cc: Fish Division
Institute for Fisheries
Research

April 27, 1953

Report No. 1369

THE RELATIONSHIP AMONG CERTAIN ECOLOGICAL CONDITIONS AND TROUT POPULATIONS IN THE PIGEON RIVER

By

Norman G. Benson

Abstract

THE RELATIONSHIPS AMONG CERTAIN ECOLOGICAL FACTORS AND TROUT POPULATIONS IN THE PIGEON RIVER, MICHIGAN

by Norman G. Benson

Information was collected on the ecological determinants of the density in populations of brook trout (Salvelinus f. fontinalis Mitchill) and brown trout (Salmo trutta fario L.) in the Pigeon River, Otsego and Cheboygan counties, Michigan. Chemical, physical, and biological data were collected in four study areas (each 400 yards long) during all seasons of the year in the period from June, 1950 to June, 1952. Estimated numbers of trout (collected by D. C. electrical shocker) in July, 1951, were: study area I, 1140; study area II, 737; study area III, 89; and study area IV, 1.

Dissolved oxygen (8.0 to 13.5 p.p.m.), methyl orange alkalinity (126 to 215 p.p.m.), phenolphthalein alkalinity (0.0), hydrogen ion concentration (7.4 to 8.8), phosphorus (0.000 to 0.023 p.p.m.), and specific conductance (185 to 208 reciprocal megohms) did not vary significantly among the study areas. Maximum water temperatures from March 14 to November 3, 1951, in the respective study areas were: I, 67° F.; II, 76° F.; III, 78° F.; and IV, 78° F. Percentage of surface ice cover was used to indicate winter water temperatures and was greater in study areas III and IV (maximum, 100 percent) than in I (maximum, 20 percent) or in II (maximum, 75 percent). The maximum ground water seepages (recorded as percentage increase in volume of flow per mile of stream) found in the respective study areas were: I, 23.5 percent; II, 23.3 percent; III, 6.4 percent; and IV, 1.7 percent. Mean depth (9.8 to

Note

19.5 inches), mean width (37.6 to 61.0 feet), or percentage gradient (0.057 to 0.335 percent) showed little relationship to numbers of trout. Bank and midstream cover were greatest with the largest numbers of trout; the exact relationships of cover were not determined. Bottom soil types were classified by improved means using standardized sieves and included: silt, sand, fine gravel, coarse gravel, and rubble.

Estimated winter standing crops of macroscopic bottom organisms per acre (principally Ephemeroptera, Trichoptera, and Diptera) in the respective study areas were: I, 49,189 cc.; II, 41,934 cc.; III, 23,553 cc.; and IV, 59,340 cc. Estimated total standing crops in pounds per acre of non-salmonoid fishes for each study area in July, 1951, were: I, 9.95; II, 10.68; III, 20.65; and IV, 10.01. The largest standing crop of fish in pounds per acre (45.77 in July, 1951) was present with the largest trout population (1440 in July, 1951).

Lack of ground water seepage was found to be the only condition that definitely limited the density of trout populations. Trout spawning areas were present only where ground water seepage occurred. Due to apparently limited migration of trouts, the amount of spawning determined the numbers of all sizes and age groups. Ground water seepage was determined (within limitations) by summer water temperature, winter water temperature, surface ice cover, bottom soil temperatures, and seepage runs. In conclusion, for survey work and for environmental improvement in trout streams, ground water seepage should be considered.

THE RELATIONSHIP AMONG CERTAIN ECOLOGICAL CONDITIONS AND TROUT POPULATIONS IN THE PIGEON RIVER

by
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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in the
University of Michigan
1953

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INTRODUCTION

It is generally known that trout are not uniformly distributed in streams (Malloch, 1910; Bergman, 1938; Needham, 1938; Crowe, 1947; Allen, 1951). However, the factors responsible for such variations in population density have never been analyzed intensively. It is the purpose of this investigation to examine some of the possible ecological determinants of the localizations of trout in streams.

The present study was confined to parts of the Pigeon River in Otsego and Cheboygan counties, Michigan; these are designated as study areas I, II, III, and IV (Fig. 1). Pertinent chemical, physical, and biological features of the stream were studied at various times during the period from June, 1950 to June, 1952. The trout species concerned were the brook and the brown.[1]

Although tremendous amounts of money and time have been spent on stream surveys in the United States, few workers have attempted to correlate known size and distribution of trout populations with ecological conditions. Particularly scant attention in these surveys and related studies has been given to an early ecological concept, the so-called "Law of Limiting Factors" (Blackman, 1905). According to Allee, et al. (1949), a limiting factor exerts its influence when, despite the favorable nature of the remainder of the environment, it comes to control the habitat.

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