SCREEN ELECTRODES

Resistivity 2950 ohms, line voltage 130, amperage 1.3

(Range of values given in parentheses)

Species		Number of fish	Total length (inches)	Paralysis gradient (volts) Per inch	Head-to-tail
A	Brown trout	1	12.0	0.15[1] (...)	1.8[1] (...)
B	Common shiner	2	4.8	0.4 (0.3-0.5)	1.9 (1.4-2.4)
B_1	Common shiner	2	3.9	0.5 (0.4-0.5)	1.8 (1.6-2.0)
C	Bluegill	1	5.8	0.4 (...)	2.3 (...)
C_1	Bluegill	1	5.5	0.3 (...)	1.7 (...)
C_2	Bluegill[2]	2	5.0	0.6 (0.4-0.8)	3.0 (2.0-4.0)
D	Pumpkinseed	2	4.4	0.4 (0.3-0.5)	1.8 (1.3-2.2)
	Average		5.4	0.41	2.07

[1] An estimated value since the fish was outside the plotted field when paralyzed.

[2] Parallel to the lines of equipotential.

A lack in the number and precision of measurements in the present study made it impractical to attempt a determination of the differential voltage drop required by species, although casual observations, both by the writer and by others, seem to indicate that a slight difference does exist. Burr (1932) reported that in Louisiana voltages (100 to 400 volts) which were fatal to gar pike only stunned smaller game fishes. Schiemenz and Humburg (1939) listed the paralysis gradients for trout (2.0 volts) and non-trout species (1.4 volts). Smolian (English translation by Holmes, 1948b) noted similar specific differences in susceptibility to electronarcosis which he believed were directly proportional to the oxygen demands of the species. Smith and Elson (1950) noticed differences in catchability (electrofishing) between species, but they believed that such variation was more closely associated with habits of the species than with inherent differences in sensitivity to electricity.

Comparison of Collection Performance of A. C. and D. C. Shockers

The reliability of the "mark-and-recovery" method of obtaining population estimates depends, among other things, on the proportion of marked fish in the total population--the higher it is, the better. As mentioned earlier, the alternating-current shocker made it possible, in some situations at least, to recover a sizable portion of the total fish present. Yet in swift or roily water the efficiency appeared to decrease very markedly. Many workers have expressed the opinion that direct current, because of its power of attracting fish to the positive electrode, would yield better returns in such conditions.

Although direct current has been widely used in Europe since 1926 in the collection of fish for commercial and scientific purposes, its first reported use in North America was described by Rayner in 1949, as previously indicated. Also, during the summer of 1949, Phillip Wolf of Malmo, Sweden, made several demonstrations of his direct-current unit to various state and provincial fishery officials on this continent. Following these demonstrations, direct-current shockers have become increasingly important in North American stream-population studies. However, all workers who have used this type are not in agreement on the results obtained.

Rayner (1949) claimed a superior performance by D. C. over A. C., especially in rapid and turbid waters because of the leading of the fish to the operator. His apparatus consisted of a 230-volt, 2500-watt, D. C. generator, a 16-inch by 36-inch piece of copper hardware cloth as the negative electrode, and two dip nets, each threaded with copper wire, as the positive electrodes.

Smith and Elson (1950) found an advantage in the use of the Wolf D. C. shocker (purchased by the Fisheries Research Board of Canada) in taking smaller fish and in removing fish from hiding places. The Wolf unit supplied a maximum current of about 5 amps at 250 volts, or a power output of 1250 watts. The electrode arrangement differed from that of Rayner in that the positive electrodes were metal grids on insulated handles. Scap nets were used to recover the stunned fish from the water.

Webster (1950) reported definitely unsatisfactory results with direct current in attempting to compare the efficiency of the two types of current in Fall Creek, New York, but, as he pointed out (personal communication), the experiment was designed primarily as a demonstration and not an exhaustive test. The current supplied by the 230-volt, 2500-watt, D. C. generator was conveyed to the water by two types of electrodes. One type consisted of two hand-held, 10-inch sheet-aluminum paddles, the other a grounded system in which the negative pole made contact with the ground either by iron stakes or bars, or by bare, weighted wires dragging on the bottom. If a different type of electrode had been used by Webster, results might have been improved, for when two aluminum plates are used as electrodes, a high resistance is built up in one plate which greatly reduces the current flow and hence the effective shocking power. Schiemenz and Humburg (1939) pointed out that poorer results are usually obtained when one electrode is grounded and explained that the field is made weaker because grounding causes it to be spread out over a large area.

The relative efficiency of the two units currently used by the Michigan Institute for Fisheries Research was measured during the summer of 1950 in a limited number of trials in Spring Brook, Kalamazoo County, and in Wilder Creek, Calhoun County.

Two study sections in Spring Brook were blocked by means of seines supported by chicken wire and iron fence posts driven into the stream bottom. Rocks and gravel were piled on the bottom of the seines to prevent washing out. Dredging operations in Wilder Creek made it impossible to maintain a blocking seine without constant cleaning; for this reason a 1000-foot section, open at both ends, was used. It was believed that any error caused by driving fish out of the unblocked area would be minimized by the substantial length of the section. Further, it had been repeatedly observed that fish would be driven only short distances ahead of the electrodes before they would turn and enter the electrical field. Although the conditions were not strictly comparable in the two watercourses, the error introduced by using an unblocked section of stream was judged insignificant on the basis of experience.

The physical and chemical characteristics of both Spring Brook and Wilder Creek are such that electrical fish shockers should provide satisfactory results. During the time of the experiment, the total hardness of each was within 235 to 270 p.p.m., as calcium carbonate, while the resistivity remained between 1880 and 2280 ohms per cubic centimeter, corrected to 25°C.

The upper section on Spring Brook was 500 feet long; it averaged 12.3 feet in width and 2 feet in depth. There were no deep pools. The water was very clear and slow-moving. The lower, 300-foot stretch averaged 12.1 feet in width and 1.5 feet in depth. There was one pool 3 feet deep. The water was much swifter in this area than in the upstream one, making recovery of fish more difficult. The 1000-foot open section on Wilder Creek averaged 14.2 feet in width and 2 feet in depth.

The alternating current was supplied by a portable 500-watt generator weighing 63 pounds (Universal Motor Company, Oshkosh, Wisconsin). The two hand-held electrodes employed were of the all-purpose type (Figure 8).

The direct-current power was furnished by a 230-volt, 2500-watt, gasoline-driven generator, the total weight of which was 135 pounds (The Homelite Corporation, Port Chester, New York). A sheet of copper, approximately 14 inches by 8 feet and mounted on the bottom of the boat used to float the shocker, served as the negative electrode. The two hand-held positive electrodes consisted of wooden handles on each of which was bolted a 9-inch by 12-inch loop of 1/4-inch copper tubing. To this framework 12-gauge copper wire was soldered to form a grid of 1-1/2-inch squares. The completed electrode resembled a long-handled, coarse-meshed tennis racket.

In operation, the generator was placed in a shallow-draught plywood boat and towed behind the two operators

(Figure 8). The stunned or immobilized fish were collected with scap nets and placed in a tub of water in the boat. At frequent intervals, the captured fish were anesthetized with Urethane in a manner such as that described by Gerking (1949b) and were marked by clipping off a part of a fin. They were returned immediately to the water. Two shocking runs were made with each unit in each study section, with the exception of the one on Wilder Creek. Here the water was too muddy for satisfactory results with alternating current. The interval between runs was kept between 6 and 24 hours. These limits were set to reduce possible errors resulting from (1) attempts to recapture fish which had not fully recovered from earlier electrical shock, (2) the removal of fish from the sections by fishermen, and (3) losses or gains by migration into and out of the unblocked section of Wilder Creek. It is believed that no significant error resulted from these causes.

The pe rcentage recovery of marked fish by individual species in all sections varied greatly with shockers (Table 8). Such great variation no doubt was caused largely by differences in size of fish and ease of capture. Because smaller specimens not only require relatively stronger field intensity for paralysis, but also are more difficult to see and recover than are the larger specimens, the comparatively high return of trout can be attributed largely to size-the majority encountered of all three species were of legal length.

TABLE 8. THE TOTAL NUMBER AND PERCENTAGE OF FISH RECOVERED WITH A. C. AND D. C. FISH SHOCKERS IN SPRING BROOK AND WILDER CREEK

Location and date	Species	DIRECT CURRENT: Number marked fish present	DIRECT CURRENT: Number recovered: Marked	DIRECT CURRENT: Number recovered: Unmarked	DIRECT CURRENT: Percent recovery	ALTERNATING CURRENT: Number marked fish present	ALTERNATING CURRENT: Number recovered: Marked	ALTERNATING CURRENT: Number recovered: Unmarked	ALTERNATING CURRENT: Percent recovery
Spring Brook Lower section June 5-7, 1950	Brown trout	49	26	11	53.1	35	10	4	28.6
	Rainbow trout	17	11	6	64.7	5	4	2	80.0
	Brook trout	2	2	0	100.0	1	1	0	100.0
	White sucker	...	...	...	...	0	0	2	0.0
	Sculpin	19	0	13	0.0	11	0	1	0.0
	TOTAL	87	39	30	44.8	52	15	9	28.8
Spring Brook Upper section June 6-7, 1950	Brown trout	43	21	31	48.8	57	20	16	35.1
	Rainbow trout	18	11	6	61.1	21	6	5	28.6
	White sucker	11	6	4	54.5	25	13	6	52.0
	Blacknose dace	15	5	17	33.3	9	6	26	66.7
	Sculpin	22	2	37	9.1	22	2	17	9.1
	TOTAL	109	45	95	41.2	134	47	70	35.1
Wilder Creek[1] June 12-13, 1950	Brown trout	37	18	14	48.7				
	Rainbow trout	16	12	7	75.0				
	Brook trout	3	1	1	33.3				
	Mudminnow	128	6	112	4.7				
	White sucker	1	0	2	0.0				
	Creek chub	1	0	0	0.0				
	Sculpin	39	0	36	0.0				
	TOTAL	225	37	172	16.4				

[1] Wilder Creek was so roily that the few fish taken with A. C. in the first shocking did not warrant a second trip.

In the lower, swifter section on Spring Brook, 44.8 percent of the total number of fish were retaken with the direct-current unit, whereas only 28.8 percent were recovered with the alternating-current shocker. The differential in efficiency is 64.3 percent, in favor of the direct-current aggregate.

In the slower, upper section of Spring Brook, the advantage of D. C. over A. C. was not so noticeable. The alternating-current recovery (36.1 percent) was 85.2 percent of the direct-current figure (41.2 percent).

The rates at which I recovered marked fish are less than those reported by certain other workers (83 to 89 percent, Smith and Elson, 1950; 50 to 95 percent, Schuck, as cited by Elson, 1950). It should be pointed out that the populations assayed by me were largely composed of very small fish, many of which were taken in swift water where it is difficult to see and capture them. The procedure followed was the same as that used in making population estimates in which no concentrated effort was made to obtain a high percentage of all the fish present.

In spite of the unfavorable conditions in Wilder Creek which made use of the alternating-current unit impractical, a total recovery of 16.4 percent of the marked fish of all species was obtained with direct current. The average recovery of trout (all species combined) of 55.5 percent in the muddy water compares very favorably with the alternating-current trout recovery of 34.9 percent in both sections of

Spring Brook. Although these trials were limited, they do indicate that, of the two shockers described, the direct-current machine was superior in all situations encountered. However, they do not indicate that population estimates made with this unit are more reliable.

Fish Mortality Due to Electric Shock

One of the principal objections to the use of electrical shockers in obtaining population estimates has been the relatively high fish mortality reported by some workers (Hauck, 1949; Gerking, unpublished). Such mortality seems to be of two types: (1) instantaneous, where the shocked fish die without recovering consciousness and (2) delayed, where the fish appear to recover but die in a few days, presumably from injuries caused by electrical shock and/or handling.

Hauck (1949) described a 26 percent delayed mortality in the rescue of large rainbow trout (average weight, 3.7 pounds) from an Idaho irrigation canal. Gerking (personal communication), in his experimental work, noticed an apparently similar mortality among bluegill and redear sunfishes. If such mortality is common, and if the extent of such losses is not known, then the value of the shocker in making estimates of the total population will be reduced.

I experimented to determine the extent of mortality caused by both alternating and direct current during the summer of 1950 at the Almena sub-station of the Wolf Lake State Fish Hatchery. Four hundred and fifty legal-sized (7 inches or more in total length) brook, brown, and rainbow trout were used in the experiment. Fifty of each species were marked by removing the anal fin. They were held in an alternating-current field for 15 seconds, one foot from the nearest electrode. An additional 50 of each species, fin-clipped by removal of the adipose fin, were shocked for 15 seconds with direct current. Again they were placed one foot from the electrode. A third group of 50 of each species was kept for controls after having been marked by removing the dorsal fin. They were handled in the same manner as were the others with the exception that they were not exposed to electrical shock.

The brook trout averaged 9.9 inches in total length, the brown trout 7.7 inches, and the rainbow trout 7.5 inches. The two groups were shocked, as described, on May 31, June 19, and again on July 6 when the experiment was terminated. Between exposures to shock, the three groups were randomly mixed and placed in two raceways which were covered with wires to prevent depredations by fish-eating birds. The fish were seined from the pools in order to separate the three groups prior to shocking. Hatchery personnel visited the pools daily to feed the fish and to find, remove, and record any dead specimens.

The physical and chemical conditions of the water appeared to be well within the limits deemed necessary for good results with the shocker. Measurements made on May 31 and June 19 indicated that the resistivity was approximately 3250 ohms per cubic centimeter at 25°C., the pH was 8.0, and the methyl orange alkalinity was 140 p.p.m., expressed as calcium carbonate.

The fish mortality caused by electrical shock and/or handling turned out to be both of the instantaneous and delayed kinds (Table 9). All of the 13 fish killed at once had been left in the electrical field longer than the prescribed period. These fish escaped from the scap nets in which they were being held and were lost from view in the water made turbid by the seining operations. As a result, they lay on the bottom directly under the electrode for several minutes before they were found and removed.

During the course of the experiment, cooperating hatchery personnel found six fish which had died. But at the termination of the tests an additional 25 fish were not recovered. It appears that these fish were taken by two boys with fishing poles who were chased from the pools on the night of June 12. These 25 fish are, therefore, excluded from the sample on the assumption that their loss was due to vandalism and not to the experimental treatment.

The figures show that of the corrected number of 275 fish shocked, 6.5 percent (18 fish) were killed. Mortality caused by alternating current was 11.2 percent (15 trout); that caused by direct current was 2.0 percent (3 fish). Total instantaneous mortality amounted to 4.4 percent, the

TABLE 9. COMPARISON OF INSTANTANEOUS AND DELAYED MORTALITIES IN THREE SPECIES OF TROUT SUBJECTED TO ELECTRICAL SHOCK AND HANDLING

Group	Instantaneous mortality			Delayed mortality[1]			Total number recovered		
	May 31, 1950			May 31, 1950, to June 19, 1950			June 19, 1950		
	Brook	Brown	Rainbow	Brook	Brown	Rainbow	Brook	Brown	Rainbow
Control	0	0	0	0	0 (4)	0	50	46	50
A. C.	1	2	2	1 (3)	2 (10)	0 (2)	45	36	46
D. C.	0	0	0	0	2 (1)	1 (2)	50	47	47
	June 19, 1950			June 19, 1950, to July 6, 1950			July 6, 1950		
Control	0	0	1[2]	0 (1)	0 (1)	0	49	45	49
A. C.	3	4	0	0	0	0	42	32	45
D. C.	0	0	0	0	0	0	50	47	47
TOTALS	4	6	3	1	4	1	141	124	141

[1] Parentheses indicate fish assumed to have been removed by poachers.
[2] Caught in the seine and accidentally crushed by foot of operator.

corrected delayed mortality, 2.1 percent, and grand total, 6.5 percent. That electrical shock is the factor responsible for these deaths, rather than handling, is supported by the fact that none of the fish found dead were among the control individuals.

My data do not approach the high mortality (26 percent) reported by Hauck (1949), even if the unrecovered specimens are included. Neither do they indicate the tendency for mortality in a given species to increase with size of fish as has been reported by some workers. It further appears that the mortality rate in this experiment was considerably higher than that resulting in routine stream work, for in streams (1) there are usually no great concentrations of fish near the electrodes, and (2) the operators move the electrodes quite rapidly so that paralyzed fish do not remain in the field very long even if unseen--hence minimizing the opportunity even for instantaneous mortality.

On the strength of the above experiment and casual observations, it is believed that the fish mortality caused by electrical shock in routine population studies is negligible. Although actual counts were not made, it is doubtful that more than 20 fish were killed in making the population estimates described later in this report. It also appears that, of the few fish so killed, the majority will die without recovering consciousness and will, therefore, be withdrawn from the calculations. It may furthermore be concluded that fish mortality will probably be less with direct current than with alternating current.

Reliability of the Mark-and-Recovery Method of Estimating the Size of Populations

It was pointed out earlier that, although the mark-and-recovery method of estimating the size of populations has been widely used in fishery management in recent years, its reliability has not been universally accepted. According to Ricker (1948) the reliability of this method depends on (1) the assumption that marked fish show the same rates of mortality and response to the collection method employed as do unmarked individuals, (2) a negligible recruitment to the population between the time of marking and recapture, (3) the presence of a relatively high proportion of the total population as marked fish, and (4) the recovery of a high percentage of the marked fish present.

It was reported by Shetter (personal communication) and substantiated by my own experience that shocked and marked fish show no change in response to collection gear when taken with an electrical shocker, provided that the fish are permitted to recover from the initial shock before being shocked again for recapture.

Conflicting statements exist in the literature concerning the effects of fin-clipping on mortality. Shetter (1939) reported a 35.3 percent mortality of fin-clipped brook trout fingerlings, while unmarked fish of the same lot suffered only 26.7 percent mortality. The same author (1951) has shown statistically that lake trout fingerlings marked by the removal of various fin combinations (left pectoral excepted) suffered no increased mortality when kept in captivity a year after marking. On the other hand, the relatively few studies of the effects of marking on fish returned to their natural habitat seem to indicate an appreciable increase in mortality. Ricker (1949) cited the work of Foerster (1936) in which it was found that removal of various fin combinations from fingerling sockeye salmon resulted in a 13 percent average increase in mortality during their 2-1/2 years' absence from the lake where they were marked.

In his own studies, Ricker (ibid.) indicated that larger individuals of certain spiny-rayed species were not harmfully affected by the removal of fins, whereas small bass fingerlings so marked exhibited a survival rate only 52 percent as great as that of unmarked ones. The figures presented above seem not to apply in the present study. Admittedly, small fish in streams probably are more vulnerable to predation by birds, snakes, and larger fish when in a state of partial immobility or loss or partial loss of equilibrium due to: (1) electronarcosis and stages of recovery therefrom (either after fin-clipping or on being shocked in the stream but not recovered) and/or (2) anesthesia from ethyl carbamate. However, the net result in influencing a population estimate is probably slight for the reasons that: (1) only smaller fish are concerned, (2) smaller fish are the ones least likely to be collected when shocked, (3) they are the first to recover from electrical shock, and (4) recovery of fish was attempted within 36 hours and generally within 24 hours after marking. Experience has shown that fish generally do not feed for several hours after recovering from electronarcosis so that predation by larger fish is probably minimal. Mortality due to electrical shock, marking, and handling in such a short period of time is assumed to be negligible.

Since in my studies the stream sections were blocked, with few exceptions, from the time of marking until recovery, usually 24 hours later, recruitment by immigration or losses by emigration can be ignored. The use of the shocker permitted the marking of a relatively large percentage of the total population in most instances. Sculpins were not always taken in proportion to their abundance because of their small size and secretive habit.

Since the percentage of recovery of marked fish varied noticeably, it was considered desirable to measure the reliability of the estimates in terms of the recovery percentages. To conduct these tests, two stream sections, one on Paint Creek, the other on Spring Brook, were used. The sections will be described in greater detail later in this report. Each section was blocked with seines, and the fish were collected electrically and marked as previously described. After a 6-hour wait to permit the shocked fish to recover, a second shocking run was made. The numbers of marked and unmarked fish were recorded, following which the section was shocked repeatedly until no more fish were taken. Population estimates based on the first two trips through the section were then made, using the formula given by Ricker (1948):

$$P = \frac{N\ H}{R} \qquad \text{or} \qquad P = \frac{H}{u}$$

where P = the total estimated population

N = the total number of marked fish present

R = the number of marked fish recovered

H = the total recovery of both marked and unmarked fish

u = the quotient R/N

The estimated and actual numbers of the various species determined are shown in Tables 10 and 11. From the ratio of marked fish recovered to the total number of fish recovered (R/H) in the second shocking run, and by referring to the table of 95 percent confidence limits in Snedecor (1946, page 4), the limits of the estimate at the 95 percent level can be determined. These fiducial limits are shown in parentheses immediately below the estimated numbers of each species in Tables 10 and 11. In no case did the estimate fail to fall within these broad limits.

The magnitude of R/N is a measure of the reliability of the estimate, for the greater the value of the quotient, the narrower will be the spread of the fiducial limits and the greater the reliability of the estimate if it falls within these limits. It may be seen that the estimated numbers of larger fish very closely approximate the actual numbers recovered after repeated shocking. The sizable discrepancies

TABLE 10. THE ESTIMATED AND ACTUAL NUMBERS OF FISH IN A BLOCKED-OFF SECTION OF SPRING BROOK, MICHIGAN, AS DETERMINED WITH AN ELECTRICAL SHOCKER

The limits at the 95 percent level of confidence are shown in parentheses

Species	Number of marked fish present (N)	Number of marked fish recovered (R)	Total number recovered (H)	Ratio R/H	Estimated number (P)[1]	Actual number in section
Brook trout	16	14	16	0.88	18 (16-24)	18
Brown trout	117	63	90	0.70	167 (148-195)	153
White sucker	35	28	32	0.88	40 (35-45)	44
Blacknose dace	12	6	9	0.67	18 (14-46)	36
Sculpin	167	29	189	0.15	1092 (835-1670)	839
TOTALS					1335	1090

[1] $P = \frac{N\,H}{R}$, see text.

TABLE 11. THE ESTIMATED AND ACTUAL NUMBERS OF FISH IN A BLOCKED-OFF SECTION OF PAINT CREEK, MICHIGAN, AS DETERMINED WITH AN ELECTRICAL SHOCKER

The limits at the 95 percent level of confidence are shown in parentheses

Species	Number of marked fish present (N)	Number of marked fish recovered (R)	Total number recovered (H)	Ratio R/H	Estimated number (P)[1]	Actual number in section
Brown trout	1	0	1	...	2	2
White sucker	13	4	9	0.44	30 (18-108)	29
Blacknose dace	16	4	9	0.44	36 (29-200)	39
Bluntnose minnow	6	2	3	0.67	9 (7-32)	14
Sculpin	117	23	114	0.20	580 (403-900)	672
TOTALS					657	756

[1] $P = \frac{N\ H}{R}$, see text

between estimated and actual numbers of blacknose dace and sculpin may be explained on the premise that these very small individuals are not readily seen or captured so that the values of the total number taken even after careful and repeated shocking, may be no more reliable than the estimates.

From the results of these tests, although they are limited in number, it may be assumed safely that estimated numbers of large fish based on R/H values of 0.50 or greater are generally reliable within the limits of practicality as arbitrarily set at the 95 percent fiducial level. Estimates based on low values of R/H are not reliable regardless of the size of the fish.

ECOLOGY OF THE STREAMS AND THEIR FISH POPULATIONS

Most of the waters designated as trout streams in the southern part of the state receive extremely heavy fishing pressure during the early spring, while the better ones among them provide angling for numerous fishermen throughout most of the open trout season. All are stocked with legal-sized hatchery trout (7 inches in length or greater) prior to the opening day and occasionally during the course of the season.

Except for a few catch records and some subjective reports, there exists little factual information on the success of stocking and the ability of the various streams to support and produce trout. Yet from these reports, there is an indication that both the success of stocking and the ability of the streams to support trout vary tremendously between streams. This phase of the investigation was conducted with the purpose of determining and isolating if possible the factors influencing trout production in representative southern Michigan streams.

The Streams Studied

The thirteen streams chosen for study are located in that part of the state south of highway M-46. Nearly all are within convenient driving distance of large centers of population and are heavily fished at least during the early part of the open season. All streams were receiving annual plantings of hatchery-reared trout at the time of the study. These water courses are so widely scattered across the state that the time required for travel would have made it impractical to attempt a detailed study of all of them. Therefore, following a superficial examination of each stream, four were selected for intensive investigation. The nine streams examined only superficially are listed below and are described at length in Appendix II.

Paint Creek, Oakland County

Rice Creek, Calhoun and Jackson Counties

Glass Creek, Barry County

Silver Creek, Allegan County

Bear Creek, Allegan County

Sand Creek, Allegan County

Swan Creek, Allegan County

East Branch of the Paw Paw River, Van Buren County

Kenzie Creek, Cass County

The four waters studied intensively were chosen to include, insofar as it was possible to determine from existing information, both good trout streams with sizable populations of naturally reproduced fish and streams whose trout populations are believed to be maintained largely, if not entirely, by the stocking of legal-sized hatchery-reared trout.

The four streams that received intensive study are:

Paint Creek, Washtenaw County

North Branch of the Saline River, Washtenaw County

Wilder Creek, Calhoun County

Spring Brook, Kalamazoo County

Basis for Selection of Streams and Sections for Study

The selection of the four streams and the sections on each to receive intensive study were based on accessibility and personal judgment, rather than on a method of random sampling as suggested by Mottley (1942b), for several reasons: (1) relatively large portions of some streams flow through privately owned lands and were not then open to me for study; (2) some waters are too deep and others support excessive cover of brush and shrubs on the banks which made impossible the use of census methods selected for the investigation; and (3) it was desirable to have the group include both good and marginal trout streams located relatively close to each other in order to facilitate the work. The number and size of the sections selected for study were also determined by accessibility and physical characteristics.

It is true that the findings obtained from the study of these arbitrarily selected streams cannot be applied with complete reliance to all southern Michigan trout waters. Such was not the purpose of the investigation. However, the results of the study may be of great value in the management of other streams in the region if conditions are similar, and if the methods of obtaining the information in the present investigation are given careful consideration.

Procedure

Before attempting to evaluate the effects of the various physical, chemical, and biological factors influencing trout production in each of the streams, a measure of the production first had to be made. To obtain this information, periodical estimates of the fish populations, both trout and non-trout, were conducted according to the methods described earlier. These estimates were designed in some instances to give an indication of the extent of migration into and out of the sections over short periods of time. Since complete creel censuses were impractical, estimates of relative fishing pressure on the streams were obtained through occasional spot creel counts.

On each stream selected, physical and chemical features suspected of influencing production were measured, often at successive intervals. These features include temperature, fluctuation in flow and level, depth, bottom type, distribution of pools, pH, hardness, and electrical conductivity. Samples of the bottom food organisms were taken from randomly selected sites in each of the major bottom types represented. At approximately the same time, samples of the fish population were made in order to compare the food utilized in relation to the food available and to provide an indication of the extent of predation and food competition and the relationship between standing crop of fish and of food.

An effort was made to measure the success of trout spawning in each stream by making nest counts throughout the spawning season and by determining the number of viable eggs in a sample of nests. All hatchery-reared fish of each planting were given a distinctive fin-clip in order that they might be identified at a later date, and that survival rates might be estimated.

Description of the Streams

The four waters studied intensively include, by reputation, excellent, fair, and marginal trout streams as indicated. Two are in the southeastern, one in the south-central, and one in the southwestern portion of the state.

Paint Creek

Paint Creek arises in Washtenaw County in the southeastern part of the state. It flows 30 miles generally south and east and enters Lake Erie in the vicinity of Monroe, Michigan. The soil in this region is composed largely of a mixture of clay, loam, and fine sand, and is relatively impervious to water infiltration. Most of the rainfall leaves the soil as surface runoff and very little percolates into the ground. The runoff is further increased by intensive cultivation of the gently rolling land; and as a result, very few spring-fed lakes and streams are found in the region. Generally, only the marginal land along the stream has a permanent vegetative cover which does aid somewhat in the retention of moisture in the soil.

Paint Creek is formed by tributaries arising in Pittsfield and Ypsilanti townships. The two principal branches originate in agricultural land; but because they are shaded by deciduous trees and dense growths of shrubs and vines along their banks (Figure 9), the water remains cold even during the hot summer periods. The two branches join near the southern boundary of the Washtenaw County Sportsmen Club grounds, southwest of Ypsilanti. Shortly after leaving the Club grounds, the stream flows through open farmlands, and during normal summers, these lower reaches warm to temperatures unfavorable to trout. It therefore appears that only the upper two or three miles of the streams may be considered trout water on the basis of average summer water temperatures (range of midsummer maxima, 53° to 67°F.).

The water in the Paint system is slow-moving over a bottom of fine sand and silt. Only rarely is fine gravel encountered. The organized sportsmen in the area have installed numerous artificial improvement devices designed to create pools, and without doubt have succeeded in improving conditions considerably. On the basis of these improvement devices, a pool-grade value of 1 (Embody, 1927a) is assigned this portion of the stream. Vegetation in the stream is practically non-existent, probably due largely to the shifting of bottom materials. The brown and the rainbow trouts are the only game fish in the upper portions of the stream, although a sizable non-game fish population occurs in the spring and early summer. The various

Figure 9. Paint Creek within the Washtenaw County Sportsmen Club grounds approximately four miles southwest of Ypsilanti. Note the heavy foliage which almost completely shades the stream.

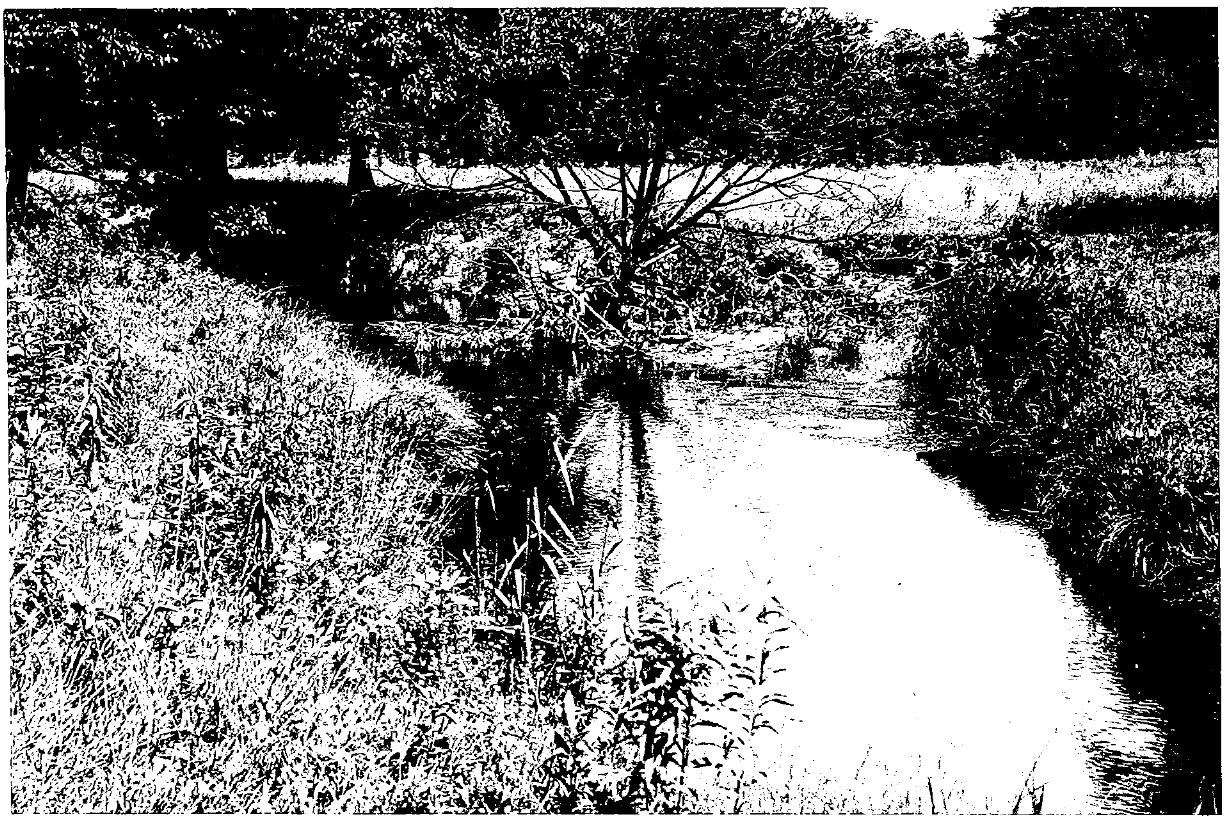
physical, chemical, and biological features of Paint Creek are discussed in greater detail in following sections.

North Branch of the Saline River

The North Branch of the Saline River also arises in the agricultural lands of Washtenaw County. It is formed by three tributaries which are little more than agricultural drains and by one short branch which has its source in a small spring-fed swamp on the west side of the Ann Arbor-Saline highway. Two of the principal tributaries arise in Pittsfield township and one in Lodi. During normal summer levels, these affluents are so small and shallow that they can scarcely be considered trout waters, although their summer temperatures (range of maxima, 61° to 76°F.) appear to be tolerable to trout. Upstream from the Ann Arbor-Saline highway bridge, all portions of the stream suitable for trout are closed to public access. For a quarter-mile below the bridge, the North Branch is quite well shaded (Figure 10) and summer water temperatures are generally within the tolerance limits of trout. However, it then flows through open pasture for a mile before it joins the main Saline River. During this mile of shallow, open-water traverse, through farm and pasture land, the temperature rises rapidly. Figure 11 illustrates the general lack of shade and cover in this portion of the stream.

The Saline River itself is a slow-moving, shallow, warm-water stream and is apparently unsuitable for trout during normal summer weather. Immediately below the

Figure 10. The North Branch of the Saline River, Washtenaw County, Michigan, six miles south of Ann Arbor, as it leaves a wooded area and enters open pasture land. Note flood debris piled against the tree in the center of the picture.



confluence of the North Branch with it, the main stream runs through a reservoir in the city of Saline and then south to join the River Raisin, which empties into Lake Erie at Monroe, Michigan.

Apparently because the North Branch of the Saline River has considerably less shade and cover along its banks than does Paint Creek, it is subject to greater extremes of summer water temperatures throughout its fishable length of 1-1/4 miles. Similarly, the smaller area of the North Branch drainage basin under permanent vegetative cover results in a noticeably greater fluctuation in water levels. Floods are of common occurrence during the spring and early summer months. The stream bottom is composed largely of gravel with large areas of rubble and sand interspaced. A comparatively high stream gradient in the lower stretches tends to keep the gravel and rubble exposed. Aquatic vegetation is rare, represented only by an occasional mat of filamentous algae and Rannunculus. Along the shores are stands of Mentha, Myosotis laxa, Dianthera, and Iris.

The stream is subjected to heavy fishing pressure, particularly during the first few days of the trout season. During the later summer months, few fishermen are seen on the stream. There have been no attempts at trout habitat improvement apparently because there appears to be a good distribution of pools and riffles. However, the quality of the pools is generally poor. Except for a few deep holes with good cover, the majority are shallow, exposed, and

Figure 11. The North Branch of the Saline River, Washtenaw County, Michigan, near its junction with the Saline River proper, approximately seven miles south of Ann Arbor. The general lack of shade and cover is evident.

small. A pool grade of 2 (Embody, 1927a) is assigned. Brown trout and rainbow trout are found in varying numbers from season to season and year to year. They are present as a direct result of yearly stocking operations, and are a small part of a highly varied native fish fauna.

Wilder Creek

Wilder Creek is located in Calhoun County in the south-central portion of the state. It has two major tributaries, one of which arises from seepage and springs in the township of Eckford, and the other as the outlet from the northernmost of the three Kesler Lakes in Albion Township. The stream flows generally west and north for nine miles and enters the Kalamazoo River two miles east of Marshall. Because the soil in this region is more porous than in the eastern part of the state, absorption and percolation of water are proportionately greater. As a direct result of this increased absorption and the relatively wide strip of tree- and shrub-covered land on either side of the stream, fluctuations in water level are usually slight and summer water temperatures are generally low throughout the whole length of stream.

There are no falls of consequence in Wilder Creek and few very deep pools in the accessible areas. Pools of moderate depth and good cover are numerous warranting a pool grade of 1. The bottom is composed of large extents of fine gravel interspaced with similar zones of soft, silty bottom. These conditions are to be expected in this region in streams having a relatively slight gradient. Submerged aquatic vegetation is practically non-existent, although there are dense tangles of willow roots in the water. These roots serve as excellent hiding places for fishes and as habitat for aquatic organisms.

The 1-1/2-mile section farthest downstream in Wilder Creek is closed to public access and was, therefore, not studied. Immediately upstream, the local sportsmen have converted a rearing pond adjacent to the creek into a trout pond. Further improvements by this group include a club-house known locally as the "Castle," and the planting of 1/4-mile of stream bank to weeping willows (*Salix babylonica*). These plantations and the native trees and shrubs provide almost complete shade for the stream during the summer months (see Figure 12).

Because Wilder Creek is comparatively close to several urban communities and is considered by the fishermen to be a good trout stream, it naturally is subjected to rather heavy fishing pressure. Angling intensity is greatest at the club grounds, in the 1/2 mile of accessible water below, and in the three miles immediately above the club property. From this point, three miles above the club grounds, to the head of each of the two major tributaries, dredging operations begun in July of 1949 and continuing through the spring and summer of 1950, have straightened and leveled the stream channel to such an extent that it is now merely an agricultural drain. Pools and cover in this portion are no longer

Figure 12. Dense growth of deciduous trees and shrubs provides almost complete shade for Wilder Creek, Calhoun County, Michigan

of preferred quality for optimal trout abode. It appears that water action and the encroachment of bank vegetation will, however, eventually convert the creek to its former condition. Brown trout have been planted annually since 1933; brook trout and rainbow trout have been stocked extensively in the last few years. The three species are a small part of a varied fauna.

Spring Brook

Spring Brook, in Kalamazoo County, is by reputation one of the best trout streams in southern Michigan. It arises in Richland Township approximately seven miles north of Kalamazoo, and, fed by springs all along its course, flows south through moderately hilly terrain to join the Kalamazoo River near Parchment. The organized sportsmen of the region have within the last few years placed a dam at the mouth of Spring Brook and have diverted its waters through a shallow, open ditch into Farwell Creek, thence into Burns Creek. This latter stream empties into the Kalamazoo River approximately two miles north of the original mouth of Spring Brook. The diversion was designed to prevent the trout in the stream from entering the Kalamazoo River so near the city of Kalamazoo, where pollution was thought to be a menace to fish life. The success of this venture cannot be properly evaluated because information on the number trout killed by pollution before the dam was built does not exist. Trout are found in the diversion nearly to the mouth and there is little reason to suspect that they may not enter the Kalamazoo River by this indirect route.

The soil in the western part of southern Michigan is composed mostly of sand and gravel. Although much of the surrounding land is under intensive cultivation, that part of the drainage basin bordering the stream is well covered with deciduous shrubs and trees. The soil porosity and the vegetative cover cause much of the rainfall to be retained in the soil. This water percolates slowly through the ground and emerges as numerous cold springs. The results are that the stream remains cold even on the hottest days, (midsummer maxima, 59° to 62°F.), and it is seldom subject to flooding.

The first mile of Spring Brook from its source flows through open meadows and is so small that it supports few legal-sized trout except temporarily during the spawning season. The remainder of the stream all of the way to its original confluence with the Kalamazoo River, flows through alternately-spaced open meadows and wooded areas (such as shown in Figure 13). Approximately one and one-half miles of this stretch of water is closed to public access. Many excellent pools are thus not available to fishermen. Because the stream gradient appears to be considerably steeper than that of Wilder Creek, there is a greater number and better distribution of riffles. There are relatively few deep pools, but as in Wilder Creek, pools of moderate depth and good cover are numerous. A pool-grade value of 1 is assigned to Spring Brook.

Figure 13. Open meadow on Spring Brook, Kalamazoo County, Michigan, with deciduous forest in the background.

An estimated 80 percent of the bottom of the accessible portions of the stream are gravel; the remainder is composed largely of rubble with some silt and sand present. A total of nine species of fishes has been recorded from Spring Brook. The brook trout and brown trout, both of which have been established by plantings, are the two important game fishes present.

Ecological Features of the Environment

Selected physical, chemical, and biological features of the environment suspected of influencing trout production were measured, some at frequent intervals. The quantitative values of these measurements, together with a discussion of the method employed, will be presented in the following section. Evaluation of the factors will be attempted in the section following the presentation of the fish population characteristics. Although certain features, such as fishing pressure and spawning success, are a vital part of the environment, they are more typically associated with fish populations and will be discussed under that heading.

Location of the Study Sections

The study sections were selected in those portions of each stream which were open to public access, which were known to have trout present, and which could be waded. Only on Paint Creek were the size and location of sections seriously affected by these restrictions. Except for one relatively short stretch of suitable water, there was either an absence of trout during the time of the survey or the stream was so completely grown over with shrubs and vines that walking in the stream was impossible. The locations of the six study stations are given below.

Paint Creek. The section began at a point 55 feet upstream from the lower boundary of the Washtenaw County Sportsmen Club property and extended 550 feet upstream. The upper limit of the section was the junction of the two stream branches.

North Branch of the Saline River

Section A. The lower boundary of this study area was located 175 feet below the Water Works Road bridge. The section extended 1,420 feet upstream to Schultz's wagon bridge or a point 20 feet below the current confluence of the North Branch and a drainage ditch entering from the northeast.

Section B. This part began at the junction just described and continued 1,000 feet upstream to a small natural rock dam. The two sections include most of the stream open to public access which contained trout during the summer months.

Wilder Creek. The study area on Wilder Creek had as its lower boundary the steel and stone bridge just above the sportsmen's clubhouse known as the Castle. The first highway bridge 2,300 feet upstream served as the upper limit of the section.

Spring Brook

Section A. The lower boundary was located at the foot of a riffle 365 feet below the bridge on DE Avenue. The study area extended upstream 300 feet.

Section B. This section began at the fence immediately above the 24th Street bridge and extended 500 feet upstream.

Methods

Measurements of the various features of the environment were taken at the beginning of the study and those which appeared to be subject to variation were made at frequent intervals. The methods employed in obtaining these measurements are given in the following section.

Shallow riffles were generally chosen for the section boundaries for ease in blocking off the areas against fish migration. The barriers consisted of chicken wire fences on steel fence posts driven into the stream bottom. Seines were stretched over the wire and were pegged into the bottom and sides of the stream with steel tent stakes. Rocks and gravel piled on the bottom of the seines with one exception prevented the barriers from washing out underneath and at the sides during the short period of use.

Section lengths were measured to the nearest 5 feet with a 100-foot steel tape. Stream widths were measured generally at 10-foot intervals, to the nearest foot. Depth measurements, taken from a yardstick held vertically on the bottom, were obtained at uniform intervals along the lines denoting width of the stream and usually ranged from

4 to 8 measurements per line. Maps of the sections were prepared which show depth contours at 6-, 12-, 24-, and 36-inch intervals and the extent and location of the various bottom types. The area between successive depth contours and the area occupied by each of the major bottom types were measured from the maps with a planimeter.

Throughout this study, bottom materials have been designated as follows:

Silt - extremely finely divided particles which when disturbed go into suspension and settle very slowly.

Sand - particles varying in size from approximately 0.1 to 2 mm. in diameter.

Gravel - particles ranging from approximately 2 to 50 mm. in diameter.

Rubble - particles ranging from approximately 50 to 150 mm. in diameter.

Bedrock - solid mineral rock.

Hardpan - generally composed of sand and gravel particles cemented together with clay.

The particle sizes given above are only approximations. Because the size of components usually varies with depth into the bottom material, the designation of bottom type has been based on the size of particles predominating in the surface layer.

Air and water temperature measurements were obtained at two- or three-hour intervals in conjunction with other work on the stream at that time. Taylor pocket thermometers were used to obtain these readings. Air temperatures were read with the thermometer shaded from the sun and held at waist height directly above the stream. Water temperatures were determined while the bulb was submerged.

Three-foot graduated stakes or depth gauges were set out to measure the flustuation in water level. The stakes were adequate except during one flood period on the North Branch of the Saline River. In this instance, the height of the water was measured from a pencil mark placed on the bridge near the Saline Water Works pumping station during the crest of the flood. Attempts to measure the extent of siltation in the various sections were made by driving 18-inch stakes into the bottom at selected locations. The stakes were driven down until a notch previously cut coincided with the surface of the bottom. At a later date, the level of the bottom with respect to these notches determined the extent of siltation or digging.

Hydrogen-ion concentration, alkalinity and electrical resistivity were measured primarily for the purpose of determining their influence on the efficiency of the electrical shocker in censusing the fish populations. These variables have been considered important features of the environment and are discussed here. Colorimetric measurements of pH were obtained with Hellige indicator solutions and glass comparator discs graduated to the nearest 0.2 unit. Alkalinity was measured with phenolphthalein and methyl orange indicator solutions and titrated with 1/50 normal sulfuric acid, following the methodology given by the American Public Health Association (1946, page 9); results are expressed as parts per million (p.p.m.) of calcium carbonate. Electrical resistivity measurements were made with a conductivity bridge and dip cell manufactured by Industrial Instruments Company. All values obtained were corrected to 25°C. and expressed as ohms per cubic centimeter.

Samples of the bottom food organisms were taken from randomly selected sites in each of the major bottom types represented. The samples were taken with the square-foot stream sampler described by Surber (1937). After sifting, the organisms were removed and preserved in 70 percent ethyl alcohol. Volumetric measurements by water displacement were made according to the method described by Lagler (1950) for food studies. At approximately the same time the bottom samples were taken, samples of the fish population, both trout and dominant non-trout species, were collected and preserved for study of food habits.

Physical Features

Morphometry. The measurements presented in Table 12 were made during normal summer levels. The length, average width, and area of the various study sections are shown in the first three rows of the table. In the first column under the heading "Depth" are shown the arbitrarily selected depth zones such as 0 to 6 inches, 6 to 12 inches, and so forth. In the columns to the right are

TABLE 12. MORPHOMETRIC AND PHYSICAL FEATURES OF STUDY SECTIONS OF TROUT STREAMS OF DIFFERENT QUALITY IN SOUTHERN MICHIGAN

Observation	Paint Creek	North Branch Saline River Section A	North Branch Saline River Section B	Wilder Creek	Spring Brook Section A	Spring Brook Section B
Length (feet)	550	1420	1000	2300	300	500
Average width (feet)	12.5	11.3	12.3	14.2	12.1	12.3
Area (square feet)	6875	16046	12250	32660	3630	6150
Depth zones (inches), as percentage of surface area of the section						
0-6	29.9	33.6	33.7	14.5	17.6	14.9
6-12	38.3	41.1	21.4	18.5	38.4	25.6
12-24	26.7	23.0	34.7	48.2	39.2	28.3
24-36	4.3	2.1	8.8	18.2	4.3	27.4
36 and deeper	0.8	0.2	1.4	0.6	0.5	3.8
Bottom type, percentage of total area of section						
Silt	1.0	0.8	1.0	27.8	0.8	11.8
Sand	90.6	26.0	93.0	36.0	3.8	62.1
Gravel	8.4	67.9	4.4	27.5	91.2	23.7
Rubble	0.0	4.7	1.2	8.7	4.0	2.4
Hardpan	0.0	0.6	0.4	0.0	0.0	0.0

the areas occupied by each zone in the various sections expressed as percentages of the surface area of the respective section. Completing the table is the presentation of the areas occupied by each of the major bottom types represented. These figures are also expressed as percentages of the total surface area. The possible significance of these values will be discussed later.

Shade and Cover. Hoover and Morrill (undated) showed that in certain New Hampshire trout streams there was no correlation between bank cover (shade) and the numbers or size classes of trout. They also found no correlation between shelter (hiding places) and trout numbers or size classes. However, the variation in amounts of shade and shelter or cover in their streams was slight in comparison to the extremes found in my study sections. Because it was suspected that these extremes might influence trout production significantly, the extent of these features in each section was measured.

The extent of mid-day shade in the study sections ranges from none in Section A of the North Branch to nearly complete streambank cover in Paint Creek. The dense growths of deciduous trees and shrubs margining this latter stream have been described. Section A of the North Branch flows through open pasture land and is entirely without shade except for that provided by the bridge on the Water Works Road. Further, there are no areas of undercut banks nor deep pools to provide shelter. About 30 percent of Section

B of the North Branch flows through deciduous woods. The remainder of the section is in open pasture but has several deep holes with undercut banks. The study section on Wilder Creek is about 90 percent sheltered from the sun by willow plantings. There are numerous deep pools with good bottom cover. Section A of Spring Brook flows through pastureland and has only an estimated 10 percent of its length covered with streamside vegetation. There are, however, four excellent pools with deeply undercut banks. Section B of this stream, although of greater average depth (see Table 12) has only slightly more extensive streamside shrubs, and practically no undercut banks. Bottom cover in the form of a few large boulders and stumps is scarce.

Water Temperature. It has been generally accepted (Allee *et al.*, 1949) that the various species of aquatic animals have different optimum temperature values and that these temperatures, generally above the midpoint of the range tolerated by the species, cause an increase in the rate of biological processes of the animal beyond that of higher or lower temperatures. The warmer the water, within limits, the faster is the growth rate and the sooner will poikilothermal animals reach sexual maturity. Numerous workers have listed slightly different values of the maximum water temperature tolerated by the various species of trout (Embody, 1922, 1927b; Brett, 1944; Fry, Hart, and Walker, 1946; and others).

Since at least a few trout were present in all four of the southern Michigan streams under study, it seemed doubtful that summer water temperatures in any of them would reach the lethal limits reported by these workers. However, frequent readings of both air and water temperatures were taken during the summer of 1949 and 1950 to give some indication of the effect of thermal differences on trout production and to show the correlation between air and water temperatures on any one stream. These temperature readings have been grouped into two-hour periods and are presented in Figure 14. Since the two sections in Spring Brook and the two in the North Branch of the Saline River are adjoining in each stream, the results have been combined to give one set of readings in each stream and thereby provide a larger sample. Admittedly, the numbers of observations during a stated time interval are not sufficient to determine the mean summer temperatures with accuracy. However, they are no doubt adequate to measure the correlation between air and water temperatures and to be suggestive of extremes and the durations thereof (Table 13). From similar measurements, Embody (1927a) was able to predict for streams in the vicinity of Ithaca, New York, the maximum water temperature for any stated air temperature reading.

In spite of the small number of degrees of freedom, it appears that there is very significant correlation at the 5 percent level of significance between mean summer air and water temperatures in all streams except the North Branch.

Figure 14. The relationship in 1949 and 1950 between mean summer air and water temperatures grouped in two-hour periods in four southern Michigan streams. Figures in parentheses denote the number of pairs of readings.

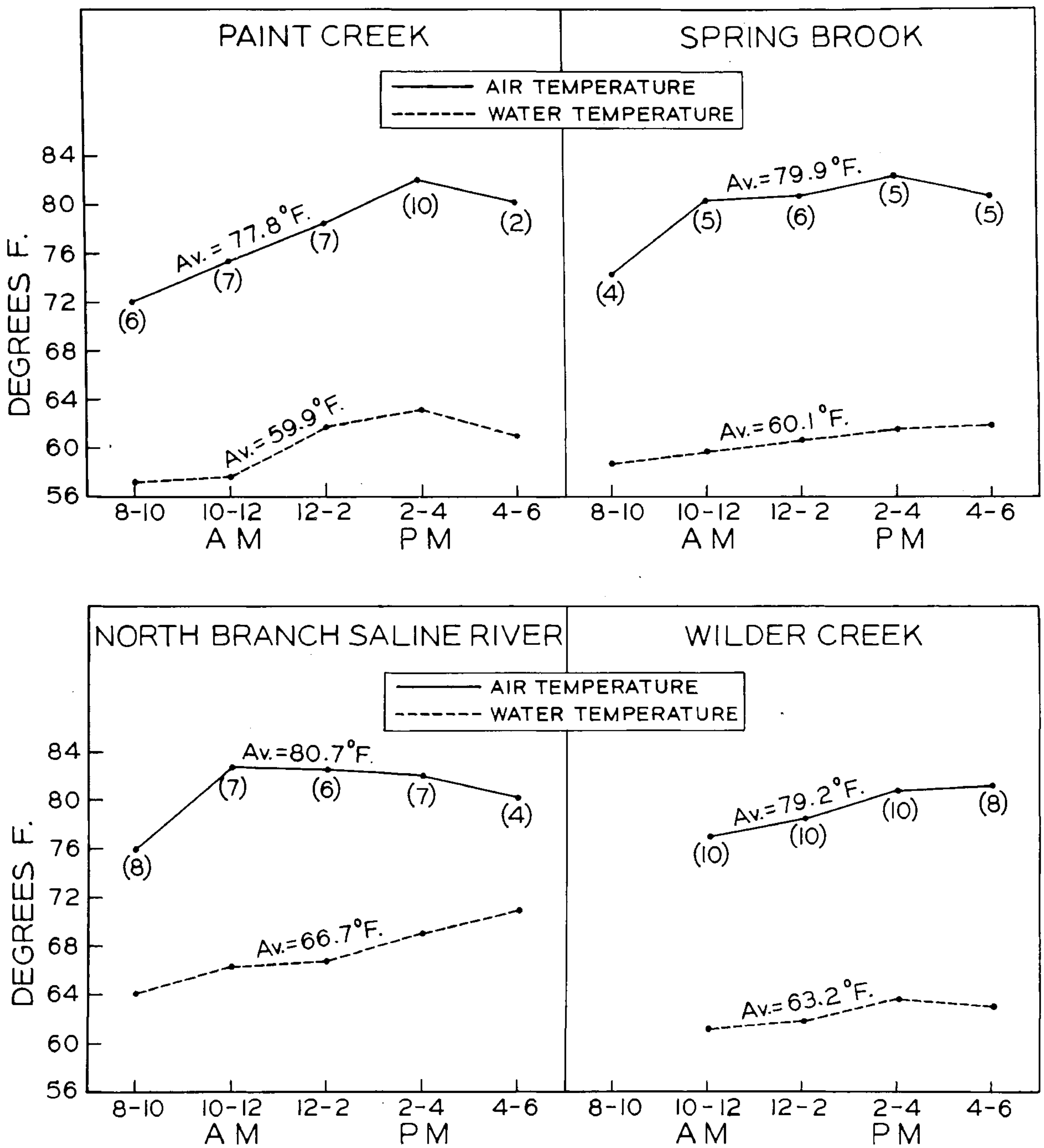

PAINT CREEK
SPRING BROOK
AIR TEMPERATURE
WATER TEMPERATURE
DEGREES F.
84
80
76
72
68
64
60
56
Av. = 77.8°F.
(6)
(7)
(7)
(10)
(2)
Av.=59.9°F.
Av.=79.9°F.
(4)
(5)
(6)
(5)
(5)
Av.=60.1°F.
8-10
10-12
12-2
2-4
4-6
A M
P M
NORTH BRANCH SALINE RIVER
WILDER CREEK
AIR TEMPERATURE
WATER TEMPERATURE
DEGREES F.
Av.=80.7°F.
(8)
(7)
(6)
(7)
(4)
Av.=66.7°F.
Av.=79.2°F.
(10)
(10)
(10)
(8)
Av.=63.2°F.
8-10
10-12
12-2
2-4
4-6
A M
P M

TABLE 13. CORRELATION COEFFICIENTS OF AIR TEMPERATURE WITH MEAN SUMMER WATER TEMPERATURES IN FOUR STREAMS OF EXTREME SOUTHERN MICHIGAN

Stream	Degrees of freedom	Correlation coefficient (r)	Significant correlation at 5 percent level (r)
Paint Creek	3	0.967	0.878
North Branch of Saline River	3	0.160	0.878
Wilder Creek	2	0.978	0.950
Spring Brook	3	0.945	0.878

For the latter, examination of Figure 14 will show an apparent lag in the rise and fall of water temperatures as the air temperatures increase and decrease. This lag explains the lack of correlation (r = 0.160), and is no doubt caused by the relatively great distance between the points where temperatures were read and the source of spring water.

In other words, the water in flowing from its source to the downstream sections had been exposed to warm air (afternoon) for several hours and was still becoming warmer after the air had begun to cool.

Floods and Siltation. Some difference of opinion apparently exist in regard to the effects of floods on stream life. Gerking (1950) in an Indiana stream recovered 75 percent of the warm-water fish population in its original location a few days following a severe flood. He found that small fish were not more seriously affected than large fish by the flood waters. On the other hand, Lord (1946) reported that floods cause serious trout mortality, particularly among the smaller brook trout and in streams with low banks. In addition to direct fish mortality, floods are also reported to lower the oxygen level of the water (Faigenbaum, 1936), and to cause a marked decrease in the supply of invertebrate forage organisms through scouring action and siltation (Nevin, 1936; Allen, 1951; Newcombe, 1951).

Fluctuations in level and volume varied greatly from stream to stream throughout the period of study. The greatest increase in level and flow above summer normals occurred in the North Branch of the Saline River when 437 cubic feet per second of flow were measured on April 4, 1950 (summer normal, 4 cubic feet per second). The Leupold-Stevens midget current meter was employed to measure the current velocity. All other values of volume flow (Table 14) are based on velocities measured by the float method described by Welch (1948, p. 153) and are presumably less accurate.

Attempts at measuring the extent of siltation by means of stakes driven into the stream bottom were successful only to a slight degree. With the exception of the locations at such markers in the North Branch of the Saline River, there was either no apparent change in the bottom level at these points or the markers were removed, presumably by floods. Yet, it was known from maps made previously that in both the North Branch of the Saline River and Paint Creek there was considerable shifting of bottom materials and changes in

Table 14. MAXIMUM OBSERVED FLUCTUATIONS IN WATER LEVEL AND VOLUME OF FLOW IN FOUR SOUTHERN MICHIGAN STREAMS

Measurement	Paint Creek	North Branch of the Saline River	Wilder Creek	Spring Brook
Observed maximum level above normal,[1] inches	4	42	9	5
Normal[1] flow, cubic feet per second	3	4	10	7
Maximum flow, cubic feet per second	14	437[2]	39	23

[1] Normal is taken to be the average of 3 to 7 measurements in June and July, 1949, and 1950.

[2] Value determined using current meter; others by float method.

depth, particularly following periods of high water. Two stakes set out in November, 1949, near a brown trout spawning site in clean gravel showed, four weeks later, a deposition of 4- to 6-inch overlay of sand. The effects of siltation will be discussed in a later section.

Chemical Features

The mean values of selected chemical features are shown in Table 15. Data for the two sections on the same stream have been combined since no appreciable differences in values existed between such sections on the same date. The differences between streams appear to be so small that it is doubtful if hydrogen-ion concentration, alkalinity, or electrical resistivity influence trout production favorably in some streams or unfavorably in others. However, the results are presented here and their possible effects are discussed later.

Biological Features

Consideration of the biological features of a stream which may affect fish production should include aquatic plants and animals present as well as their ecology. However, there was such a scarcity of vegetation in the streams studied that the vegetation influences may be ignored. Since a large part of the field study was concerned with the ecology of the fish populations found in the various stream sections, this discussion is presented in another

TABLE 15. MEAN VALUES OF HYDROGEN-ION CONCENTRATION, PHENOLPHTHALEIN AND METHYL ORANGE ALKALINITY, NORMAL CARBONATE AND BICARBONATE, AND RESISTIVITY MEASURED IN FOUR STREAMS OF EXTREME SOUTHERN MICHIGAN

Stream	pH	Phenolphthalein alkalinity (p.p.m. $CaCO_3$)	Normal carbonate (p.p.m. $CaCO_3$)	Methyl orange alkalinity (p.p.m. $CaCO_3$)	Bicarbonate (p.p.m. $CaCO_3$)	Resistivity (ohms/cc at 25°C.)
Paint Creek	7.96	11.8	23.6	279	255.4	1652
North Branch Saline River	7.85	3.8	7.6	274	266.4	1224
Wilder Creek	7.71	5.3	10.6	249	238.4	1949
Spring Brook	7.98	12.1	24.2	230	205.8	2179

section as a major topic. Of the animals present, only the invertebrates are considered in this section.

Food Supply. During the period of May 5 to August 5, 1949, 110 samples of the bottom food organisms were taken for the purpose of providing a means of comparing potential productivity of the streams in terms of fish food. Then, by comparing the abundance or frequency of occurrence of the various organisms, both in the bottom samples and in sample fish stomachs, it should be possible to evaluate the streams as producers of fish food.

The bottom samples were collected and analyzed according to the methods described earlier. The numbers of organisms by major taxonomic groups in each of the six stream sections are shown in Table 16. Volumes are not included, since the small sizes and small numbers of some of the organisms in many samples made volumetric determinations impossible. The volume of these organisms was recorded as a trace, and hence could not be added. It can be seen that Trichoptera and Diptera, principally Tendipedidae, were the most numerous groups in all sections. A more detailed analysis to lower taxonomic levels of classification is presented as Appendix III, where the 59 different kinds, identified to species in some instances, are listed. Included are the total numbers of organisms and the frequency of their occurrence in the samples.

One of the outstanding features of the distribution of the bottom animals is the extreme variability as shown

TABLE 16. THE NUMBER OF SAMPLES AND THE NUMBERS OF ORGANISMS, GROUPED IN MAJOR TAXONOMIC DIVISIONS, TAKEN IN SIX SECTIONS IN SOUTHERN MICHIGAN

Numbers of samples are given in parentheses

Taxonomic group[1]	Paint Creek	North Branch Saline River Section A	North Branch Saline River Section B	Wilder Creek	Spring Brook Section A	Spring Brook Section B
	(15)	(18)	(23)	(24)	(14)	(16)
Turbellaria	...	...	...	...	1	4
Oligochaeta	143	17	21	3	32	32
Gastropoda	11	17	44	3	11	4
Pelecypoda	...	...	2	3	5	3
Isopoda	...	5	6	9	...	...
Amphipoda	3	3	37	60	1	2
Neuroptera	4	...	1	...	4	6
Ephemeroptera	1	41	48	...	46	52
Plecoptera	97	...	...	...	10	14
Hemiptera	2	34	26	...	...	...
Coleoptera	8	17	57	90	138	178
Trichoptera	5	260	314	173	1021	894
Diptera	519	435	692	719	346	631
Acarina	4	4	5	...	9	5
Totals	797	833	1253	1060	1624	1825

[1]For a more detailed classification, see Appendix III.

both in numbers and volumes of organisms per sample, even when taken from apparently identical situations and types of bottom. This variability is indicated (Table 17) by the large values of the standard deviations with respect to the corresponding means. When the samples are stratified by bottom type, the variation is generally less than when nonstratified, with a few exceptions, but they fail to approach the uniformity reported by Leonard (1939).

The variance (standard deviation squared) for each bottom type is in most instances much greater than the mean. This condition indicates that the organisms are clumped and not randomly distributed even within the major bottom types. It can be seen in Table 18 that the values of the nonstratified samples approach the Poisson type distribution more closely than they do the normal. However, because the values of the nonstratified samples are so greatly influenced by the samples taken in sand, it seemed impractical to calculate a Poisson series to test for fit.

Because of the great variation in numbers and volume of organisms per unit area, a relatively small number of samples, nonstratified or even stratified by bottom type, cannot be used to estimate with any degree of certainty the total population of organisms in a known area. From a further examination of Table 14, however, it does seem reasonable to conclude that bottom types may be classified in decreasing order of richness, both by number and volume of organisms per unit area, as follows: silt, rubble,

TABLE 17. THE MEAN NUMBERS AND VOLUMES (IN CC.) OF ORGANISMS AND STANDARD DEVIATIONS (IN PARENTHESES) OF 110 BOTTOM SAMPLES, NONSTRATIFIED AND STRATIFIED BY BOTTOM TYPES

Study area	Silt		Rubble		Gravel		Sand		Nonstratified	
	Number	Volume	Number	Volume	Number	Volume	Number	Volume	Number	Volume
Paint Creek	125.5 (109.0)	0.99 (0.661)	... ...	... ...	38.3 (29.1)	0.50 (0.173)	19.8 (17.6)	0.09 (0.059)	53.1 (70.6)	0.41 (0.516)
North Branch of the Saline River										
Section A	81.3 (39.4)	0.75 (0.310)	54.5 (29.3)	0.63 (0.330)	42.2 (41.3)	0.30 (0.306)	15.8 (11.0)	0.05 (0.035)	46.3 (37.9)	0.41 (0.374)
Section B	129.7 (56.8)	0.70 (0.519)	67.1 (114.4)	0.57 (0.692)	51.0 (49.5)	0.57 (0.874)	17.4 (26.9)	0.05 (0.110)	54.5 (70.7)	0.41 (0.583)
Wilder Creek	142.8 (113.7)	1.73 (1.52)	42.8 (44.6)	0.46 (0.448)	29.8 (38.9)	0.20 (0.255)	10.0 (8.80)	0.14 (0.148)	44.0 (63.8)	0.48 (0.576)
Spring Brook										
Section A	102.0 (46.6)	0.80 (0.283)	231.5 (67.5)	2.40 (0.547)	89.8 (74.8)	1.54 (0.546)	15.0 (11.5)	0.18 (0.189)	114.0 (98.6)	1.39 (0.940)
Section B	63.0 (35.6)	2.28 (0.826)	282.3 (32.6)	3.10 (0.336)	82.8 (12.9)	0.48 (0.359)	28.5 (14.3)	0.15 (0.040)	114.0 (104.7)	1.50 (1.340)

gravel, sand. This listing is in complete agreement with that of Pate (1934) based on studies in the Raquette watershed in New York. The notable exception is Spring Brook where very large numbers of caddisfly larvae (Brachycentrus americanus) are found on rubble bottom and to a lesser extent on gravel.

It would also seem safe to assume that those stream sections having a large percentage of their area occupied by silt and rubble (as indicated in Table 12) are richer than those in which sand and gravel predominate. On this assumption, it appears that the sections may be listed in order of decreasing richness, by volume of organisms per square foot, as follows: (1) Spring Brook, Section A, 1.510 cc.; (2) Wilder Creek, 0.626 cc.; (3) Spring Brook, Section B, 0.550 cc.; (4) North Branch of the Saline River, Section A, 0.253 cc.; (5) Paint Creek, 0.133 cc.; and (6) North Branch of the Saline River, Section B, 0.085 cc.

These data merely give an approximation of the relative sizes of the standing crop of invertebrates in the various stream sections at the time the sampling was accomplished. They do not indicate the importance of the various groups as food organisms.

Food Habits. The stomachs from 265 fish were collected and the contents analyzed by the same methods employed in the analysis of the bottom samples. With very few exceptions, stomachs were taken at the time the bottom samples were collected. The fish species represented include trout

TABLE 18. FREQUENCY DISTRIBUTION OF ORGANISMS IN 110 BOTTOM SAMPLES, NONSTRATIFIED AND STRATIFIED BY BOTTOM TYPES

Number of organisms per sample	BOTTOM TYPE				Nonstratified
	Silt	Rubble	Gravel	Sand	
0 - 9	2	0	4	11	17
10 - 19	0	5	3	13	21
20 - 29	2	1	5	8	16
30 - 39	0	3	3	1	7
40 - 49	0	1	0	1	2
50 - 59	0	1	1	1	3
60 - 69	4	1	4	1	10
70 - 79	1	0	4	0	5
80 - 89	1	0	2	0	3
90 - 99	0	1	0	0	1
100 - 109	3	1	2	0	6
110 - 119	2	0	0	0	2
120 and up	6	9	2	0	17

and dominant non-trout species in each stream. Only 14 stomachs were empty; the contents of the remaining 251 ranged in volume from a trace to 3.1 cubic centimeters.

It was noted that generally those organisms which occurred most frequently in the bottom samples occurred most commonly in the trout stomachs as well. This was not always true of the smaller non-trout species. In many instances, sculpins, blacknose dace, and the smaller common shiners had fed on organisms that had been taken rarely or not at all in the bottom samples. Usually, fewer kinds of organisms were utilized by these small fishes than by trout and larger individuals of the same species. As an example, in Spring Brook, 20 sculpins had eaten 16 kinds of invertebrates, 11 blacknose dace had consumed 10 different types, while 11 brook trout, 22 brown trout and 9 rainbow trout stomachs contained 30, 36, and 29 different kinds, respectively. Included in the trout stomachs were 7 kinds of terrestrial insects, none of which were found in the non-trout species. However, in the North Branch of the Saline River, 7 creek chubs, 9 common shiners, and 4 pumpkinseeds, ranging from 5 inches to 7 inches in length, had consumed 14, 11, and 19 different types, whereas 12 brown trout and 10 rainbows had utilized 28 and 26 kinds, respectively, a fact which indicates that size of fish in relation to the size of food items determines to a large extent the food habits and preferences of the species. The same relationship between size of fish and food preference is apparent in the data from Paint and Wilder Creeks. (For a complete listing of stomach analysis data see Appendix IV.)

The forage ratios (Hess and Swartz, 1941) of a number of organisms for different fish species were calculated, but because of the great variability in the bottom samples and stomach analysis data, they appear to have limited value in determining the food grade of streams.

Although some competition for food does appear to exist between the trout and non-trout groups, its seriousness cannot be determined, since the food requirements of the fish populations in relation to the food supply are not known. Predation on young trout by non-trout species appears to be rare. However, large brown trout in natural waters were seen to feed on recently planted, smaller hatchery-reared rainbows. (For further discussion of competition for food, see below.)

Ecological Characteristics of the Fish Populations

A knowledge of the size and composition of the fish population at various seasons seems essential to the sound management of a trout stream. Such information should include numbers, weights, and size distribution of the species present so that stream productivity may be measured and rate of harvest by anglers regulated accordingly.

In the attempt to measure the ability of the streams to support and produce trout, special attention was paid to the fish populations themselves. Population estimates were made periodically to detect seasonal changes in species- and age-composition and to measure the survival rates of the trout. Observations during the spawning season were made to determine the extent and success of natural reproduction. Scale samples were taken from naturally reproduced trout for growth analysis. Fingerlings were planted in three of the streams in December (exemplary of earlier stocking practice) to permit a comparison of the success of such planting with that of legal-sized fish made during the fishing season (more recent management procedure).

Since all fish stocked in these streams for several years prior to 1949 had been marked, it was usually possible to distinguish wild trout from planted stock. The fact that unmarked hatchery trout or those marked with a fin-clip not scheduled for release at that time were rarely encountered, attests the fine cooperation of hatchery personnel.

Seasonal changes in the relative abundance of certain fish species were observed in all the study sections. The apparent changes in abundance of the larger fish are no doubt real, whereas those of very small specimens, such as the blacknose dace, Johnny darter, sculpin, and others may be due in part to vagaries of the sampling technique which is admittedly less reliable for smaller fish. It was pointed out earlier that the larger the proportion of marked fish recovered, the more valid the estimate of the standing crop is likely to be. When no marked fish are recovered, an estimate of the number will not be possible. Variations in the calculated sizes and in species composition of the fish populations in the study areas are shown in Tables 19 to 24. Estimates are assumed to be reliable except where indicated otherwise.

Species Composition by Streams

During the period of study, 11 species were encountered in Paint Creek (Table 19). Of these, the hog sucker, common shiner, bluntnose minnow, and brook stickleback appear to be rather uncommon migrants from the more open and warmer water sections downstream. The fact that the number of white suckers increased from 240 per acre on June 7 to 335 per acre on August 19, 1949, while the weight of these fish during the same period decreased from 54.62 to 46.90 pounds per acre, can be explained. During early June, there were still present in the section large mature suckers which had recently spawned. Some of these remained while others gradually dropped into the lower portions of the stream. By August 19, young suckers were being taken and included in the estimates with the result that more fish weighed less. The decrease both in weight and number from May 12 to June 21, 1950, appears also to be directly correlated with the spawning migration of the species. By June 21, many of the adults had returned to downstream areas, while the young were not yet large enough to appear in the census results.

The gradual decrease in the number of blacknose dace and sculpins may be associated with the increased number of legal-sized trout planted in Paint Creek during the course

TABLE 19. SEASONAL VARIATION IN THE CALCULATED SIZE OF THE FISH POPULATION OF THE PAINT CREEK STUDY AREA

Values are expressed as numbers and pounds of fish per acre

Species	June 7, 1949		August 19, 1949		May 12, 1950		June 21, 1950	
	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number
Brown trout	37.01	146	62.94	259	65.95	171	22.79	76
Rainbow trout	47.78	196	11.44	44	11.39	38	3.23	25
White sucker	54.62	240	46.90	335	69.62	253	29.13	145
Hog sucker	...	...	...	...	...	...	0.93	6
Creek chub	2.34	101	0.09	6	1.01	152	...	...
Common shiner	4.90	70	...	...	...	...	...	...
Blacknose dace	9.43	1139	1.37	165	0.25	38	0.70	57
Bluntnose minnow	0.06	6	...	...	...	...	...	...
Johnny darter	0.06	25	0.01	6	...	...	...	...
Brook stickleback	...	...	...	...	...	...	0.03	25
Sculpin	64.68	7583	35.17	5861	20.51	2550	40.09[1]	5331[1]
TOTALS	220.88	9506	157.92	6676	168.73	3202	96.90	5665

[1] No previously marked sculpins were recovered in the second shocking of the section. Therefore, the values used here are the averages of those obtained on the other three dates.

of the study. The average annual plant was increased from approximately 150 trout during the period of 1946 to 1948 to 1,000 in 1949. Fluctuations in the numbers and weight of the natural stock of salmonids were also evident. For the period of study, trout averaged 39.6 percent of the total weight of the population.

During the investigation, 19 species of fishes were observed in Section A of the North Branch of the Saline River (Table 20). The infrequent occurrence of such species as the hog sucker, the hornyhead chub, and the bluntnose minnow in Section A and their apparent abundance in Section B immediately upstream (see Table 21) suggest that the lower study area does not meet the habitat requirements of these species, or, at least that they had moved upstream from it.

The number of white suckers appears to be much more stable in the North Branch of the Saline River than in Paint Creek. Considerable numbers of adults were found in both study areas at all seasons of the year. The slight seasonal fluctuations in numbers may be caused by upstream and downstream migrations through the sections. Discussion of the trout population in the North Branch will be deferred except for the statement that the population apparently is maintained entirely by hatchery plantings of legal-sized trout.

During the period of the investigation, 18 species were recorded in the upper study section on the North Branch of the Saline River (Table 21). As in the previously discussed populations, and as might be expected, there was a general

TABLE 20. SEASONAL VARIATION IN THE CALCULATED SIZE OF THE FISH POPULATION IN STUDY SECTION A IN THE NORTH BRANCH OF THE SALINE RIVER

Values are expressed as numbers and pounds of fish per acre

Species	1949						1950			
	April 5		May 6		August 10		April 14		May 25	
	Lbs.	No.	Lbs.	No.	Lbs.	No.	Lbs.	No.	Lbs.	No.
Brown trout	13.44	5[1]	7.47	3		73	4.40	5		160
Rainbow trout	...	...	...	...		38	0.33	3		122
White sucker	242.74	394	183.82	304		274	127.73	106		426
Northern redhorse	...	...	...	...		...	6.25	5		...
Hog sucker	3.58	19	...	...		8		...		...
Creek chub	6.94	302	0.39	109		750		185		144
Common shiner	33.22	204	11.11	76		73		29		76
Hornyhead chub	...	...	...	...		22		...		...
Blacknose dace	2.52	315	4.08	204		878		321		197
Bluntnose minnow	0.05	14	...	...		8		...		...
Stoneroller	16.89	307	10.35	370		1035		410		451
Grass pickerel	0.73	8	...	...		43		6		12
Mudminnow	0.21	19	0.86	95		30		21		36
Rainbow darter	...	...	0.03	8		228		114		28
Johnny darter	0.25	84	0.03	14		285		528		394
Largemouth black bass	...	...	...	...		17		...		36
Pumpkin-seed	...	...	0.38	11		8		...		8
Rock bass	...	...	1.52	3		8		3		3
Sculpin	29.25	3250	35.59	5084		4611		3660		7383
TOTALS	349.82	4921	255.63	6281		8389		5396		9476

[1]Fish stocked in previous years.

tendency toward increasing numbers of smaller sized individuals as the season progressed, probably due to recruitment by young-of-the-year fish. There is, however, a gradual decrease (with a few exceptions) in average weight of fish from April through August for such species as the white sucker, creek chub, common shiner, and bluntnose minnow. It may be assumed that in one other species, the stoneroller, which does not show such a pronounced decrease in average weight, the young were not recovered in sufficiently large numbers to make estimates reliable. The stoneroller was especially abundant in both sections at all seasons sampled. Smith et al. (1949) noted that in southeastern Minnesota trout streams, a great abundance of stonerollers indicates that the stream is too warm or too muddy for high production of trout. Apparently the same condition is true of the North Branch of the Saline River. In Sections A and B, trout consisted of only 3.4 percent and 12.5 percent, respectively, of the total average weight of the populations during the period of study, and over 95 percent of these fish came from plantings of the current season.

The total fish production in both sections of the North Branch of the Saline River during the period of the study appears to be considerably higher than that in Paint Creek. The higher mean summer water temperature and smaller percentage of low-productivity sand bottom (Table 12) in the North Branch doubtless contributes at least somewhat to its greater productions.

TABLE 21. SEASONAL VARIATION IN THE CALCULATED SIZE OF THE FISH POPULATION IN STUDY SECTION B ON THE NORTH BRANCH OF THE SALINE RIVER

Values are expressed as numbers and pounds of fish per acre

Species	1949								1950	
	April 11		June 13		July 12		August 15		May 11	
	Lbs.	No.	Lbs.	No.	Lbs.	No.	Lbs.	No.	Lbs.	No.
Brown trout	37.44	18[1]	18.94	107	10.41	43	22.14	82	32.13	135
Rainbow trout	1.64	4[1]	16.05	107	4.63	25	1.77	11	9.77	85
White sucker	83.70	135	164.21	431	109.98	235	123.12	342	148.58	242
Hog sucker	2.04	7	21.60	100	2.10	7	1.69	7	1.24	4
Creek chub	6.01	154	22.95	765	22.32	797	61.07	4698	7.51	221
Common shiner	1.41	43	2.13	71	2.99	299	0.31	11	2.34	57
Hornyhead chub	0.17	4	0.90	29	0.22	7	...	...	...	...
Blacknose dace	10.56	352	6.84	285	38.63	6438	20.50	1708	14.90	573
Bluntnose minnow	0.01	7	0.14	14	...	...	...	...	0.07	11
Stone-roller	15.13	488	36.76	1313	2.56	128	54.49	1679	10.46	317
Grass pickerel	0.46	7	4.00	50	0.51	57	8.72	178	1.38	14
Mudminnow	0.22	28	0.23	57	0.40	50	0.45	64	0.01	4
Rainbow darter	0.06	28	0.38	189	0.11	57	0.50	249	0.04	21
Johnny darter	0.17	171	0.38	384	1.25	1253	1.22	1217	0.03	25
Largemouth black bass	...	...	0.04	4	...	...	0.49	14	...	...
Pumpkin-seed	...	...	0.22	7	0.35	7	0.31	7	0.35	11
Rock bass	1.26	14	...	...	...	...	...	...	...	...
Sculpin	16.65	1850	42.32	7053	33.65	5609	39.81	7961	19.93	3690
TOTALS	176.93	3310	338.09	10966	230.11	15012	336.59	18428	251.91	5410

[1] Fish stocked in previous years.

The results of the fish population estimates in the Wilder Creek study section during 1949 and 1950 show it to be composed of 16 species (Table 22). It is believed that the estimates made on the last three dates shown in the table are only moderately reliable because after the middle of July, 1949, the stream was kept in an extremely roily condition by dredging operations upstream (described earlier) which made it difficult to recover shocked fish. In fact, the water was so turbid during the spring and summer of 1950 that the alternating-current shocker could not be used satisfactorily. Even the direct-current unit, employed on June 12, resulted in a low recovery rate of marked fish present; as a result the estimates are not too reliable. Also because of the dredge-dislodged debris in the water, a blocking seine could not be used at the ends of the section to prevent fish migration.

It appears that many species showed a decrease in numbers shortly after the dredging began in Wilder Creek. Whether this decrease was real or due to a shortcoming of the sampling method is not definitely known. The average production in pounds of fish per acre, although based on only two estimates, appears to be considerably lower than that in the study areas of the North Branch of the Saline River and Paint Creek. In this stream, trout comprised an average of 30.9 percent of the weight of the whole population during the period of study.

In both sections of Spring Brook, relatively few species of fish were noted (Table 23). As in the other streams studied, the sculpin is most numerous. The apparent seasonal

TABLE 22. SEASONAL VARIATION IN THE CALCULATED SIZE OF THE FISH POPULATION IN THE STUDY SECTION ON WILDER CREEK

Values are expressed as numbers and pounds of fish per acre

Species	May 27, 1949		July 20, 1949		August 17, 1949		June 12, 1950	
	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number
Brook trout	9.22	49		5		3	1.29	5
Brown trout	18.09	117		88		107	12.08	89
Rainbow trout	17.37	104		53		21	2.76	35
White sucker	27.20	136		327		175	0.81	4
Creek chub	5.05	101		3		131	0.07	1
Common shiner	0.28	7		24		37	...	...
Blacknose dace	0.34	17		79		13	...	...
Black bullhead	0.02	3		...		1	...	...
Grass pickerel	...	...		4		93	0.32	3
Mudminnow	3.09	309		867		929	33.52	3356
Johnny darter	0.20	40		8		12	...	...
Blackside darter	0.03	5		...		3	...	...
Green sunfish	0.02	4		5		3	0.01	1
Bluegill	0.02	2		3		1	0.01	4
Pumpkinseed	...	...		1		...	0.01	1
Sculpin	20.46	2273		4099		7600	40.10[1]	4567[2]
TOTALS	101.39	3167		5566		9117	90.98	8076

[1] Based on the average weight of sculpins measured May 27, 1949.

[2] This value is the average of three earlier estimates and is used since no previously marked fish were recaptured during the second shocking of the section.

fluctuations in abundance of this species more probably reflects an inadequacy of the census method for such small fish of secretive habit than a real change in the population size. For unknown reasons, the data fail to show the usual seasonal changes in average weight and numbers of white suckers in the section. It appears that the relatively large size of the standing crop of all species in pounds of fish per acre is due mainly to the size of the trout component (which averaged 56.2 percent of the total population) for the period of study in this stream.

The seven species in the fish population of Section B, Spring Brook, seem to be permanent residents of this stretch, although the brook trout and grass pickerel are not common (Table 24). The presence of the grass pickerel in the slower, downstream portions is considered by sportsmen of the region to be a serious factor in trout survival. The numbers of the predatory esocid, however, appear to have been reduced in recent years by natural means to a level which I do not consider serious. Recruitment to the population by young-of-the-year fish, which can be estimated by the means employed, generally appears in July. However, since the section was not censused in late summer, the effects of such recruitment are not shown fully in the data.

The average weights of the Spring Brook populations for the period of study are essentially the same in both study sections. In Section B, trout comprised 72.0 percent of the total population by weight. Variations in total weight of

TABLE 23. SEASONAL VARIATION IN THE CALCULATED SIZE OF THE FISH POPULATION IN STUDY SECTION A ON SPRING BROOK

Values are expressed as numbers and pounds of fish per acre

Species	June 2, 1949		June 29, 1949		April 18, 1949		June 5, 1950		June 12, 1950	
	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number
Brook trout	30.48	168	4.35	24	6.39	60	2.05	24		24
Brown trout	75.33	482	88.41	566	118.19	878	97.95	856		735
Rainbow trout[1]					10.60	229	14.70	313		169
White sucker	43.01	229	81.50	434	55.18	145	...	...		265
Blacknose dace	0.96	72	...	...	0.12	24	...	...		48
Sculpin	93.85[2]	12373[2]	16.54	2205	16.15	2170	42.18[3]	5534[3]		5386
TOTALS	279.59	13553	190.80	3229	207.23	3506	156.88	6727		6639

[1] Rainbow trout first stocked in Spring Brook December 13, 1949.

[2] These apparently high figures are the result of recovery of only one marked fish. The estimate for this species is probably not too reliable.

[3] Because no marked fish were recovered in the second shocking of the population, the values for this estimate are the average of weights and numbers of the other estimates shown.

non-trout species between sections on comparable dates is no doubt the result of both migration and natural mortality, including fishing. Similar variations in the weight of the trout population will be discussed in the following section.

Comparison of Standing Crops of Fishes with Those of Other Regions

The size of the standing crop of fish, expressed as an average for the period of study, shows considerable variation between streams. These values are: Paint Creek, 161.1 pounds per acre; North Branch of the Saline River, Section A, 302.7 pounds per acre, and Section B, 266.7 pounds per acre; Wilder Creek, 96.2 pounds per acre; Spring Brook, Section A, 208.6 pounds per acre, and Section B, 200.5 pounds per acre.

Other investigators, too, have determined the standing crop of fish (in pounds per acre) in trout waters using the same censusing methods I have employed and other methods not described here. In New Hampshire, Hoover (1938) found a range of 29.7 to 158.4 pounds of fish in unfished primitive brook trout streams, and 1.3 to 94.47 pounds in fished streams. Shetter and Hazzard (1939) estimated 4.09 to 177.95 pounds in northern Michigan. Smith, *et al.* (1949) reported weights of 91.10 pounds to 547.21 pounds of fish per acre in Minnesota. Still others have reported similar results. Although the sizes of the standing crops determined in the present study are similar to those cited, the conditions under which these values were obtained were not strictly comparable. None of the streams investigated by the workers cited was stocked

TABLE 24. SEASONAL VARIATION IN THE CALCULATED SIZE OF THE FISH POPULATION IN STUDY SECTION B ON SPRING BROOK

Values are expressed as numbers and pounds of fish per acre

Species	June 2, 1949		February 2, 1950[1]		April 19, 1950		June 7, 1950	
	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number
Brook trout	12.87	156		28	0.70	21	...	...
Brown trout	47.04	489		645	140.32	1,567	185.74	1,638
Rainbow trout[2]				390	48.72	865	19.93	284
White sucker	39.63	184		78	30.71	156	41.84	262
Blacknose dace	0.36	42		21	1.03	113	3.12	340
Grass pickerel	...	...		...	0.42	7	...	...
Sculpin	8.20	1,000		816	8.58	943	12.13	1,482
TOTALS	108.10	1,829		1,978	230.48	3,672	262.76	4,006

[1] Extreme cold made fin-clipping difficult; results are based on two shocking operations through the section in which all fish were removed, counted, and returned to the section at the end of the second run.

[2] Rainbow trout first stocked in Spring Brook December 13, 1949.

during the season of the studies prior to the time the populations were measured; whereas, in the present investigations, hatchery trout were planted at frequent intervals during the course of the work. Such frequent plantings during the census period may well have increased the size of the standing crop considerably over the level it would maintain without such plantings.

Dynamics of the Trout Populations

It was stated earlier that, as far as could be determined from existing information, some of the streams were considered excellent trout waters whereas others probably did not support sizable populations of naturally reproduced fish. The results presented here are in agreement. All the streams studied were stocked with legal-sized trout at approximately monthly intervals just preceding and during the regular trout fishing season. In addition, a large December planting of sub-legal fingerlings was made in Spring Brook, in Wilder Creek, and in the North Branch of the Saline River. The trout were well scattered to prevent unnatural concentrations inside the sections and to eliminate the possibility of attracting fishermen in more than normal numbers. The composition of the trout populations in the various sections and the survival rates of trout of the several plantings were determined by periodical population estimates.

Structure of the Trout Populations. All southern Michigan streams now having trout populations probably have them as the result of artificial plantings, past or current. Sportsmen reported that Paint Creek supported many large brook trout 35 to 50 years ago. This species has now been replaced by brown trout and rainbow trout, but the latter apparently have failed to become well established. No naturally reproduced or wild[1] rainbows and relatively few wild brown trout were recovered in the study section (Table 25). It is believed that these results are valid for the stream as a whole since the study area represents a large proportion of the suitable summer trout water in the stream.

The North Branch of the Saline River has been stocked annually with brown and intermittently with rainbow trout since 1942. Apparently neither species has become well established. The trout populations estimated in the two study sections (Tables 26 and 27) consist almost entirely of currently stocked fish. The only other trout observed were a few brown trout planted before 1949. Apparently trout fishing in the North Branch is being maintained entirely by current plantings of legal-sized fish.

Wilder Creek has been receiving plantings of brown trout annually since 1933. Brook trout have been stocked annually since that date with a few exceptions, whereas rainbows were first planted in 1948. Of the three species, only the brown trout seems to have become established in Wilder Creek. Neither wild brook or rainbow trout nor survivors of these species from earlier plantings were taken in the study

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[1] The term "wild" refers to the progeny from eggs actually laid in the stream by the parent fish regardless of parent-fish origin.

TABLE 25. THE COMPARATIVE SURVIVAL RATES OF HATCHERY-REARED TROUT IN PAINT CREEK

The distinguishing fin-clips are shown

(Planting dates shown in parentheses)

Species and mark	Number planted	Number per acre (estimated)				
		June 7, 1949	August 19, 1949	May 12, 1950	June 21, 1950	July 10, 1950
Brown trout						
Rt. pectoral	...	6[1]	...	...	...	...
L. pect. (5-24-49)	100	134	0	0	0	0
L. pelv. (6-28-49)	100	...	0	0	0	0
Rt. pelv. (7-29-49)	100	...	76	6	6	6
Rt. pect.-ad. (8-18-49)	100	...	177	6	6	13
Anal (4-20-50)	100	...	...	133	13	13
Dorsal (5-17-50)	100	...	...	...	44	19
Rt. pelv.-ad. (6-27-50)	100	...	...	...	...	209
Wild	...	6[2]	13[2]	...	6	13[2]
Rainbow trout						
Rt. pect. (4-15-49)	200	101	0	0	0	0
L. pect. (5-24-49)	100	95	0	0	0	0
L. pelv. (6-28-49)	100	...	0	0	0	0
Rt. pelv. (7-29-49)	100	...	6	6	0	0
Rt. pect.-ad. (8-18-49)	100	...	38	0	0	0
Anal (4-20-50)	100	...	...	38	0	0
Dorsal (5-17-50)	100	...	...	...	25	6
Rt. pelv.-ad. (6-27-50)	100	...	...	...	...	140

[1] Represents a recovery of one fish apparently planted by mistake.
[2] Includes fish stocked before 1949.

TABLE 26. THE SURVIVAL RATE OF HATCHERY-REARED TROUT IN SECTION A OF THE NORTH BRANCH OF THE SALINE RIVER

The distinguishing fin-clips are shown

(Planting dates shown in parentheses)

Species and mark	Number planted	Number per acre (estimated) April 5, 1949	May 6, 1949	January 20, 1950	April 14, 1950	May 25, 1950
Brown trout						
L. pect. (5-24-49)	100	...	...	22	3	5
L. pelv. (6-28-49)	100	...	...	8	0	8
R. pelv. (7-29-49)	100	...	...	52	3	3
R. pect.-ad. (8-18-49)	100	...	...	14	0	5
Adipose[1] (12-14-49)	250	...	...	76	0	19
Anal (4-20-50)	100	...	...	...	...	63
Dorsal (5-17-50)	100	...	...	...	...	71
Wild	...	5[2]	3[2]	...	...	...
Rainbow trout						
Rt. pect. (4-15-49)	400	...	0	0	0	0
L. pect. (5-24-49)	100	...	...	0	0	0
L. pelv. (6-28-49)	100	...	...	0	0	0
R. pelv. (7-29-49)	100	...	...	0	0	0
R. pect.-ad. (8-18-49)	100	...	...	35	0	0
Adipose[1] (12-14-49)	256	...	...	0	3	43
Anal (4-20-50)	100	...	...	...	...	30
Dorsal (5-17-50)	100	...	...	...	...	60

[1] Fingerlings.

[2] Stocked before 1949.

TABLE 27. THE SURVIVAL RATE OF HATCHERY-REARED TROUT IN SECTION B OF THE NORTH BRANCH OF THE SALINE RIVER

The distinguishing fin-clips are shown

(Planting dates shown in parentheses)

Species and mark	Number planted	Number per acre (estimated)				
		June 13, 1949	July 12, 1949	August 10, 1949	April 21, 1950	July 11, 1950
Brown trout						
L. pect. (5-24-49)	100	103	7	4	14	0
L. pelv. (6-28-49)	100	...	32	21	7	0
Rt. pelv. (7-29-49)	100	...	...	57	50	7
Rt. pect.-ad. (8-18-49)	100	...	...	...	11	4
Adipose[1] (12-14-49)	250	...	...	...	43	14
Anal (4-20-50)	100	...	...	...	384	28
Dorsal (5-17-50)	100	...	...	...	...	25
Rt. pelv.-ad. (6-27-50)	100	...	...	...	...	64
Wild	...	4[2]	4[2]	...	4[2]	...
Rainbow trout						
Rt. pect. (4-15-49)	400	46	7	0	0	0
L. pect. (5-24-49)	100	60	14	4	0	0
L. pelv. (6-28-49)	100	...	4	0	0	0
Rt. pelv. (7-29-49)	100	...	...	7	4	0
Rt. pect.-ad. (8-18-49)	100	...	...	...	28	4
Adipose[1] (12-14-49)	256	...	...	...	64	11
Anal (4-20-50)	100	...	...	...	320	0
Dorsal (5-17-50)	100	...	...	...	...	21
Rt. pelv.-ad. (6-27-50)	100	...	...	...	...	146

[1] Fingerlings.

[2] Stocked before 1949.

section. On the other hand, of the total brown trout estimated to be present (Table 28), an average of 40.25 percent were wild fish. The return of wild fish to the fishermen will be discussed in a following section.

Brook trout and brown trout have been stocked annually in Spring Brook since 1933. Prior to this date, the former species seems to have been the dominant trout according to records in the files of the Institute for Fisheries Research. The first recent stocking of rainbow trout occurred in 1949, yet catch records of 1928 show the presence of this species in the stream. At the time of the present study, both the brook trout and brown trout appeared to be firmly established in Spring Brook (Tables 29 and 30). However, the relatively high percentage of wild fish in the brook trout populations is due not so much to large numbers of wild trout as to the low survival rate of planted fish of this species. The apparently lower percentage of wild brown trout in Section B is exaggerated by the unreliably high estimates of the fingerlings planted in December, 1949. Omitting these unreliably high estimates, wild brown trout comprise an average for the period of study of 72.1 percent of all brown trout present in Section A and 35.9 percent in Section B.

It appears from the estimates of the trout populations that the rainbow has failed to become established in any of the streams under investigation. The fact that the rainbow was not observed spawning in any of these streams lends further evidence of its failure to maintain itself. The

TABLE 28. THE SURVIVAL RATE OF HATCHERY-REARED TROUT IN WILDER CREEK

The distinguishing fin-clips are shown

(Planting dates shown in parentheses)

Species and mark	Number planted	Number per acre (estimated) May 27, 1949	July 20, 1949	August 17, 1949	July 12, 1950
Brook trout					
Rt. pect. (4-15-49)	350	11	0	0	0
L. pect. (5-24-49)	300	38	5	2	0
Adipose[1] (12-14-49)	700	...	...	...	3
Anal (4-27-50)	300	...	...	...	1
Dorsal (5-16-50)	300	...	...	...	1
Brown trout					
Rt. pect. (4-15-49)	200	28[2]	4	8[2]	0
L. pect. (5-24-49)	200	41	13	19	0
Rt. pelv. (6-17-49)	700	...	49	35	3
Adipose[1] (12-14-49)	700	...	1[3]	5[3]	36
Anal (4-27-50)	300	...	...	...	11
Dorsal (5-16-50)	300	...	...	...	19
Wild	...	48	20	40	21
Rainbow trout					
Rt. pect. (4-15-49)	400	27	0	0	0
L. pect. (5-24-49)	400	77	8	1	0
Rt. pelv. (6-17-49)	900	...	45	20	0
Adipose[1] (12-14-49)	700	...	...	...	33
Anal (4-27-50)	300	...	...	...	0
Dorsal (5-16-50)	300	...	...	...	1

[1] Fingerlings.

[2] Includes specimens of the same plant marked by removal of right pectoral and adipose fins.

[3] Fish stocked before 1949 but marked by removal of the adipose fin.

brown trout seems to have become a permanent resident in Spring Brook and Wilder Creek. Its permanence in Paint Creek is questionable for reasons to be presented later. Even though comparatively small numbers of brook trout were found in the study sections of Spring Brook, the species is well established in other parts of the stream. A few small spring-fed tributaries are well populated with fry and fingerlings and will no doubt continue to supply the main stream with a moderate number of catchable fish.

Survival of Hatchery-Reared Trout. The apparent survival rate of hatchery-reared trout showed considerable variation between species and streams, but was generally quite low. The numbers of fish planted and the numbers estimated in the sections at later dates give an indication of survival rates (Tables 25 to 30). Legal-sized rainbow trout in all streams usually had disappeared entirely in three or four months and only an estimated 38 per acre persisted over winter. Six of these were in Paint Creek and the remaining 32 were in Section B of the North Branch of the Saline River. By July, only 4 fish per acre remained.

Plantings of legal-sized brook trout showed an even lower rate of survival. Few planted fish remained more than a month after planting and no brook trout stocked in the streams during 1949 were recovered in 1950. Comparatively large numbers of brown trout survived the season of planting and many of these persisted through the winter in all streams except Wilder Creek. The conditions in Wilder Creek

TABLE 29. THE SURVIVAL RATE OF HATCHERY-REARED TROUT IN SECTION A OF SPRING BROOK

The distinguishing fin-clips are shown

(Planting dates shown in parentheses)

Species and mark	Number planted	Number per acre (estimated) June 2, 1949	June 29, 1949	April 18, 1950	June 5, 1950	July 12, 1950
Brook trout						
Rt. pect. (4-15-49)	1,000	24	0	0	0	0
L. pect. (5-16-49)	1,000	96	0	0	0	0
Adipose[1] (12-13-49)	1,200	...	...	12	0	0
Anal (4-19-50)	700	...	...	...	0	0
Dorsal (5-16-50)	700	...	...	...	0	0
Rt. pect.-ad.	None	...	...	...	...	24[2]
Wild	...	48	24	48	24	0
Brown trout						
Rt. pect. (4-15-49)	700	72	132	12	0	0
L. pect. (5-16-49)	500	253	0	0	0	0
Rt. pelv. (6-22-49)	500	...	205	60	0	0
L. pelv. (7-26-49)	500	...	...	96	0	0
Rt. pect.-ad. (8-18-49)	500	...	...	120	0	0
Adipose[1] (12-13-49)	1,200	...	...	313	229	96
Anal (4-19-50)	700	...	...	...	48	24
Dorsal (5-16-50)	700	...	...	...	133	36
Wild	...	157	229	277	446	578[3]
Rainbow trout						
Adipose[1] (12-13-49)	1,200	...	...	229	313	169

[1] Fingerlings.

[2] None planted according to available records.

[3] Includes an estimated 434 native fingerlings.

TABLE 30. THE SURVIVAL RATE OF HATCHERY-REARED TROUT IN SECTION B OF SPRING BROOK

The distinguishing fin-clips are shown

(Planting dates shown in parentheses)

Species and mark	Number planted	Number per acre (estimated) June 2, 1949	February 2, 1950	April 19, 1950	June 7, 1950
Brook trout					
Rt. pect. (4-15-49)	1,000	57	0	0	0
L. pect. (5-16-49)	1,000	85	0	0	0
Adipose[1] (12-13-49)	1,200	...	14	7	0
Anal (4-19-50)	700	...	...	...	0
Dorsal (5-16-50)	700	...	...	...	0
Wild	...	14	14	14	0
Brown trout					
Rt. pect. (4-15-49)	700	106	0	7	0
L. pect. (5-16-49)	500	227	0	0	0
Rt. pelv. (6-22-49)	500	...	0	28	7
L. pelv. (7-26-49)	500	...	21	71	0
Rt. pect.-ad. (8-18-49)	500	...	78	177	14
Adipose[1] (12-13-49)	1,200	...	461	574	1,206[2]
Anal (4-19-50)	700	...	...	...	7
Dorsal (5-16-50)	700	...	...	...	191
Wild	...	156	85	319	213
Rainbow trout					
Adipose[1] (12-13-49)	1,200	...	383	865	227
Dorsal	None	...	...	...	57++
Rt. pect.-ad.		...	7+	0	0

[1] Fingerlings.

[2] The one marked fish recovered causes this value to be high.

++ None planted according to available records.

+ The one rainbow trout recovered apparently was planted by mistake with brown trout, having the same fin-mark.

at that time have already been described. Such muddy water made the reliability of census data questionable and may actually have contributed to the apparently low survival. These carry-over fish were numerous in Spring Brook in April, 1950, but by June their numbers had been reduced to 21 fish per acre in Section B and they were absent entirely in Section A (Tables 29 and 30).

Although the survival values just described appear to be low, they are probably not greatly different from those in other trout waters. Investigators who have measured relative survival rates in terms of the catch of marked hatchery fish by fishermen (Gee, 1942; Hazzard and Shetter, 1939; King, 1942), reported similarly low survival rates. It was the general finding that the majority of hatchery fish recovered are taken in the first month to six weeks following planting, although brown trout are not removed quite so quickly as are brook and rainbow trout. The catch of hatchery trout in Michigan streams in the second season following planting has been reported by Shetter (1947b) as generally less than 2 percent, although season-to-season survival appears to be best among brown trout.

The sub-legal fingerlings of the three trout species planted in December, 1949, showed a much better over-winter survival than did the legal-sized individuals of the same species, if measured by the numbers estimated in the study sections. However, it should be noted that the fingerlings were planted in December and in large numbers, while the larger fish were stocked during the previous spring and summer through August. Had they been planted on the same date and in comparable numbers, survival would have been considerably different.

The brook trout fingerlings, like the legal-sized individuals of this species, suffered the highest over-winter mortality rate. However, the extremely small survival of these fingerlings to the last census in 1950 may be partially explained by the fact that these fish averaged 6.5 inches (total length) when planted as compared to 5.1 inches and 4.7 inches for the brown trout and rainbow trout, respectively. A high percentage of those brook trout remaining in the stream on the opening day of trout season (April 29, 1950) were of legal-size, whereas, it is doubtful if many individuals of the other two species were large enough to enter the fishermen's catch at that time. Survival of the brown trout fingerlings was not noticeably better than that of the rainbows. These results are not in agreement with those of many workers who have compared survival rates of the two species and have noted a much higher over-winter survival of brown trout.

Migration. Although it is certain that sizable numbers of fish left the study areas, the extent to which migration influenced the apparent survival of the planted trout is not known. Both wild and hatchery-reared trout, marked within the section boundaries, were later recovered short distances upstream and downstream from the points where the fish were released. Similarly, fish marked above and below the section boundaries were later found inside the study areas.

Of the 30 brown trout marked August 19, 1949, in the study area in Paint Creek, only one (3.3 percent) was taken in the stream below on August 22. However, 6 (40.0 percent) of the 15 suckers marked at the same time were taken below the section boundary 3 days after marking. Only 2 white suckers, or 3.1 percent of the 64 that were marked below Section B in the North Branch on August 10, 1949, had migrated upstream into the section 5 days later. Of the 33 fish marked above the area, 3 suckers (17.7 percent of those marked) had migrated into the section in 5 days.

Of the 479 fish marked on April 18, 1950, in a 300-yard stretch of Spring Brook immediately below Section B, 19 brown trout (10.2 percent of the 185 marked), 5 rainbows (12.2 percent of the 41), and 2 white suckers (2.1 percent of 95) were recovered inside the area the following day. The 123 fish marked above the section on April 18, 1950, yielded only 4 brown trout (2.5 percent) and 6 white suckers (33.3 percent) inside the section the following day. Although Ricker, Mosbaugh, and Lang (1949) reported that in Indiana streams, wandering by trout represents exceptional rather than typical behavior, Shetter and Hazzard (1941) noted considerable migration in Michigan streams, particularly among brook and rainbow trout.

These data, although very limited, do indicate that migration is of considerable magnitude even over short periods of time. The cause of the comparatively great upstream migration of brown trout in Spring Brook in August, 1949, is unknown. The noticeably greater downstream movement of suckers is a result of their apparently greater susceptibility to the shocker. Large specimens are frequently shocked severely with only average exposure to electrical currents. They remain unconscious for long periods and when they do regain their normal swimming position, they appear to be carried helplessly by the current for a variable period of time. When they resume normal activity, many have often been carried long distances downstream.

Had it been practical to conduct a census over greater distances from the sections and at more frequent intervals, the extent of trout migration from the sections might have been more accurately measured and presumably would have been greater than that indicated by the few examples above.

Fishing Intensity in the Streams

Although an intensive creel census was considered impractical, as stated earlier, it was felt that an occasional check of the fishermen's catch might provide information that would be helpful in classifying the streams on the basis of trout production. It was hoped that these spot checks might also add to the information on hatchery-trout survival.

Such checks were made during the opening day of the 1949 trout season (April 30) on the North Branch of the Saline River and on Paint Creek, and during the first two days of the 1950 season (April 29 and 30) on Wilder Creek. Fishermen on Spring Brook were contacted June 2 and 29, 1949, and June 6 and 7, 1950. A few additional reports were received through the local conservation officers. Very few fishermen were encountered on Paint Creek and the North Branch after the first two weeks of the season. The fishing pressure on Spring Brook continued to be heavy into August in 1949, and 8 fishermen were seen June 6 and 7, 1950, in the vicinity of the study sections alone. It was reported by local sportsmen that Wilder Creek is usually intensively fished from opening day (as evidenced by Figure 15) throughout the summer, but that the number of fishermen using the stream decreased sharply in July in 1949, presumably because of the muddy water from the dredging operations upstream.

An analysis of the creel data (Table 31) indicates that the catch in all streams was quite low. Fishermen on the North Branch of the Saline River appeared to be least successful, and those on Paint Creek most successful, in terms of total trout caught per hour of fishing. Although Shetter and Hazzard (1941) noted that in four northern Michigan streams the increase in catch per hour and the total number of hatchery fish caught are inversely proportional to the density of the native fish of the species stocked, it is believed that the higher values reported from Paint Creek are due more to the failure of unsuccessful fishermen to admit the number of hours fished than to a high success rate. It was noticed that they were reluctant to report results, whereas six successful fishermen reported by telephone the following day.

Figure 15. Opening day of the 1950 trout season on Wilder Creek. Note that 11 fishermen may be seen in less than 100 feet of stream.

The catch on Wilder Creek seemed particularly low in view of the fact that 350 brook trout, 200 brown trout, and 400 rainbow trout were stocked in the stream only two days before the opening of the season. Yet in two days of fishing, 125 fishermen removed 26.0 percent of the brook trout, 23.5 percent of the brown trout, and 8.7 percent of the rainbows, or an average of 18.2 percent of all trout stocked. Nineteen fishermen removed 20.5 percent of the 200 rainbows stocked in Paint Creek, whereas 15 fishermen on the North Branch removed only 1.5 percent of the 400 rainbows stocked two weeks earlier.

From the results of marking experiments and creel censuses in several northern Michigan streams (Shetter and Hazzard, 1939, 1941; Shetter, 1947b), it appears that hatchery trout contribute relatively little to the total catch in the majority of streams studied. However, in more recent studies (1949-1951) E. L. Cooper (MS) reported that hatchery trout made up about 70 percent of the total catch in the experimental areas of the Pigeon River in northern Michigan. In the present investigation, the proportion of hatchery fish in the total catch reported ranged from 83.8 percent in Wilder Creek to 100.0 percent in both the North Branch and Paint Creek, with a four-stream average of 90.4 percent. These high figures probably indicate a general scarcity of native trout in the streams as well as a successful planting program.

TABLE 31. NUMBER OF TROUT CAUGHT AND THE CATCH PER HOUR BY SPECIES REPORTED BY 176 FISHERMEN IN FOUR SOUTHERN MICHIGAN STREAMS

Stream	Trout species: Brook Planted	Brook Wild	Brown Planted	Brown Wild	Rainbow Planted	Rainbow Wild	Total trout Planted	Total trout Wild	Number of fishermen hours
Paint Creek									
Number caught	...	...	2[1]	...	41	...	43	...	80
Catch per hour	...		0.03	...	0.51	...	0.54	...	
North Branch, Saline River									
Number caught	...	...	1[1]	...	6	...	7	...	66
Catch per hour	...	...	0.02	...	0.09	...	0.11	...	
Wilder Creek									
Number caught	91	6	47	15	35	...	173	21	619
Catch per hour	0.15	0.01	0.08	0.02	0.06	...	0.28	0.03	
Spring Brook									
Number caught	14	1	17	5	...	...	31	6	83
Catch per hour	0.17	0.01	0.20	0.06	...	...	0.37	0.07	

[1]Stocked before 1949.

Although the catch-per-hour values appear low (Table 31), they approximate figures reported by others for similar streams. Shetter (1950) noted catches of brook trout in Hunt Creek during the 1947 season of 0.20 and 0.26 fish per hour, and in Gamble Creek the same year catches of brown trout of 0.06 and 0.30 trout per hour. Shetter and Hazzard (1941) reported seasonal average values ranging from 0.37 to 0.77 fish per hour for all three species of trout in five northern Michigan streams. Cooper (MS) reported mean annual catches in the Pigeon River ranging from 0.244 to 0.501 hatchery-reared trout per hour and from 0.101 to 0.180 wild fish per hour. Smith and Smith (1945) determined total trout catches in Duschee Creek, Minnesota, of 1.49 fish per hour in 1942 and 1.55 per hour in 1943, but stated that most of the fishing load was borne by natural reproduction.

Although fishing pressure generally declines somewhat with the progress of the open season, there is reason to believe that the gradual reduction in numbers of hatchery-reared trout is greatly influenced by angling. The North Branch of the Saline River is a probable exception, because of the low reported removal of trout on opening day and the fact that very few fishermen were believed to have used the stream after the first two weeks of the season.

Age Composition and Growth Rate of Wild Trout

In order to compare the growth rate of fish in the four streams, all wild trout encountered were measured and weighed and scale samples were removed. Only wild brown trout in Spring Brook and Wilder Creek were taken in sufficient numbers to make such a comparison reliable. Although the great majority of these specimens came from within the study sections, a few individuals were collected in adjacent areas. Total lengths were taken to the nearest tenth-inch, weights to the nearest gram. The smaller fish were weighed on a Chatillon platform balance of 500-gram capacity. The weights of fish too large for this balance were obtained with a Braun flat-back spring balance and scoop (30-pound capacity with 1/4-pound divisions).

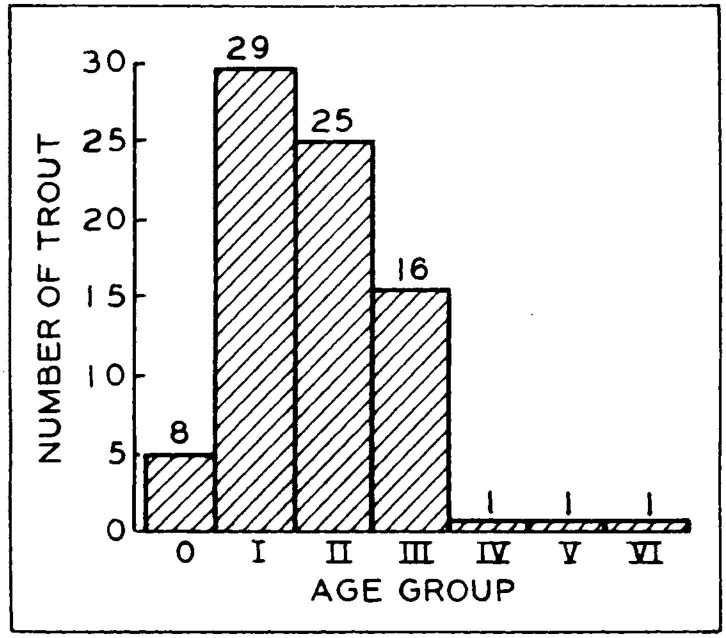
A group of 5 or 6 scales was removed from the side above the lateral line and opposite the anterior base of the dorsal fin. These data and scales were taken from 81 trout in Spring Brook and from 33 trout in Wilder Creek. Lengths were back-calculated assuming a straight-line body-scale relationship. It appeared impractical to attempt the determination of the true body-scale relationship with so few fish, particularly in the older age groups. For the same reason, determination of the condition factor was not attempted.

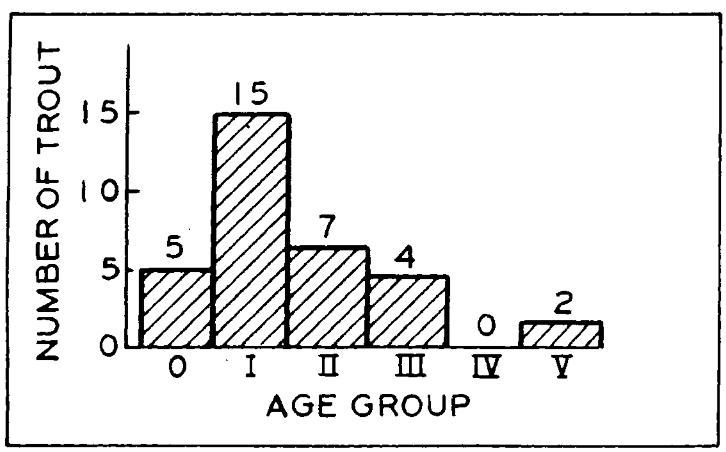
The distribution of ages among wild brown trout in Spring Brook, although based on relatively few fish, is normal for heavily fished streams (Figure 16). The comparatively small number of individuals (8) in age-group 0 may be due to the fact that very small trout are not so readily taken by the shocker as are larger fish.

The age distribution of brown trout in Wilder Creek

Figure 16. Age distribution of 81 wild brown trout in Spring Brook.

Figure 17. Age distribution of 33 wild brown trout in Wilder Creek.


NUMBER OF TROUT
30
25
20
15
10
5
0
29
25
16
8
1
1
1
0
I
II
III
IV
V
VI
AGE GROUP


NUMBER OF TROUT
15
10
5
0
15
5
7
4
0
2
0
I
II
III
IV
V
AGE GROUP

(Figure 17) is similar to that in the Spring Brook population, although the disappearance of members of age-groups II and III is slightly more abrupt. Only 5 fish in age-group 0 were recovered.

The brown trout in Wilder Creek apparently grow much faster than those in Spring Brook. Empirical lengths at the time of capture and calculated lengths at annulus formation for these two groups are shown in Tables 32 and 33. The majority of the fish from Spring Brook were taken in April and May at the time of annulus formation, while most of those in Wilder Creek were taken in July and August; hence the greater empirical lengths of fish of the same age group from the latter stream. That the fish actually are larger in Wilder Creek can be proved by a comparison of the lengths calculated at the date of annulus formation which is assumed to be the same time in each stream.

TABLE 32. EMPIRICAL AND CALCULATED TOTAL LENGTHS OF 81 WILD BROWN TROUT FROM SPRING BROOK

Total length, inches	Age Group						
	0	I	II	III	IV	V√	VI√
Empirical	3.8	5.7	7.5	9.2	11.1	17.2	20.1
Calculated	...	4.5					
	...	3.9	7.0				
	...	4.6	7.5	8.9			
	...	5.1	6.8	9.4	10.2		
	...	5.7	11.2	14.2	15.7	17.2	
		3.7	6.9	11.2	13.8	17.2	20.1
Average total calculated length, inches	...	4.5	7.8	10.9	13.2	17.2	20.1

√Indicates that fish taken after January 1 are placed in this age group although the last annulus has not yet been formed.

The values of the empirical lengths presented above compare favorably with those reported by others. Shetter and Hazzard (1939) reported total lengths of brown trout in the Little Manistee River in June as follows: 0 age group, 2.8 inches; I age group, 6.7 inches; II age group, 7.8 inches; and III age group, 8.7 inches. Calculated fork lengths of Minnesota brown trout reported by Eddy and Carlander (1939) compare equally well.

TABLE 33. EMPIRICAL AND CALCULATED TOTAL LENGTHS OF 33 BROWN TROUT FROM WILDER CREEK

Total length, inches	Age Group					
	0	I	II	III	IV	V
Empirical	4.4	6.8	10.1	15.7	...	18.9
Calculated	...	4.1				
	...	4.6	8.1			
	...	4.3	9.7	13.5		
	...	3.5	6.5	10.2	14.3	17.0
Average calculated total length, inches	...	4.1	8.1	11.9	14.3	17.0

Spawning Success

The extremely low percentage of wild trout, both in the reported early-season catch and in the periodical population estimates, indicated a low rate of natural reproduction. The scarcity of small fingerlings in Paint Creek and their apparent absence in the North Branch of the Saline River suggested the possibility of a nearly complete spawning failure in these two streams. However, an examination of the populations with the electrical shocker just preceding the spawning season showed that sexually mature trout were present, if not numerous. Observations were made during the trout spawning season on several streams with the twofold purpose of measuring the extent and success of spawning activity in the four streams under study and of determining the site characteristics where nest-building was actually taking place. These observations consisted of locating, marking, and recording the location of all new nests. Nest sites were marked by driving a stake into the stream bottom nearby. The physical features of the stream such as depth, width, current velocity, cover, and bottom type near a few nest sites were measured and recorded. Egg samples were taken at intervals from several nests to measure egg mortality. The apparent failure of rainbow trout to spawn in any of the streams studied is no doubt due to the apparent absence of sexually mature fish during the spring spawning season of this species. There was no evidence of mature rainbow trout in the very small number of legal-sized fish or among the more numerous fingerlings which survived to the spring of 1950. Therefore, these observations of reproductive activities refer only to the brook and brown trout.

The first indication of spawning occurred with the discovery of two partially completed brown trout nests in Wilder Creek on October 25, 1949. By November 10, spawning by both brook trout and brown trout had apparently reached its peak. The last evidence of nesting activity was noted in Wilder Creek on November 17, although there may have been limited spawning in all the streams after this date. The water temperature in Wilder Creek was 49°F. at the time the first nests were found. At the end of observed activities, slightly more than three weeks later, it was 40°F. Nest-building by brown trout was observed in the North Branch of the Saline River on November 11 when the water temperature was 54°F., and by brook trout in Silver Creek, Allegan County, November 8 when the water was 51°F. It appears from these observations that both species spawn at approximately the same time in this locality and that the time of the season is probably influenced more by the length of day than by water temperature. The effect of the length of day on the date of brook trout spawning season has been shown by Hoover (1937) and by Hazard and Eddy (1951).

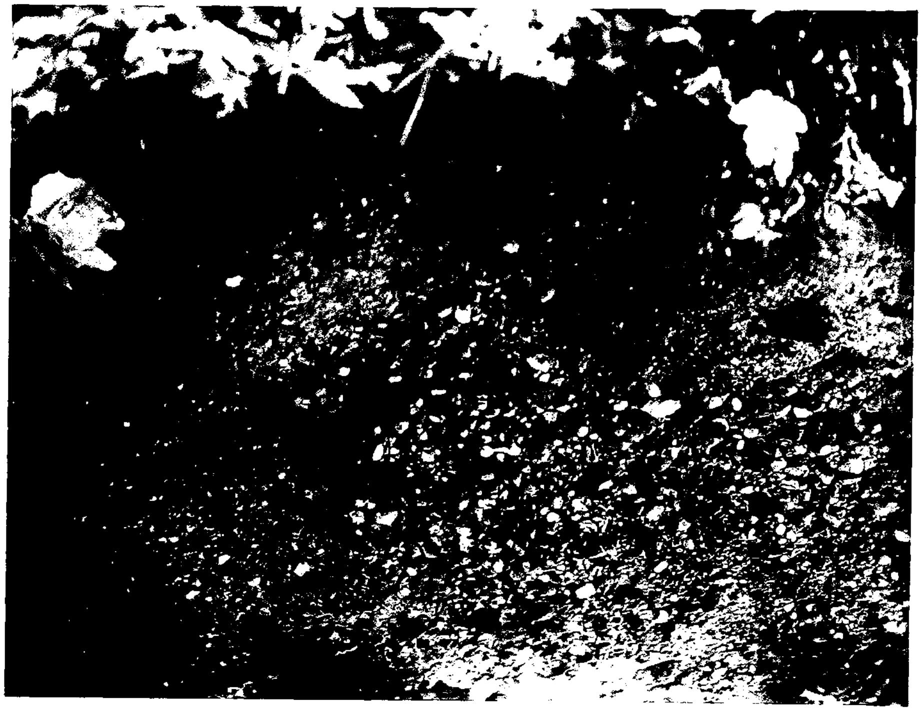
It was believed that once the characteristics of the nesting site had been determined, it would be possible to estimate the extent of suitable spawning area in each stream. The site characteristics of both species showed much variation. Redds were located in stream areas which varied in width from 4 to 13 feet, and in depth from 8 to 18 inches. Current velocity at the upper end of the redd, measured midway between the surface and bottom, ranged from 0.9 to 1.5 feet per second. Brook trout nests were generally found in situations approaching the lower limits of the values listed above. Both species apparently constructed nests in open, unprotected areas as often as they chose the protective cover of overhanging banks and shrubs. Gravel with particles ranging from the size of a pea to about three inches in diameter was used, although larger sizes were preferred (Figures 18 and 19).

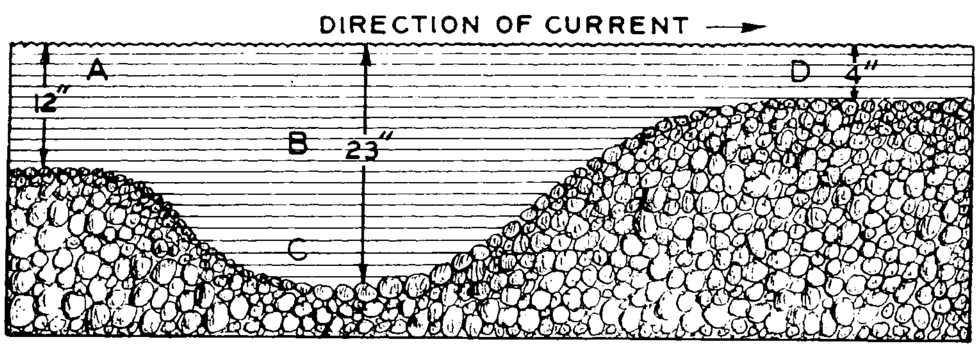
The size of the nest varies with species and with the size of the female building it. Smaller nests were noted in the relatively still-water areas as compared with those in faster riffles. Brook trout, which spawned in a small tributary to Spring Brook in Section 19 of Richland Township, made redds not more than 2 feet long and 18 inches wide, whereas brown trout nests 12 feet long and 8 feet wide were measured in Wilder Creek. Greeley (1932) reported that immediately after depositing the eggs, the female digs upstream from the egg pocket to cover the eggs. Two nests in Wilder Creek, 7 and 12 feet long, when excavated, were found to have 2 and 3 separate egg pockets, respectively. Although the eggs in the lower pockets were covered with gravel to a depth of 5 or 6 inches, those in the most upstream pocket of each nest were buried in less than one inch of fine gravel. This observation leads the writer to question the purpose of such upstream digging as stated by Greeley. It seems more probable that the eggs are covered incidentally in the preparation of a new egg pocket by the female.

On the basis of these observations, it appears that the only spawning site characteristics essential for spawning activity are: (1) gravel bottom with particles ranging in size from about one-fourth inch to 3 or 4 inches in

Figure 18. A partially completed brown trout redd in the North Branch of the Saline River, November 11, 1949.

Figure 19. Diagram of the brown trout nest pictured in Figure 18, showing the length and the depths and current velocity values at selected points. Current velocity, measured in feet per second, is 1.2 at A, 1.0 at B, 0.1 at C, and 1.1 at D.




DIRECTION OF CURRENT
A
12"
B
23"
C
D
4"

diameter, (2) current velocity over the gravel areas ranging from about 0.9 to 1.5 feet per second, and (3) a source of spring water nearby. Brown trout appear to show less dependence than do brook trout on springs in close proximity to their nests.

Of the four streams studied, only Paint Creek appeared to be lacking in any of the qualities described above. Although springs are common in the upstream areas, there is a very noticeable scarcity of gravel and an abundance of sand and clay. In the stream below the portion designated as trout water, gravel areas are extensive; but a census of this water with the electrical shocker failed to reveal the presence of trout at any season of the year. Limited observations indicate that in all the streams, brown trout migrate upstream to spawn. A careful examination of the upper portion of Paint Creek at the peak of the 1949 spawning season reveals only three partially completed, but deserted, brown trout nests. They contained no eggs. That limited successful spawning occurred in 1949 is certain because several fingerlings of this species were collected in the study section in July, 1950.

The North Branch of the Saline River has very extensive beds of suitable spawning gravel, favorable water current, and an apparently adequate supply of spring water. However, during the 1949 spawning season, only two nests were observed which had progressed beyond mere exploratory stages, and only one of these contained eggs. It became apparent that the limited spawning activity in the North Branch resulted from a scarcity of sexually mature fish. Attempted stripping of 18 of the larger hatchery trout collected November 10 failed to reveal a single ripe fish. Eight of these were dissected and found to be sexually immature. Yet numerous hatchery fish from the same stock were seen digging nests in Spring Brook three days earlier.

Conditions suitable for brown trout spawning in Wilder Creek are adequate as evidenced by a count on November 17 of 37 nests of this species in slightly less than a mile of stream below the county road bridge in the northeastern corner of Section 16, Eckford Township. The apparent failure of brook trout to spawn in this stream during the 1949 season may be attributed to a scarcity of sexually mature fish.

An estimated 75 percent of the accessible length of Spring Brook is suitable for trout spawning. On November 7, 1949, a total of 55 brown trout nests and one brook trout nest were counted in the length of stream from the highway (M-89) bridge downstream to the railroad bridge 400 yards below D Avenue, a distance of 1-1/2 miles. Nest building by hatchery trout of the current season's plantings was observed in Study Section B and immediately upstream. Measurements of 17 randomly selected specimens, including 8 females, 4 of which were "ripe," and 9 males, 5 of which were ripe, indicated that the attainment of sexual maturity is not determined entirely by size. Females as small as

8.6 inches, total length, were ripe, whereas others of the same sex as large as 8.8 and 9.0 inches were sexually immature. The average total length of the 5 ripe males was 7.3 inches, while that of the 4 immature fish was 7.5 inches. The part these trout played in the total reproduction for the season is assumed to be slight, since only 4 of them were actually observed digging nests.

Practically all the brook trout nests observed were found in the small tributary to Spring Brook described previously. On October 31, well before the peak of the spawning season, 23 partially completed brook trout nests were counted in approximately 300 yards of stream just below the pond of a deserted private trout hatchery.

As pointed out above, successful reproduction depends not only on the presence of sexually mature fish and suitable site characteristics, but also on conditions conducive to good egg survival. Although relatively little spawning activity was noted in Paint Creek, egg survival must have been satisfactory since fingerling trout were seen the following summer. In the North Branch, however, high egg mortality was indicated by the failure to recover fingerling trout in 1950 and by an examination of every nest observed during the spawning season. The only nest which contained eggs was excavated on January 12, 1950, after a mid-December flood had deposited a six-inch layer of silt and sand over the gravel. A total of 187 eggs was removed, all of which were dead. It is possible that all were not recovered, but it is doubtful if any remaining would be viable.

On the same date, 5 nests partially excavated in Wilder Creek revealed egg survival rates of 86.7 percent, 84.6 percent, 77.3 percent, 76.1 percent, and 65.9 percent, with an average value of 78.1 percent. On February 2, 1950, 4 brown trout nests in Study Section A of Spring Brook were excavated. Egg survival values here were 81.2 percent of 155 eggs, 76.4 percent of 85 eggs, 73.4 percent of 260 eggs, and 0.0 percent in the fourth nest (these eggs were not counted since live ones were not found).

EVALUATION OF FACTORS INFLUENCING TROUT PRODUCTION

The factors known or suspected of limiting trout production in the streams studied have been described qualitatively, and quantitatively wherever possible. However, only rarely can the quantitative effect of any one factor be determined because of the interaction of numerous features, both of the environment and of the fish populations themselves. In the discussion to follow, the apparent influence of each factor on production will be evaluated by stream sections. The site and species composition of the fish populations presented earlier will be used as an aid in this evaluation.

The calculated correlation coefficients between factors and fish production, both of trout and non-trout species, are based on 4 to 6 pairs of measurements and hence, there are only 2 to 4 degrees of freedom. With so few degrees of freedom, sampling errors and the element of chance may detract somewhat from the significance of the correlation even though the values exceed those presented as significant by Snedecor (1946).

Size of Stream

It has been generally accepted that large streams produce more fish of larger average size than do similar small streams. Large stream size usually implies both greater surface area and greater depth, or total water volume. Since the streams are all approximately the same width, the major variation appears in depth. In several northern Michigan streams, Shetter and Hazzard (1939) found the greatest production of all species to be in those sections having greater average depth and a higher percentage of sandy bottom. Hoover and Morrill (undated) found no such relation between production and average depth in two New Hampshire streams. Gerking (1949a) has shown that the size of stream fish populations in several Indiana streams is not proportional to the total water volume, but to the volume within the 2-foot contour. That this relationship of deep water volume to total fish production does not apply to the streams in the present study is shown in the following listing of the streams in the order of decreasing volume within the 2-foot contour (see Table 12):

(1) Spring Brook, Section B (200.5 pounds per acre);
(2) Wilder Creek (96.2 pounds per acre);
(3) Section B, North Branch of the Saline River (266.7 pounds per acre);
(4) Paint Creek (161.1 pounds per acre);
(5) Spring Brook, Section A (208.6 pounds per acre); and
(6) Section A, North Branch of the Saline River (302.7 pounds per acre).

The values of the standing crop shown in parentheses are averages for the period of study. It can be seen that Wilder Creek with the second largest percentage of water volume

2 feet deep or deeper supported the smallest average crop of fish per acre, whereas Section A of the North Branch has the smallest volume of deep water, yet had the largest standing crop during 1949 and 1950. There appears to be no correlation between percentage of deep water (pools) in the sections and size of the fish crops present. Neither is there correlation between percentage of deep water and percentage of trout weight in the total fish population. This apparent lack is no doubt partly due to the greater influence of other factors whose effects have obscured the influence of deep-water volume on production.

Shade and Cover

The two sections on Paint and Wilder Creeks with the largest percentages of their banks shaded (100 percent and 90 percent, respectively) and with the best bottom cover, had the two smallest average standing crops of fish during the period of study. Although the percentages of trout, by weight, in the two populations, 39.6 percent in Paint Creek and 37.6 percent in Wilder Creek, were considerably greater than those in either section of the North Branch, they were less than those determined in each section of Spring Brook where shade and cover were inferior. The total population of the North Branch consisted of 3.4 percent trout, by weight, in Section A and 12.5 percent in Section B. In Section A of Spring Brook, 56.2 percent and in Section B 72.0 percent of the total population weight was composed of trout. The lack of correlation between shade and cover and total fish production (size of standing crop), and also between shade and cover and the percentage of trout in the fish population, is obvious. These findings are in agreement with those of Hoover and Morrill (undated) in New Hampshire trout streams.

Mean Summer Water Temperature

In attempting to evaluate the effect of water temperature on fish production, it becomes necessary to average the weight of fish per acre in the two sections in the North Branch and in the two in Spring Brook, since the temperatures in the two sections in each stream have been combined.

There appears to be insignificant correlation between mean summer temperature in the four streams and total fish production ($r = 0.517$). A significant correlation coefficient is 0.950 at the 5 percent level of significance, with 2 degrees of freedom. There is greater negative correlation between temperature and the percentage of trout by weight in the total population although the correlation coefficient ($r = -0.892$) is only slightly less than the significant value expressed above. The lack of a more significant correlation between total fish production and temperature is partly the result of a high proportion of trout in certain of the streams. The higher negative correlation between percentage of trout weight and temperature suggests that temperature, either directly or indirectly, is partly responsible for the variation in size of trout populations.

Bottom Type

There appears to be a lack of correlation between the percentages of the various bottom types (Table 12) in the stream sections and total fish production as well as between bottom type and trout production. Gerking (1949a) noticed a similar lack of correlation in his studies on Indiana streams, although Shetter and Hazzard (1939) in Michigan reported greatest production of all species in those streams having the greatest average depth and the highest percentage of sand bottom. The effects of bottom type on fish production are no doubt mostly indirect and are reflected through a direct influence on the abundance of fish food organisms. The extent of bottom type suitable for trout spawning certainly appears to be a factor limiting the production of wild trout in Paint Creek.

Floods and Siltation

As stated previously, differences of opinion exist concerning the effects of floods on stream life. However, the extreme flood conditions which occurred in the North Branch of the Saline River appeared to have a harmful effect. The sizable decrease in numbers of all species except Johnny darter noted in Section A of the North Branch on April 14, 1950, was probably due in large part to the flood 10 days earlier. Yet, in spite of the floods, this stream supported the highest average fish population of the four streams studied.

An indirect, although no less serious, effect of floods is the shifting and deposition of bottom materials which may destroy nests and fish food organisms. The flood in December, 1949, which has been described, resulted in a layer of sand which smothered two brown trout nests and killed all the eggs. Considerable shifting of bottom materials was noted in Paint Creek also, but its extent cannot readily be expressed quantitatively in either stream. Neither can its effect on fish production be estimated satisfactorily. It is believed, however, that this shifting of bottom materials does play a major part in the scarcity of wild trout and in the low rate of spawning success in the two streams.

Chemical Features

The mean values of pH, normal carbonate, bicarbonate, and electrical resistivity (Table 12) show so little variation between streams, it is very doubtful that any of them might be exerting a differential influence in trout production or on total fish production. Variations between dates on the same streams were considerably greater than the average variations between streams. According to Ellis (1937), most fish species have great tolerance for variations of pH, carbonate concentration, and specific conductance (reciprocal of resistivity) over a wide range of values. The range shown by Ellis was greater by far than that shown above.

Although there appears to be no correlation between total weight of fish and any of the chemical features listed, there is rank correlation between average weight of trout and pH ($r_s = 0.800$) and between trout weight and normal carbonate ($r_s = 1.00$). It should be pointed out, however, that in spite of these high correlation values, significant rank correlation cannot be obtained with only 4 pairs of measurements at the 5 percent level (Snedecor, 1946). In view of the slight variation shown above and the extremely wide range of tolerance of fish for these factors, it appears that the high correlation shown is coincidental.

Food Supply

It was pointed out in an earlier section that the average numbers and volumes of bottom organisms determined by sampling are probably not sufficiently reliable to permit an accurate estimation of the total potential food supply in a stream section. However, with a knowledge of the extent of each bottom type, they do give fairly reliable approximations of the relative sizes of the standing crops of organisms in the various sections at the time of sampling.

The insignificant positive correlation ($r = 0.512$) between the average weight of trout and the weighted average volume of bottom organisms in the sections may be explained in the following way: (1) all organisms which make up the standing crop are not utilized by trout to the same degree; (2) a sizable portion of trout food during the summer consists of terrestrial organisms; and (3) the standing crop of bottom organisms, measured during a period of a few weeks, is not a reliable estimate of the total food supply available to the trout population throughout the entire growing season.

The low negative correlation (r = -0.450) between the average weight of non-trout species and the average volume of bottom organisms indicates that the potential food supply is inversely proportional to the size of the non-trout population. This relationship suggests, but does not prove, that the large fish populations in some sections are keeping the bottom organisms at a low level of abundance. Hoover and Morrill (undated) reported a similar lack of correlation between the weight of trout and sculpins per acre and the numbers of invertebrates per acre.

Competition

It was stated earlier that competition for food appears to exist between trout and non-trout species, but its seriousness cannot be determined since food requirements in relation to food supply are not known. The extent of total competition between groups, however, is suggested. The negative correlation coefficient r = -0.651, although not significant, does suggest an inverse ratio between the weight of trout and the weight of other species in the sections. This relationship may be attributed to moderate competition between the two groups, or to the failure of the stream to satisfy the habitat requirements of the lesser group represented, which does not necessarily rule out the presence of competition.

Fishing Pressure

The meager catch records do not permit a reliable estimate of the effect of fishing on the trout populations. It may be safely said that after the first few weeks of the season, very little angling occurs on Paint Creek and the North Branch of the Saline River, whereas, under normal conditions, moderate fishing pressure continues on both Wilder Creek and Spring Brook throughout most of the trout season.

Classification of the Streams

Although the size and species composition of the estimated fish population and the extent of natural reproduction do not provide a precise measure of the ability of a stream to produce trout, they do give a moderately accurate estimate. In the absence of complete information on the yield of trout to fishermen and the extent of migration out of the study sections, any attempt to classify the four streams studied in terms of trout production must be based on standing crop, natural reproduction, and the extent to which the streams appear to meet the habitat requirements of the trout species present.

On this basis, the following classification of the four streams is made:

1. *Bona-fide* trout stream: a sizable population of wild trout exists at all seasons and natural reproduction occurs annually. In this category are placed Spring Brook and Wilder Creek.
2. Marginal trout stream: the size of the wild trout population, although generally small, varies from year to year, and limited natural reproduction occurs. Paint Creek, with relatively few wild trout, is classified as a marginal trout stream.
3. Sub-marginal or seasonal trout stream: the wild trout population and natural reproduction are questionable or absent. The North Branch of the Saline River is considered a seasonal trout stream.

CONCLUSIONS

On the evidence presented above, it appears that the size of the trout population is influenced by different factors in each stream. The variation in average depth, shade and cover, and chemical characteristics is probably not so great that any of these features have a noticeable limiting effect on production in any of the streams. The very low trout production in the North Branch of the Saline River appears to be the result of several factors. The mean summer water temperature, although not above that commonly accepted as tolerable by trout, appears to limit the numbers of trout and to favor an increase in abundance of the competing fish species. The food supply in the North Branch appears to be limited in comparison to that in some of the other waters, possibly the result of a very large population of non-trout species and of floods which cause a shifting of bottom materials. The shifting of the bottom also has a serious limiting effect on the trout by destroying nests, as evidenced by the lack of natural reproduction.

The low average production of both trout and other fishes is in Wilder Creek apparently not greatly influenced by temperature. The food supply compares favorably with that in all other streams and competition apparently is slight. Because the estimated size of the total fish population decreased from 101 pounds per acre in 1949, shortly before the dredging began, to 51 pounds per acre one year later while the dredging continued, it seems safe to assume that a major part of this decrease was caused by the dredging operation which kept the stream in an extremely roily condition at all times. The comparatively high fishing intensity is no doubt partly responsible for keeping the trout population at this low level.

The factors of temperature, flooding, and competition appear not to have a serious limiting effect on the trout population in Paint Creek. However, the great scarcity of natural reproduction of trout of all ages and the very limited production of bottom organisms indicate that the high percentage of sand bottom, which is continually shifting, acts as a limiting factor.

There are no apparent conditions seriously limiting trout production in Spring Brook. Fishing intensity no doubt plays a major role in curtailing the size of the trout population, but cannot be considered a serious factor in reducing production until it becomes so great as to cause a scarcity of breeding fish.

It should be pointed out that the apparent correlation between size of trout population and the various factors discussed above has only moderately high mathematical significance, partly because of the small number of pairs of measurements, determined by the number of stream sections. Such correlation coefficients are strongly suggestive of significant relationship.

RECOMMENDATIONS

A major function of the Michigan Conservation Department's Fish Division is to provide satisfactory fishing year after year to the greatest number of fishermen. Because of the great distance to some of the northern trout waters, these southern streams near large centers of population have a definite place in the over-all recreational program if they can be made to provide trout fishing commensurate with the costs involved. The planting of legal-sized trout is expensive and not too successful in some of the streams described. Recommendations are aimed at increasing the percentage of planted trout caught by fishermen and improving environmental conditions to favor an increase in naturally produced trout.

Paint Creek

Because the fishing pressure on Paint Creek decreases abruptly after the first week of the season and because mortality of hatchery trout is high, only one pre-season planting is recommended. Brook trout and brown trout are favored since the former are easily caught by the fishermen and the latter show better survival rates and are also reproducing naturally in limited numbers.

Removal of limited areas of dense growths of shrubs would make additional water available to the fishermen without greatly increasing the water temperature. Series of deflectors in the swifter portions should expose at least small areas of gravel suitable for trout spawning. Additional deflectors designed to cut deep pools are not recommended.

North Branch of the Saline River

Under present stream conditions and slight mid-season fishing pressure, only one pre-season planting of brown trout and rainbow trout is recommended for the North Branch of the Saline River. Not much can be recommended in the way of stream bed improvement until the threat of floods has been reduced. Frequent and severe floods are predicted as long as current agricultural practices and normal weather conditions continue. However, acquisition and fencing of a 50-foot strip of land bordering the stream are recommended. The stream banks should be planted with willows or other suitable shade species to maintain low water temperatures. Cattle should be excluded. Construction of a dam with a 2-foot head in the lower portion of the stream should discourage upstream migration of non-trout species without hindering the movement of trout.

Wilder Creek

It is recommended that brook trout and rainbow trout be stocked in Wilder Creek, in view of the comparatively high catchability of these species, and that plantings be made immediately before the opening of the trout season. If fishing pressure continues at a high level, additional small monthly plantings of brown trout should be made. No further stream improvement measures are recommended.

Spring Brook

In Spring Brook, a pre-season planting of brook trout in the upper three miles of stream and of brown trout in the remaining accessible areas is recommended. Additional plantings of both species at approximately monthly intervals should be made if fishing pressure continues to be heavy. Although cover is not seriously lacking, deflectors should be installed in long shallow stretches of stream to provide additional deep holes and cover.

SUMMARY

The purposes of this investigation were (1) to evaluate the techniques and equipment currently used in the electrical censusing of stream fish populations and adopt them for use in southern Michigan streams, (2) to measure the success of the Conservation Department's trout planting program in selected southern Michigan streams, and (3) to determine the factors influencing trout production in these waters.

The analysis of the censusing techniques and equipment showed that alternating-current units of 110 volts and 500-watt capacity function satisfactorily in clear streams up to 20 feet wide and to depths readily wadable, with water resistivity values ranging from 1000 ohms to 3500 ohms per cubic centimeter. Electrical seines were not feasible because of obstructions in the streams.

The size and shape of the fields produced by electrodes of several shapes and sizes were measured with equipment consisting of ammeter, voltmeter, earphones, wire probe, and 10 equal resistors in series. Results showed that electrodes longer in the horizontal dimension perform to better advantage in shallow water whereas those longer in the vertical dimension are better in deeper, narrower streams when used with a 500-watt unit. The latter electrodes produce a comparatively small effective horizontal field irrespective of water depth. The larger the surface area of the electrodes,

within the power limits of the generator, the greater will be the efficiency of the shocker. Size and shape of electrodes for greatest efficiency are determined by (1) power output rating of the generator, (2) depth of the stream, and (3) resistivity of the water.

The voltage gradient intercepted by the total length of fishes, with due consideration of water resistivity, seems to be the more convenient unit of measurement to determine the intensity of an electrical field necessary for paralysis.

Head-to-tail voltage gradients ranging from 1.89 volts to 2.09 volts in water of moderate resistivity caused paralysis of fish of five species.

Direct-current shockers function better in swift or roily water than do alternating-current units. Recovery of marked fish in clear water ranged from 0.0 to 100.0 percent and varied directly with size of fish.

The reliability of population estimates by the mark and recovery method varies directly with the ratio of marked fish to total fish recovered (R/H).

Under artificial conditions, trout mortality with the alternating-current shocker was 11.2 percent; with direct current, 2.0 percent. Mortality would have been less in positive stream work.

The most outstanding environmental features of the four streams studied are presented. Paint Creek in Washtenaw County is a cold-water stream in its upper two or three miles. It is densely shaded, and although not subject to severe floods, there is considerable shifting of the sandy bottom. The very warm, downstream portion often floods and appears to have no trout.

The North Branch of the Saline River in Washtenaw County is considerably warmer and is subject to frequent and severe floods. The bottom is largely gravel and rubble. Numerous fish species are represented.

Wilder Creek in Calhoun County is a well-shaded, moderately cool stream. Occasional floods cause considerable damage. Dredging in the upstream areas kept the water roily in 1949 and 1950.

Spring Brook in Kalamazoo County is a cold stream. There is little shade, but springs keep the water temperature near 60°F. during the summer. Cover and pools are adequate. Few fish species are present.

Great variation in number and volume of bottom organisms per square foot sample made accurate estimation of standing crops impractical, even when analysis was made by stratifying the samples according to bottom types. Approximations of standing crops of organisms ranged from 0.085 cubic centimeter per square foot in Section B of the North Branch to 1.510 cubic centimeters per square foot in Section A of Spring Brook. Both volume and number of organisms per square foot of bottom varied with bottom type.

Volume of food in trout stomachs ranged from a trace to 3.1 cubic centimeters. Trout generally utilized more kinds of organisms than did other fish species. The number of kinds utilized varied with size of fish concerned. The most common organisms in the bottom samples generally were most common in trout stomachs, but did not occur as frequently in stomachs of other species. Terrestrial organisms were proportionately more numerous in stomachs of trout from stream sections with small bottom fauna crops.

Sizable seasonal variations in the fish populations existed. Average standing crops for the period of study ranged from 96.2 pounds of fish per acre in Wilder Creek to 302.7 pounds per acre in Section A of the North Branch of the Saline River. The average percentage of trout by number in these estimates ranged from 3.4 percent in Section A of the North Branch to 72.0 percent trout in Section B of Spring Brook. Much of the seasonal variation in total weight was the result of the spawning migrations of several species.

The extent of natural reproduction of trout, based on numbers of wild fish to hatchery fish collected, ranged from 0.0 percent in the North Branch to 72.1 percent in Spring Brook. The wild brown trout in Wilder Creek grow at a faster rate than do those in Spring Brook.

Survival of hatchery trout was low in all streams. Brook and rainbow trouts generally disappeared in four to six weeks following planting. Brown trout persisted for slightly longer periods.

Over-winter survival rates of advanced fingerlings was also low. The greatest mortality was suffered by brook trout, many of which were of legal size at the opening of the 1950 trout season.

Fishing pressure was heavy on all streams the first few days of the season but decreased rapidly on all but Spring Brook. Fishermen on Wilder Creek in the first two days of the 1950 season removed 18.2 percent of the trout planted two days before the season opened.

Rainbow trout were not observed spawning in any of the streams studied. Brown trout spawning activity was noted in all streams but successful nests were found only in Wilder Creek and Spring Brook.

Successful spawning in Paint Creek seems to be limited because of a scarcity of suitable gravel areas. There appeared to be a scarcity of sexually mature trout in the North Branch, and the one completed nest observed with viable eggs was destroyed by a December flood. Successful brown trout nests were numerous in both Wilder Creek and Spring Brook. The scarcity of Brook trout redds is attributed to a scarcity of mature fish in these streams.

The size of the standing crop of trout and of all other species did not vary directly with volume of deep water nor with the degree of shade and cover in the stream sections. Other factors exerted greater and more apparent effects.

Mean summer water temperature seemed to be insignificant in determining the size of the total fish populations, but did exert an apparent effect on the size of the trout population. Bottom type appeared to limit trout production in Paint Creek, indirectly by reducing food production, and directly by preventing successful spawning. Chemical features of the water, food supply, and competition apparently did not influence significantly the size of the standing crop of trout or of all fish species. The size of the standing crop of trout appeared to be curtailed by different factors in each stream.

Only one pre-season planting of brook and brown trout was recommended in Paint Creek. Limited areas of dense shrubs should be removed to provide more accessible water to the fishermen. Shallow deflectors in series were recommended to expose gravel.

In the North Branch of the Saline River, recommendations included (1) one pre-season planting of brown and rainbow trouts, (2) acquiring, fencing, and planting with willows a 50-foot strip of land bordering the stream, and (3) construction of a low-head dam to prevent upstream migration of non-trout species.

Planting recommendations in Wilder Creek included a pre-season stocking of brook trout and rainbow trout with small monthly plantings of brown trout as required.

In Spring Brook, one pre-season and additional small monthly plantings of brook trout and brown trout were recommended. Deflectors were recommended in long shallow stretches of stream.

LITERATURE CITED

Allee, W. C., *et al.*
1949. Principles of animal ecology. W. B. Saunders Co., Philadelphia, 837 pp.

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

American Fisheries Society
1948. A list of common and scientific names of the better known fishes of the United States and Canada. Amer. Fish. Soc., Spec. Publ., No. 1, 45 pp.

American Public Health Association
1946. Standard methods for the examination of water and sewage. Ed. 3, Amer. Publ. Health Assn., New York, 286 pp.

Brett, J. R.
1944. Some lethal temperature relations of Algonquin Park fishes. Publ. Ont. Fish. Res. Lab., No. 63, 49 pp.

Burr, J. G.
1932. Electricity as a means of garfish and carp control. Trans. Amer. Fish. Soc., Vol. 61 (1931), pp. 174-182.

Clarke, George L.
1946. Dynamics of production in a marine area. Part 2 of: A symposium on dynamics of production in aquatic populations. Ecol. Monogr., Vol. 16, No. 4, pp. 321-335.

Cooper, E. L.
MS. Returns from plantings of legal-sized brook, brown and rainbow trout in the Pigeon River, Otsego County, Michigan. Rept. No. 1346 (1952), Mich. Inst. Fish. Res., 30 pp. (Typewritten) (This paper was presented at the 1952 meeting of the American Fisheries Society).

Eddy, Samuel, and Kenneth D. Carlander
1939. Growth of Minnesota fishes. Minn. Conservationist, Vol. 69, pp. 8-10.

Ellis, Max M.
1937 Detection and measurement of stream pollution. Bull. U. S. Bur. Fish., Vol. XLVIII, No. 22, pp. 365-437.

Elson, Paul F.
1950. Usefulness of electrofishing methods. The Canad. Fish Cult., No. 9, pp. 3-12.

Embody, G. C.
1922. Concerning high water temperatures and trout. Trans. Amer. Fish. Soc., Vol. 51 (1921), pp. 58-64.

1927a. I. Stocking policy for the Genesee River system. In: A biological survey of the Genesee River system. Suppl. 16th Ann. Rept., 1926, N. Y. St. Cons. Dept., pp. 12-28.

1927b. An outline of stream study and the development of a stocking policy. Contr. Aquicult. Lab., Cornell Univ., 21 pp.

Faigenbaum, H. M.
1936. V. Chemical investigation of the Susquehanna and Delaware watersheds. In: A biological survey of the Delaware-Susquehanna watershed. Suppl. 25th Ann. Rept., 1935, N. Y. St. Cons. Dept., pp. 140-194.

Fisher, Kenneth C.
1950. Physiological considerations involved in electrical methods of fishing. The Canad. Fish Cult., No. 9, pp. 26-33.

Fry, F. E. J., J. S. Hart, and K. F. Walker
1946. Lethal temperature relations for a sample of young speckled trout, Salvelinus fontinalis. Publ. Ont. Fish. Res. Lab., No. 66, 35 pp.

Funk, John L.
1949. Wider application of the electrical method of collecting fish. Trans. Amer. Fish Soc., Vol. 77 (1947), pp. 49-64.

Gee, Merle A.
1942. Success of planting legal-sized trout in the Southwest. Trans. 7th N. Amer. Wildl. Conf. (1942), pp. 238-244.

Gerking, Shelby D.
1949a. Characteristics of stream fish populations. Invest. Ind. Lakes and Streams, Vol. III, No. 7, pp. 283-309.

1949b. Urethane (ethyl carbamate) in some fishery procedures. The Prog. Fish-Cult., Vol. II, No. 1, pp. 73-74.

1950. Stability of a stream fish population. Jour. Wildl. Mgt., Vol. 14, No. 2, pp. 193-202.

Greeley, John R.
1932. The spawning habits of the brook, brown and rainbow trout, and the problem of egg predators. Trans. Amer. Fish. Soc., Vol. 62 (1932), pp. 239-248.

1935. Fishes of the watershed. In: A biological survey of the Mohawk-Hudson watershed, Section II. Suppl. 24th Ann. Rept., 1934, N. Y. St. Cons. Dept., pp. 63-101.

Haskell, David C.
1940. An electrical method of collecting fish. Trans. Amer. Fish. Soc., Vol. 69 (1939), pp. 210-215.

Haskell, David C., and Robert G. Zilliox
1941. Further developments of the electrical method of collecting fish. Trans. Amer. Fish. Soc., Vol. 70 (1940), pp. 404-409.

Hauck, Forrest R.
1949. Some harmful effects of the electric shocker on large rainbow trout. Trans. Amer. Fish. Soc., Vol. 77 (1947), pp. 61-64.

Hazard, Thomas P., and Roland E. Eddy
1951. Modification of the sexual cycle in brook trout (Salvelinus fontinalis) by control of light. Trans. Amer. Fish. Soc., Vol. 80 (1950), pp. 158-162.

Hazzard, Albert S., and David S. Shetter
1939. Results from experimental plantings of legal-sized brook trout (Salvelinus fontinalis) and rainbow trout (Salmo irideus). Trans. Amer. Fish. Soc., Vol. 68 (1938), pp. 196-210.

Hermann, L.
1885. Eine Wirking galvanische Strome auf Organismen. Archiv für gesamte Physiologie des Menschen und der Tiere, Vol. 229, pp. 153-172.

Hess, A. D., and Albert Swartz
1941. The forage ratio and its use in calculating the food grade of streams. Trans. 5th N. Amer. Wildl. Conf. (1940), pp. 162-164.

Holmes, Harlan B.
1948a. History, development, and problems of electric fish screen. U. S. Fish and Wildlife Service, Spec. Sci. Rept., No. 53, 62 pp.

1948b. English condensation of: Die Elektrofischerei, by Kurt Smolian. Sammlung fischereilicher zeitfragen herausgegeben von Reichsverband der Deutschen Fischeri, Heft 35. Verlag J. Neumann, Neudamm und Berlin, 1944.

Hoover, Earl E.
1937. Experimental modification of the normal sexual cycle of trout. Science, Vol. 86, No. 2236, pp. 425-426.

1938. Fish populations of primitive brook trout streams of northern New Hampshire. Trans. 3rd N. Amer. Wildl. Conf. (1938), pp. 486-496.

Hoover, Earl E. and G. W. Morrill, Jr.
Undated. Autecology of brook trout (Salvelinus fontinalis) in two primitive streams of northern New Hampshire. N. H. Fish and Game Dept., Tech. Circ., Brook Trout #2, 22 pp. (Mimeographed).

Hubbs, Carl L. and Karl F. Lagler
1947. Fishes of the Great Lakes region. Cranbrook Inst. Sci., Bull. No. 26, 186 pp.

Joeris, Leonard
1949. Electric seine used in Kentucky. The Prog. Fish-Cult., Vol. 11, No. 2, pp. 119-121.

King, Willis
1942. Trout management studies at Great Smoky Mountains National Park. Jour. Wildl. Mgt., Vol. 6, No. 2, pp. 147-161.

Lagler, Karl F.
1950. Studies in freshwater fishery biology. Ed. 3, rev., J. W. Edwards, Ann Arbor, Mich., 231 pp.

Leonard, Justin W.
1939. Comments on the adequacy of accepted stream bottom sampling technique. Trans. 4th N. Amer. Wildl. Conf. (1939), pp. 288-295.

Lord, Russell F.
1946. The Vermont "test-water" study, 1935 to 1945 inclusive. Vt. Fish and Game Service, Fish. Res. Bull., No. 2, 110 pp.

McMillan, Fred O.
1930. Electric fish screen. Bull. U. S. Bur. Fish., Vol. 44 (1928), pp. 97-128.

McMillan, Fred O., H. B. Holmes, and F. Alton Everest
1937. The response of fish to impulse voltages. (Typewritten report).

Michigan State Board of Fish Commissioners
1888. Eighth Biennial Report of the State Board of Fish Commissioners from December 1, 1886, to December 1, 1888, pp. 10-11.

Mottley, Charles McC.
1942a. Experimental designs for developing and testing a stocking policy. Trans. 7th N. Amer. Wildl. Conf. (1942), pp. 224-238.

1942b. Modern methods of studying fish populations. Trans. 7th N. Amer. Wildl. Conf. (1942), pp. 256-260.

Nevin, F. R.
1936. VI. A study of the larger invertebrate forage organisms in selected areas of the Delaware and Susquehanna watersheds. In: A biological survey of the Delaware-Susquehanna watershed. Suppl. 25th Ann. Rept., 1935, N. Y. St. Cons. Dept., pp. 195-204.

Newcombe, Curtis L.
1951. Silt takes over. The Land, Vol. 10, No. 2, pp. 177-180.

Pate, V. S. L.
1934. IV. Studies on the fish food supply in selected areas of the Raquette watershed. In: A biological survey of the Raquette watershed. Suppl. 23rd Ann. Rept., 1933, N. Y. St. Cons. Dept., pp. 136-157.

Prevost, Gustave
1945. Electric fishing. In: Third Report of the Biological Bureau, pp. 59-65. (Reprinted from General Report of the Minister of Game and Fisheries for the year ending March 31, 1945).

Rayner, H. John
1949. Direct current as aid to the fishery worker. The Prog. Fish-Cult., Vol. 11, No. 3, pp. 169-170.

Regnart, H. C.
1931. The lower limits of perception of electrical currents by fish. Jour. Marine Biol. Assoc. of the United Kingdom, n.s., Vol. 17, No. 2, pp. 415-420.

Ricker, William E.
1948. Methods of estimating vital statistics of fish populations. Ind. Univ. Publ., Sci. Ser., No. 15, 101 pp.

1949. Effects of removal of fins upon the growth and survival of spiny-rayed fishes. Jour. Wildl. Mgt., Vol. 13, No. 1, pp. 29-40.

Ricker, William E., Harrell F. Mosbaugh, and Maurice Lung
1949. Utilization and survival of trout in Indiana. Invest. Ind. Lakes and Streams, Vol. 3, No. 6, pp. 273-281.

Schiemenz, Friedrich, and Karl Humburg
1939. Über den räumlichen Anwendungsbereich des elektrischen Fischfanges. Zeitschrift für Fischerei, Vol. 37, pp. 429-458.

Shetter, David S.
1939. Success of plantings of fingerling trout in Michigan waters as demonstrated by marking experiments and creel censuses. Trans. 4th N. Amer. Wildl. Conf. (1939), pp. 318-325.

1947a. The electric "shocker" and its use in Michigan streams. Mich. Cons., Vol. 16, No. 9, pp. 8-10.

1947b. Further results from spring and fall plantings of legal-sized, hatchery-reared trout in streams and lakes of Michigan. Trans. Amer. Fish Soc., Vol. 74 (1944), pp. 35-58.

1950. The relationship between the legal-sized trout population and the catch by anglers in portions of two Michigan streams. (Reprint) Papers Mich. Acad. Sci., Arts, and Letters, Vol. 34 (1948), pp. 97-107.

1951. The effect of fin-removal on fingerling lake trout (Cristivomer namaycush). Trans. Amer. Fish. Soc., Vol. 80 (1950), pp. 260-277.

Shetter, David S., and Albert S. Hazzard
1939. Species composition by age groups and stability of fish populations in sections of three Michigan trout streams during the summer of 1937. Trans. Amer. Fish. Soc., Vol. 68 (1938), pp. 281-302.

1941. Results from plantings of marked trout of legal size in streams and lakes of Michigan. Trans. Amer. Fish. Soc., Vol. 70 (1940), pp. 446-468.

Shetter, David S., and Justin W. Leonard
1943. A population study of a limited area in a Michigan trout stream, September, 1940. Trans. Amer. Fish. Soc., Vol. 72 (1942), pp. 35-51.

Smith, G. F. M. and P. F. Elson
1950. A direct-current electrical fishing apparatus. The Canad. Fish Cult., No. 9, pp. 34-46.

Smith, Lloyd L., Jr., Raymond E. Johnson, and Laurence Hiner
1949. Fish populations in some Minnesota trout streams. Trans. Amer. Fish. Soc., Vol. 76 (1946), pp. 204-214.

Smith, Lloyd L., Jr., and Beatrice S. Smith
1945. Survival of seven- to ten-inch planted trout in two Minnesota streams. (Reprint) Trans. Amer. Fish. Soc., Vol. 73 (1943), pp. 108-116.

Snedecor, George W.
1946. Statistical methods. Ed. 4, The Collegiate Press, Inc., Ames, Iowa. 485 pp.

Surber, Eugene W.
1937. Rainbow trout and bottom fauna production in one mile of stream. Trans. Amer. Fish. Soc., Vol. 66 (1936), pp. 193-202.

Trippensee, R. E.
1937. Fish population studies on some New Hampshire trout streams. In: A biological survey of the Androscoggin, Saco, and coastal watersheds. Surv. Rept., No. 2, N. H. Fish and Game Dept., pp. 119-124.

Van Herreveld, A.
1938. On galvanotropism and oscillotaxis in fish. Jour. Exper. Biol., Vol. 15, No. 2, pp. 197-208.

Webster, Dwight A.
1950. Results of electric shocking demonstration in Fall Creek, Ithaca, New York. May 16, 1950. (Dittoed memorandum).

Welch, Paul S.
1948. Limnological methods. The Blakiston Co., Philadelphia, Pa., 381 pp.

APPENDIX I

A LIST OF FISHES ENCOUNTERED IN FOUR SOUTHERN MICHIGAN STREAMS

A LIST OF FISHES ENCOUNTERED IN FOUR

SOUTHERN MICHIGAN STREAMS[1]

Rainbow trout	*Salmo gairdneri irideus*
Brown trout	*Salmo trutta*
Eastern brook trout	*Salvelinus fontinalis*
Common white sucker	*Catostomus commersonni commersonni*
Hog sucker	*Hypentelium nigricans*
Northern redhorse	*Moxostoma aureolum*
Northern creek chub	*Semotilus atromaculatus atromaculatus*
Central common shiner	*Notropis cornutus chrysocephalus*
Hornyhead chub	*Nocomis biguttatus*
Western blacknose dace	*Rhinichthys atratulus meleagris*
Bluntnose minnow	*Pimephales notatus*
Central stoneroller	*Campostoma anomalum pullum*
Northern black bullhead	*Ameiurus melas melas*
Grass pickerel	*Esox vermiculatus*
Central mudminnow	*Umbra limi*
Brook stickleback	*Eucalia inconstans*

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[1] The common and scientific names to species are those recommended in Special Publication No. 1 of the American Fisheries Society, 1948, insofar as practicable. Names of species not listed in this publication and all subspecies names are essentially as in Hubbs and Lagler, 1947.

Rainbow darter	*Poecilichthys caeruleus*
Central Johnny darter	*Boleosoma nigrum nigrum*
Blackside darter	*Hadropterus maculatus*
Largemouth black bass	*Micropterus salmoides*
Green sunfish	*Lepomis cyanellus*
Bluegill	*Lepomis macrochirus*
Pumpkinseed	*Lepomis gibbosus*
Rock bass	*Ambloplites rupestris*
Sculpin	*Cottus bairdi*

APPENDIX II

A DESCRIPTION OF ADDITIONAL SELECTED STREAMS IN SOUTHERN MICHIGAN STUDIED DURING 1949

A DESCRIPTION OF ADDITIONAL SELECTED STREAMS IN SOUTHERN MICHIGAN STUDIED DURING 1949

In addition to the studies just reported, nine other southern Michigan streams received superficial investigation during 1949. The results are presented very briefly in the following pages.

Paint Creek

Paint Creek, in Oakland County, is a comparatively small stream ranging in width from six feet to approximately forty feet, and in depth from three or four inches to four feet in the deeper pools. It arises in Orion township (T 4N - R 10E) as the outlet of Lake Orion. The stream flows in a southeasterly direction for approximately twelve miles and joins the Clinton River at Rochester. The surrounding country is generally open pasture and cultivated land with occasional stretches of deciduous trees and shrubs. In the past decade, the land bordering the immediate shoreline has become very popular as sites for summer homes and cottages. As a result, there are many small private holdings sizeable stretches of stream closed to the public. However, this pattern of ownership has resulted in the preservation of much of the streamside vegetation in limited areas and has had moderate effect in shading the stream.

Arising as the outflow from Lake Orion, Paint Creek has two features not generally associated with good trout waters. First, spring flood levels in the lake usually mean serious flood damage in the stream, both to the watercourse itself and, reportedly, to the fish life contained therein. Secondly, since the outflow comes from the surface of the lake, which becomes very warm during the summer, stream temperatures of 80° to 85°F. are not uncommon. However, shade and spring seepage in restricted downstream areas tend to lower water temperatures from 5° to 8°F. below those recorded immediately downstream from the lake.

The stream bottom is composed largely of fine gravel with extensive stretches of rubble and smaller areas of hardpan. Rooted vegetation is common, particularly in the riffles. The water is alkaline (pH readings ranged from 8.3 to 8.6 during 1949) and hard (150 to 200 p.p.m. of calcium carbonate). Samples of the bottom organisms collected in July, 1949, were very rich generally but showed great variation in numbers and volume of invertebrates per square foot.

Samples of the fish fauna in 1949 indicated the presence of 24 species with trout very much in the minority in spite of monthly plantings of legal-sized (7 inches or more, total length) fish. Although naturally reproduced trout have been reported from Paint Creek, none was taken in the samples. In view of the comparatively high summer water temperatures, Paint Creek appears not to be a good trout stream. In limited areas near the springs, Paint Creek will support brown and rainbow trouts. The following-named species were collected in 1949[1]:

Lamprey ammocoete	*Ichthyomyzon* sp.
Rainbow trout	*Salmo gairdneri irideus*
Brown trout	*Salmo trutta*
Eastern brook trout	*Salvelinus fontinalis*
Common white sucker	*Catostomus commersonni commersonni*
Hog sucker	*Hypentelium nigricans*
Northern redbelly dace	*Chrosomus eos*
Creek chub	*Semotilus atromaculatus*
Northern common shiner	*Notropis cornutus frontalis*
Hornyhead chub	*Nocomis biguttatus*
River chub	*Nocomis micropogon*
Western blacknose dace	*Rhinichthys atratulus meleagris*
Blackchin shiner	*Notropis heterodon*
Central stoneroller	*Campostoma anomalum pullum*
Stonecat	*Noturus flavus*
Grass pickerel	*Esox vermiculatus*

[1] Nomenclature follows Amer. Fish. Soc. (1948) where given; otherwise names are from Hubbs and Lagler (1947).

Blackside darter	*Hadropterus maculatus*
Central Johnny darter	*Boleosoma nigrum nigrum*
Rainbow darter	*Poecilichthys caeruleus*
Barred fantail	*Poecilichthys flabellaris flabellaris*
Largemouth black bass	*Micropterus salmoides*
Bluegill	*Lepomis macrochirus*
Pumpkinseed	*Lepomis gibbosus*
Rock bass	*Ambloplites rupestris*
Black crappie	*Pomoxis nigro-maculatus*

Rice Creek

Rice Creek is formed by several small tributaries in the west-central portion of Jackson County. It flows approximately due west for 15 miles and empties into the Kalamazoo River at Marshall, Calhoun County. Throughout much of its course, the stream is slow-moving and well shaded by deciduous trees and shrubs. The lower portion of Rice Creek is part of the Chain-of-Lake County drain. The upstream reaches form the Rice Creek Intercounty drain. As a result of early dredging for reclamation of agricultural land, the lower seven or eight miles are almost continuous pools and generally too deep to wade. Organized sportsmen in Albion and Marshall installed stream improvement devices most of which had been removed by various causes at the time of the study in 1949.

Summer water temperature readings ranged from 57° to 65°F. during 1949. However, records in the files of the Michigan Institute for Fisheries Research show that much higher summer maxima may occur (81°F. on June 30, 1941). Much of the stream bottom is composed of gravel; yet stretches of sand and silt are common. Dense beds of vegetation observed include *Myriophyllum*, *Potamogeton*, R *Rannunculus*, and *Nasturtium officinale*. Chemical analysis on July 11, 1949, indicated that the stream is alkaline (pH = 7.7) and hard (278 p.p.m. of calcium carbonate).

The 13 fish species collected in Rice Creek during 1949 are listed below. Additional species may have been present at the time, but not taken since the efficiency of the electric shocker used in making the collections was impaired by the relatively great depths. White suckers were especially abundant and appeared to be quite heavily parasitized by the chestnut lamprey.

Brook, brown, and rainbow trouts have been planted extensively in the stream but because of high summer temperatures and slight current, brown trout seem best adapted. Fishermen have reported catches of very large specimens of this species in recent years.

Chestnut lamprey . . . . . . *Ichthyomyzon castaneus*

Rainbow trout . . . . *Salmo gairdneri irideus*

Brown trout . . . . *Salmo trutta*

Eastern brook trout	Salvelinus fontinalis
Common white sucker	Catostomus commersonni commersonni
Hog sucker	Hypentelium nigricans
Creek chub	Semotilus atromaculatus
Central common shiner	Notropis cornutus chrysocephalus
Northern common shiner . . .	Notropis cornutus frontalis
Central stoneroller	Campostoma anomalum pullum
Grass pickerel	Esox vermiculatus
Central mudminnow	Umbra limi
Central Johnny darter	Boleosoma nigrum nigrum
Sculpin	Cottus bairdi

Glass Creek

Glass Creek in Barry County, is formed by the outflow of several lakes in the townships of Hope (T 2N - R 9W), Orangeville (T 2N - R 10W) and Rutland (T 3N - R 9W). The main branch, from its source in Stewart Lake, flows northeastward for approximately five miles, then northwestward for five miles and joins the Thornapple River. The Glass Creek system includes another seven miles of fishable tributaries. Although much of the watercourse is shaded by deciduous trees, summer stream temperatures are often high. Readings on June 27, 1949, ranged from 73°F. to 84°F. Such high temperatures no doubt result largely from the source of the stream: surface outflow from warm-water lakes.

A large percentage of the stream bottom is composed of gravel and sand. The water is alkaline and hard. During the summer of 1949, pH readings ranged from 7.8 to 8.0 and total alkalinity ranged from 190 to 206 p.p.m. of calcium carbonate.

Brook trout and brown trout have been stocked in Glass Creek annually since 1933 and rainbows annually since 1940. In view of the extremely high summer water temperatures and the comparatively slow current, it appears that the brown trout is best suited for stocking in these waters.

In the samples of the 1949 population trout were extremely rare. The presence of two native brown trout, 18 and 22 inches in total length, indicates that this species has been at least partially successful, and may be well established. No trout of the current hatchery plantings were seen.

The following species were collected on June 27, 1949:

Common white sucker	Catostomus commersonni commersonni
Creek chub	Semotilus atromaculatus
Western blacknose dace	Rhinichthys atratulus meleagris
Northern common shiner	Notropis cornutus frontalis
Grass pickerel	Esox vermiculatus
Sculpin	Cottus bairdi

Silver Creek

There are two streams in Allegan County named Silver Creek. The one I studied in 1949 arises in the township of Heath (T 3N - R 14W) and flows northwest 2-1/2 miles to join the Little Rabbit River. The country surrounding this stream is gently rolling and quite heavily wooded in a mixture of hardwoods with oaks predominating. The sandy soil is porous, and clear, cold springs are common the whole length of the stream bed.

Silver Creek is a small stream, generally less than 20 feet wide and less than two feet deep. It is broken into many small channels by dense growths of alders and equally dense mats of water cress. The stream bottom is soft and boggy and is composed of sand and silt. Fallen logs, brush, and the remains of stream improvement devices offer excellent trout cover. The water is clear and cold. The maximum temperature recorded June 1, 1949, was 62°F. (corresponding air temperature was 84°F.).

Two dams, located about halfway between the source and the mouth of the stream have created two small ponds. An adjoining campground makes Silver Creek popular with fishermen.

Brook trout have been planted in this stream annually since 1936, whereas, rainbows were stocked only in 1943 and 1944. On June 1, 1949, a careful check with the electric shocker in that portion of stream above the ponds indicated that only the brook trout have survived and are reproducing naturally. Two other fish species observed, the central mudminnow (Umbra limi) and the sculpin (Cottus bairdi), appeared to be abundant.

Bear Creek

Bear Creek, from its source in Heath township (T 3N - R 14W), flows southwest 6-1/2 miles through heavily wooded country and joins the Kalamazoo River two miles west of Dunningville. Although its source is very close to that of Silver Creek and the country through which it flows is similar, it differs from the stream just described in its slightly larger size, its steeper gradient, its lack of aquatic vegetation, and its stream bottom of gravel and rubble. It is shaded by dense growths of alders and deciduous trees and excellent trout cover is provided by numerous fallen logs, stumps, and brush. The water is moderately cool and on June 1, 1949, was light brown in color. The maximum water temperature reading that day was 63°F. The corresponding air temperature was 84°F.

Brook trout have been stocked annually since 1933; brown and rainbow trouts since 1940. As in previous streams described, only the brown trout has become well established although one wild brook trout was taken with the electric shocker. The only rainbows observed were those of current hatchery plantings.

The stream is used extensively as spawning grounds by the sea lamprey (Petromyzon marinus). In addition to the species mentioned, the western blacknose dace (Rhinichthys atratulus meleagris) and sculpin (Cottus bairdi) were observed.

Sand Creek

Sand Creek, also in Allegan County, has two branches, one of which arises in Heath (T 3N - R 14W) and one in Valley (T 2N - R 14W). The stream, including its tributaries, is approximately three miles long. It flows westward through mixed hardwood forest over a sandy soil and joins the Kalamazoo River. Sand Creek is fed by numerous springs, particularly near its source. Water cress (Nasturtium officinale) abounds in these swampy sites. Farther downstream, however, all aquatic vegetation is lacking, apparently because of the scouring action of the shifting sand bottom. Throughout most of its length, the stream is very shallow and level and as a result, good trout cover is rather scarce. The water is cool and probably does not exceed the upper temperature limits tolerated by trout.

Brook trout were planted in Sand Creek annually from 1936 to 1946; rainbows were stocked in 1943 and 1944. A collection trip with the electric shocker on June 2, 1949, resulted in the capture of only two species. Wild fingerling brook trout and the sculpin (*Cottus bairdi*) were especially abundant. Only one trout over four inches in length was observed.

Swan Creek

Swan Creek arises from spring seepage and from the outflow of several lakes in the township of Cheshire (T 1N - R 14W) in Allegan County. It flows northward for approximately fourteen miles and empties into the Kalamazoo River in Valley township (T 2N - R 14W). The stream is generally well shaded by hardwood forest and excellent cover is provided in the form of fallen logs, brush, and undercut banks.

Midstream depths range from about eight inches to more than five feet in some of the deeper pools. The bottom is composed largely of gravel with restricted areas of sand and silt intermixed. The water is clear, light brown in color, and moderately cool. Stream temperature readings taken May 31 to June 2, 1949, ranged from 62°F. to 65°F. while corresponding air temperatures ranged from 76°F to 84°F.

A dam at the crossing of highway M-89 forms a lake about a mile in length. It appears that conditions in the lake favor the dominance of species generally not desired in trout waters. Several warm-water species were collected in the stream above the lake.

Brown and rainbow trouts have been stocked annually since 1933, whereas brook trout were planted only from 1933 to 1936. Of these salmonids only the brown trout were taken in sizeable numbers during May 31 to June 2, 1949. The presence of several wild fish indicates that this species has become established, whereas the few rainbow trout collected were those of current hatchery plantings. In addition to those just mentioned, the following species were collected in 1949:

Lamprey ammocoetes	(Not identified)
Common white sucker	Catostomus commersonni commersonni
Creek chub	Semotilus atromaculatus
Western blacknose dace . . .	Rhinichthys atratulus meleagris
Central stoneroller	Campostoma anomalum pullum
Central mudminnow	Umbra limi
Green sunfish	Lepomis cyanellus
Sculpin	Cottus bairdi

East Branch of the Paw Paw River

The East Branch of the Paw Paw River arises as seepage from numerous springs in the townships of Texas (T 3S - R 12W) in Kalamazoo County and Antwerp (T 3S - R 13W) in Van Buren County. It flows approximately eight miles northwest, and fed by additional springs along its course, joins the West Branch of the Paw Paw at Maple Lake in the city of Paw Paw.

The soil in this part of the state is composed largely of gravel which absorbs much of the rainfall and releases it later in the form of clear, cold springs. The gently rolling terrain of the region is quite intensively cultivated and pastured although much of the land bordering the stream bed has been left with its natural vegetation of deciduous trees and shrubs.

Like the surrounding land, the stream bottom is largely gravel. The frequent and deep pools are generously provided with shelter for aquatic life. Summer water tempertture is not excessively high as evidenced by a series of readings in 1949 which ranged from 56° to 63°F. During the same period, chemical analyses indicated the water to be slightly alkaline (pH values ranged from 7.7 to 8.0) and hard (192 to 200 p.p.m. calcium carbonate).

Brook trout have been planted annually in this stream since 1933, and rainbow and brown trouts annually since 1937 and 1939, respectively. Only the brown trout seems to have become well established in the East Branch. Numerous pairs of adults of this species were observed spawning in November, 1949, and fry and fingerlings were common residents throughout the summer. It appears that naturally produced brook and rainbow trouts are rare, if present at all, since none was observed during the study.

An additional six fish species collected in this stream are listed below:

Lamprey ammocoete	(Not identified)
Common white sucker	*Catostomus commersonni commersonni*
Creek chub	*Semotilus atromaculatus*
Western blacknose dace . . .	*Rhinichthys atratulus meleagris*
Grass pickerel	*Esox vermiculatus*
Sculpin	*Cottus bairdi*

Kenzie Creek

Kenzie Creek, known also as Kenzie, Kinzie, and McKinzie Creek, is a comparatively small stream which has its source in swampy springs in Howard township (T 7S - R 16W), Cass County. It flows generally northwest for approximately eight miles and enters the Dowagiac River just north of the city of Niles. Much of the surrounding country has been cleared for agricultural purposes but in recent years a sizeable portion, near the stream, at least, has been used only as pasture and is gradually being covered with deciduous shrubs. Evidence of past dredging in the watercourse still persists in the form of high piles of earth on the banks. However, the stream bed itself is no longer straight and level. Deep pools with good shelter of undercut banks and fallen logs are common.

The stream bottom is composed mainly of gravel although some stretches of sand, silt, and rubble do occur. Rooted vegetation is extremely scarce or absent. The maximum water temperature recorded during a limited series of readings in the summer of 1949 was 63°F. Air temperature at the same time was 88°F. It is improbable that the water becomes much warmer even on very hot days because of the copious supply of cold spring water that enters the upper reaches of the stream.

Brown and rainbow trouts have been stocked annually since 1933 and brook trout since 1942. As in the East Branch of the Paw Paw River, it appears that only the brown trout has become successfully established in Kenzie Creek. Dredging operations in the upstream areas in the fall of 1949 kept the water muddy and attempts to observe spawning activities failed. Yet the presence of numerous wild fry, fingerlings, and adults of this species indicates that natural reproduction is successful. The only specimens of other trout species observed were hatchery fish from current plantings.

Additional fish species collected during 1949 are as follows:

Lamprey ammocoete . . . . . (Not identified)

Common white sucker . . . . *Catostomus commersonni commersonni*

Creek chub . . . . <u>Semotilus</u> <u>atromaculatus</u>

Western blacknose dace . . <u>Rhinichthys</u> <u>atratulus</u> <u>meleagris</u>

Sculpin . . . . <u>Cottus</u> <u>bairdi</u>

APPENDIX III

NUMBERS AND FREQUENCY OF OCCURRENCE OF BOTTOM ORGANISMS IN FOUR SOUTHERN MICHIGAN STREAMS

NUMBERS AND FREQUENCY OF OCCURRENCE (IN PARENTHESES) OF ORGANISMS TAKEN IN 110 BOTTOM SAMPLES IN FOUR SOUTHERN MICHIGAN STREAMS

Frequency of occurrence is expressed as a percentage of the total number of samples taken on the stream

Organism	Paint Creek		North Branch Saline River				Wilder Creek		Spring Brook			
			Section A		Section B				Section A		Section B	
	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
Turbellaria (Planaria)									1	(7.1)	4	(18.8)
Annelida (Tubificidae)	143	(53.3)	17	(27.8)	21	(8.7)	3	(8.3)	32	(42.9)	32	(37.5)
Mollusca												
Physa	9	(20.0)	17	(16.7)	44	(8.7)	3	(12.5)	11	(21.4)	4	(18.8)
Planorbis	2	(6.7)										
Pisidium					2	(8.7)	3	(8.3)	5	(28.6)	3	(12.5)
Isopoda (Asellus)			5	(16.7)	6	(4.3)	9	(12.5)				
Amphipoda												
Gammarus							32	(33.3)	1	(7.1)	2	(12.5)
Hyallela	3	(13.3)	3	(11.1)	37	(30.4)	28	(29.2)				
Neuroptera												
Sialis	4	(6.7)			1	(4.3)						
Chauliodes									4	(7.1)	6	(37.5)
Ephemeroptera												
Hexagenia									5	(21.4)	10	(31.3)
Baetidae			2	(5.6)					32	(21.4)	28	(37.5)
Baetis	1	(6.7)			20	(26.1)						
Leptophelebiinae			1	(5.6)	2	(4.3)						
Ephemerella									4	(21.4)	12	(37.5)
Tricorythodes			38	(61.1)	22	(30.4)			5	(21.4)	2	(12.5)
Caenis					1	(4.3)						
Pseudocloeon					3	(4.3)						
Plecoptera												
Leuctridae									4	(14.3)	1	(6.3)

APPENDIX III (CONTINUED)

Organism	Paint Creek		North Branch Saline River Section A		North Branch Saline River Section B		Wilder Creek		Spring Brook Section A		Spring Brook Section B	
	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
Nemoura	97	(20.0)										
Paragnetina media									6	(14.3)	13	(25.0)
Hemiptera (Corixidae)	2	(6.7)	34	(33.3)	26	(8.7)						
Coleoptera												
Gyrinidae			5	(11.1)	1	(4.3)						
Dytiscidae	6	(13.3)	9	(22.2)	12	(4.3)						
Dryopidae	2	(13.3)	1	(5.6)	37	(34.8)	90	(41.7)	138	(85.7)	178	(62.5)
Haliplidae			2	(5.6)	7	(17.4)						
Trichoptera												
Glossosoma (nigrior)							72	(20.8)	485	(85.7	385	(56.3)
Chimarra aterrima									4	(7.1)	6	(12.5)
Trentonius									4	(21.4)	9	(6.3)
Psychomyia			28	(16.7)	17	(4.3)			1	(7.1)	6	(18.8)
Polycentropus					20	(8.7)						
Hydropsyche			50	(38.9)	68	(13.0)	10	(25.0)	15	(42.9)	14	(31.3)
Hydropsyche bifida			4	(11.1)	53	(21.7)	5	(16.7)	1	(7.1)	6	(31.3)
H. slossonae			17	(27.8)	14	(13.0)	34	(33.3)	15	(28.6)	20	(37.5)
H. betteni			2	(11.1)	24	(8.7)	9	(20.8)				
Cheumatopsyche			147	(66.7)	106	(30.4)	2	(4.2)	15	(35.7)	15	(43.8)
Hydroptila			2	(11.1)	1	(4.3)						
Pycnopsyche			6	(5.6)	2	(8.7)	12	(25.0)				
Limnephilus	1	(6.7)										
Athripsodes	1	(6.7)										
Oecetis			3	(16.7)	2	(8.7)						
Lepidostoma	3	(20.0)	1	(5.6)	6	(8.7)			4	(2.14)	2	(20.0)
Micrasema									2	(14.3)	1	(6.3)
Brachycentrus numerosus							29	(25.0)				

APPENDIX III (CONTINUED)

Organism	Paint Creek		North Branch Saline River Section A		North Branch Saline River Section B		Wilder Creek		Spring Brook Section A		Spring Brook Section B	
	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
Brachycentrus americanus									475	(92.9)	430	(50.0)
Helicopsyche					1	(4.3)						
Diptera												
Antocha			18	(66.7)	47	(21.7)			37	(64.3)	105	(93.8)
Eriocera			14	(27.8)	12	(26.1)	8	(8.3)	9	(28.6)	12	(31.3)
Hexatoma	1	(6.7)	5	(22.2)	9	(21.7)	12	(12.5)				
Dicranota	5	(6.7)			2	(8.7)	27	(20.8)	19	(42.9)	42	(68.8)
Tipula	1	(6.7)										
Atherix									17	(14.3)	28	(31.3)
Chrysops	3	(13.3)	8	(22.2)	6	(8.7)	6	(20.8)				
Tendipedidae	502	(86.7)	384	(88.9)	608	(82.6)	666	(91.7)	242	(100.0)	421	(81.3)
Simulium	1	(6.7)	6	(16.7)	6	(4.3)			4	(14.3)	6	(12.5)
Syrphus	6	(13.3)										
Hemerodromia									18	(28.6)	17	(37.5)
Anthomyiidae					2	(8.7)						
Hydracharina	4	(13.3)	4	(22.2)	5	(13.0)			9	(14.3)	5	(6.3)
TOTALS	797		833		1253		1060		1624		1825	

APPENDIX IV

FOOD ORGANISMS IN THE STOMACHS OF SOUTHERN MICHIGAN STREAM FISHES

TABLE 1. TOTAL NUMBER OF ORGANISMS IN THE STOMACHS OF SEVENTY-FOUR FISH FROM PAINT CREEK, WASHTENAW COUNTY, MICHIGAN

Frequency of occurrence (number of stomachs) shown in parentheses

Organism	Fish species and number stomachs examined				
	Brown trout 14	Rainbow trout 11	White sucker 18	Blacknose dace 16	Sculpin 15
Annelida (Tubificidae)					1 (1)
Mollusca (Physa)	3 (1)	1 (1)			
Crustacea					
Asellus	1 (1)	2 (2)			
Hyallela	3 (2)		1 (1)	2 (2)	5 (4)
Neuroptera (Sialis)	5 (3)				1 (1)
Ephemeroptera (nymphs)	7 (3)	6 (4)	1 (1)	4 (3)	
Baetidae	3 (2)	1 (1)			2 (2)
Leptophlebiinae	1 (1)		4 (2)		
Plecoptera (Nemoura)	17 (6)	8 (4)	1 (1)	2 (2)	7 (3)
Hemiptera					
Corixidae	8 (3)	1 (1)			
Pentatomidae	1 (1)		2 (2)		
Coleoptera (larvae)	4 (3)	1 (1)	2 (2)	2 (1)	1 (1)
Dytiscidae	2 (1)	5 (3)			
Dryopidae	2 (2)	1 (1)			
Hydrophilidae		2 (2)			
Trichoptera (larvae)	6 (4)	1 (1)			8 (5)
Limnephilidae	8 (4)	7 (3)			
Lepidostoma	14 (5)	3 (2)		2 (1)	1 (1)
Athripsodes	1 (1)		1 (1)	2 (2)	
Hydropsyche	2 (2)	1 (1)	2 (2)		6 (4)
Diptera (larvae)	9 (4)	1 (1)	16 (6)	1 (1)	1 (1)
Hexatoma	2 (2)		5 (3)		
Dicranota		2 (1)		1 (1)	
Tendipedidae	28 (9)	22 (6)	48 (13)	3 (2)	14 (6)
Hemerodromia	1 (1)				
Diptera (adults)	3 (2)	2 (1)			
Zygoptera (adult)		1 (1)			
Hymenoptera (Formicidae)	3 (3)	16 (5)			
Hydracharina			2 (1)		3 (3)
TOTALS	134	84	83	19	17
KINDS	24	20	12	9	12

TABLE 2. TOTAL NUMBER OF ORGANISMS IN THE STOMACHS OF FORTY-NINE FISH FROM THE NORTH BRANCH OF THE SALINE RIVER, WASHTENAW COUNTY, MICHIGAN

Frequency of occurrence (number of stomachs) shown in parentheses

Organism	Fish species and number of stomachs examined					
	Brown trout 12	Rainbow trout 10	Creek chub 7	Common shiner 9	Pumpkin-seed 4	Sculpin 7
Mollusca (Physa)		8 (4)				
Crustacea						
Asellus	3 (3)	2 (1)		1 (1)		
Gammarus		3 (2)				
Hyallela	1 (1)	6 (5)				2 (1)
Neuroptera (Sialis)	9 (5)	2 (1)			2 (2)	
Ephemeroptera (nymphs)	18 (7)	13 (5)	3 (1)	2 (2)	1 (1)	3 (2)
Baetidae	4 (2)	1 (1)	2 (2)	1 (1)		1 (1)
Leptophlebiinae	1 (1)	3 (1)	1 (1)		2 (1)	
Trichorythodes	11 (6)	15 (9)	8 (4)	1 (1)	3 (1)	2 (2)
Caenis	2 (2)	1 (1)	2 (1)		1 (1)	
Pseudocloeon	1 (1)					
Hemiptera (Corixidae)	5 (2)	17 (5)	1 (1)	1 (1)	2 (1)	
Coleoptera (larvae	2 (1)	1 (1)				
Gyrinidae	4 (4)		1 (1)		3 (2)	2 (2)
Dytiscidae	7 (3)		1 (1)			
Dryopidae	10 (4)				1 (1)	
Haliplidae		1 (1)				
Coleoptera (terrestrial)	15 (8)	29 (9)	1 (1)		4 (3)	
Trichoptera (larvae)	1 (1)	23 (6)		1 (1)	3 (3)	5 (4)
Polycentropus					1 (1)	
Psychomyia	4 (2)	1 (1)	1 (1)	3 (3)		1 (1)
Hydropsyche	8 (5)	15 (4)	1 (1)		3 (3)	3 (3)
Hydropsyche slossonae	1 (1)	8 (7)	3 (1)	2 (1)		
Cheumatopsyche	68 (9)	31 (8)			14 (3)	2 (1)
Hydroptila	3 (1)					
Oecetis		1 (1)				
Diptera (larvae)	1 (1)	2 (2)			4 (2)	2 (2)
Antocha	3 (1)			1 (1)		
Tipula	1 (1)					
Tendipedidae	70 (10)	36 (6)	17 (4)	8 (3)	6 (3)	34 (7)
Simulium		3 (3)		1 (1)	4 (1)	
Anthomyiidae			1 (1)			
Diptera (adults)	7 (3)	18 (6)			2 (2)	
Hymenoptera (Formicidae)	3 (2)	14 (3)			1 (1)	
Hydracharina	2 (2)	4 (1)			2 (1)	1 (1)
TOTALS	275	258	43	21	59	58
KINDS	28	26	14	11	19	12

TABLE 3. TOTAL NUMBER OF ORGANISMS IN THE STOMACHS OF FORTY-FIVE FISH FROM WILDER CREEK, CALHOUN COUNTY, MICHIGAN

Frequency of occurrence (number of stomachs) shown in parentheses

Organism	Fish species and number of stomachs examined			
	Brown trout 10	Rainbow trout 11	Mudminnow 14	Sculpin 10
Crustacea				
Asellus	1 (1)			
Hyallela	8 (4)		5 (3)	3 (3)
Ephemeroptera (nymphs)	6 (3)	9 (4)	15 (8)	1 (1)
Baetidae		2 (2)		4 (2)
Baetis			1 (1)	
Blasturus	5 (1)	5 (3)		2 (1)
Hemiptera (Corixidae)	7 (5)	10 (5)		
Coleoptera (larvae)	1 (1)			
Gyrinidae	2 (2)	1 (1)	2 (1)	
Dryopidae	3 (1)	2 (2)	5 (4)	
Haliplidae		1 (1)		
Coleoptera (adults)	13 (4)	5 (2)		
Trichoptera (larvae)	1 (1)			
Glossosoma	7 (5)	11 (4)	5 (3)	1 (1)
Hydropsyche	13 (5)	8 (4)		2 (1)
Hydropsyche slossonae	3 (2)	3 (1)		
Ptilostomis	26 (4)	31 (6)		
Pycnopsyche	9 (6)	5 (3)	2 (2)	1 (1)
Neophylax	8 (2)	3 (1)		
Limnephilidae	1 (1)	1 (1)	1 (1)	
Brachycentrus numerosus		21 (4)		3 (1)
Protoptila		3 (2)	1 (1)	
Diptera (larvae)		2 (1)		
Eriocera	2 (1)	1 (1)		1 (1)
Tabanidae	2 (1)	8 (5)		
Hexatoma	1 (1)			
Tendipedidae	8 (4)	17 (7)	9 (4)	18 (5)
Diptera (adults)	3 (1)	1 (1)		1 (1)
Hymenoptera (Formicidae)	3 (1)	16 (2)	1 (1)	
Araneae	1 (1)			
Hydracharina	2 (2)	3 (1)	1 (1)	1 (1)
TOTALS	136	169	48	38
KINDS	26	24	12	12

TABLE 4. TOTAL NUMBER OF ORGANISMS IN THE STOMACHS OF EIGHTY-THREE FISH FROM SPRING BROOK, KALAMAZOO COUNTY, MICHIGAN

Frequency of occurrence (number of stomachs) shown in parentheses

Organism	Fish species, number stomachs examined					
	Brook trout 11	Brown trout 22	Rainbow trout 9	White sucker 10	Blacknose dace 11	Sculpin 20
Annelida (Tubificidae)						1 (1)
Mollusca (Physa)	1 (1)	2 (2)	2 (2)			
Crustacea						
Decapoda					1 (1)	1 (1)
Isopoda (Asellus)		2 (2)	1 (1)			1 (1)
Gammarus		2 (2)			2 (2)	5 (3)
Hyallela	3 (3)	4 (3)		6 (2)		7 (3)
Neuroptera (Sialis)	2 (1)				1 (1)	1 (1)
Ephemeroptera (nymphs)	7 (2)	19 (5)	22 (7)	3 (1)	4 (4)	19 (11)
Hexagenia			1 (1)	11 (3)		
Baetidae	1 (1)	1 (1)	5 (3)			
Baetis			4 (3)			1 (1)
Ephemerella	17 (7)	17 (6)	12 (4)			8 (3)
Caenis	1 (1)	1 (1)				
Ephemeroptera (adults)	2 (2)					
Plecoptera (nymph)	1 (1)					
Hemiptera						
Corixidae	8 (4)	23 (11)	3 (3)			
Pentatomidae		1 (1)				
Cerambycidae	3 (2)	11 (4)	3 (2)			
Homoptera	104 (1)	4 (3)				
Coleoptera (larvae)		15 (1)				
Dytiscidae	5 (3)					
Gyrinidae	10 (1)	2 (2)	3 (2)	2 (1)		1 (1)
Haliplidae			1 (1)			
Coleoptera (adults)	19 (4)	11 (5)	13 (4)	1 (1)		
Trichoptera (larvae)	7 (4)	15 (9)	8 (3)	6 (4)	5 (5)	26 (13)
Glossosoma	9 (4)	36 (11)	4 (2)	1 (1)	5 (3)	
Psychomyia	2 (1)	8 (1)				
Hydropsyche		2 (2)	2 (1)	3 (2)		
Hydropsyche slossonae		2 (2)	2 (2)			1 (1)
Cheumatopsyche	1 (1)		2 (1)	1 (1)		5 (3)
Hydroptila	2 (2)	1 (1)				
Pycnopsyche	1 (1)	12 (5)				
Limnephilus		4 (3)				1 (1)
Lepidostoma		5 (3)				

TABLE 4 (CONTINUED)

Organism	Fish species, number stomachs examined					
	Brook trout 11	Brown trout 22	Rainbow trout 9	White sucker 10	Blacknose dace 11	Sculpin 20
Micrasema	14 (4)	24 (11)	17 (6)			
Brachycentrus		3 (2)				
Brachycentrus americanus	47 (9)	40 (12)	31 (6)	2 (1)	1 (1)	1 (1)
Diptera (larvae)	7 (3)	27 (10)	8 (2)	2 (2)	3 (3)	
Antocha		3 (2)	1 (1)			
Tipula		3 (3)	2 (2)			
Tendipedidae	29 (5)	15 (7)	12 (4)		18 (7)	62 (16)
Simulium	2 (2)				1 (1)	
Syrphus			1 (1)			
Diptera (adults)	11 (3)	16 (1)	2 (2)			
Zygoptera (adults)		9 (2)				
Hymenoptera (Formicidae)	53 (7)	16 (4)	43 (4)			
Diplopoda	10 (4)	64 (6)	1 (1)			
Hydracharina	7 (1)	2 (1)	1 (1)			
TOTALS	386	422	207	141	41	38
KINDS	30	36	28	16	10	11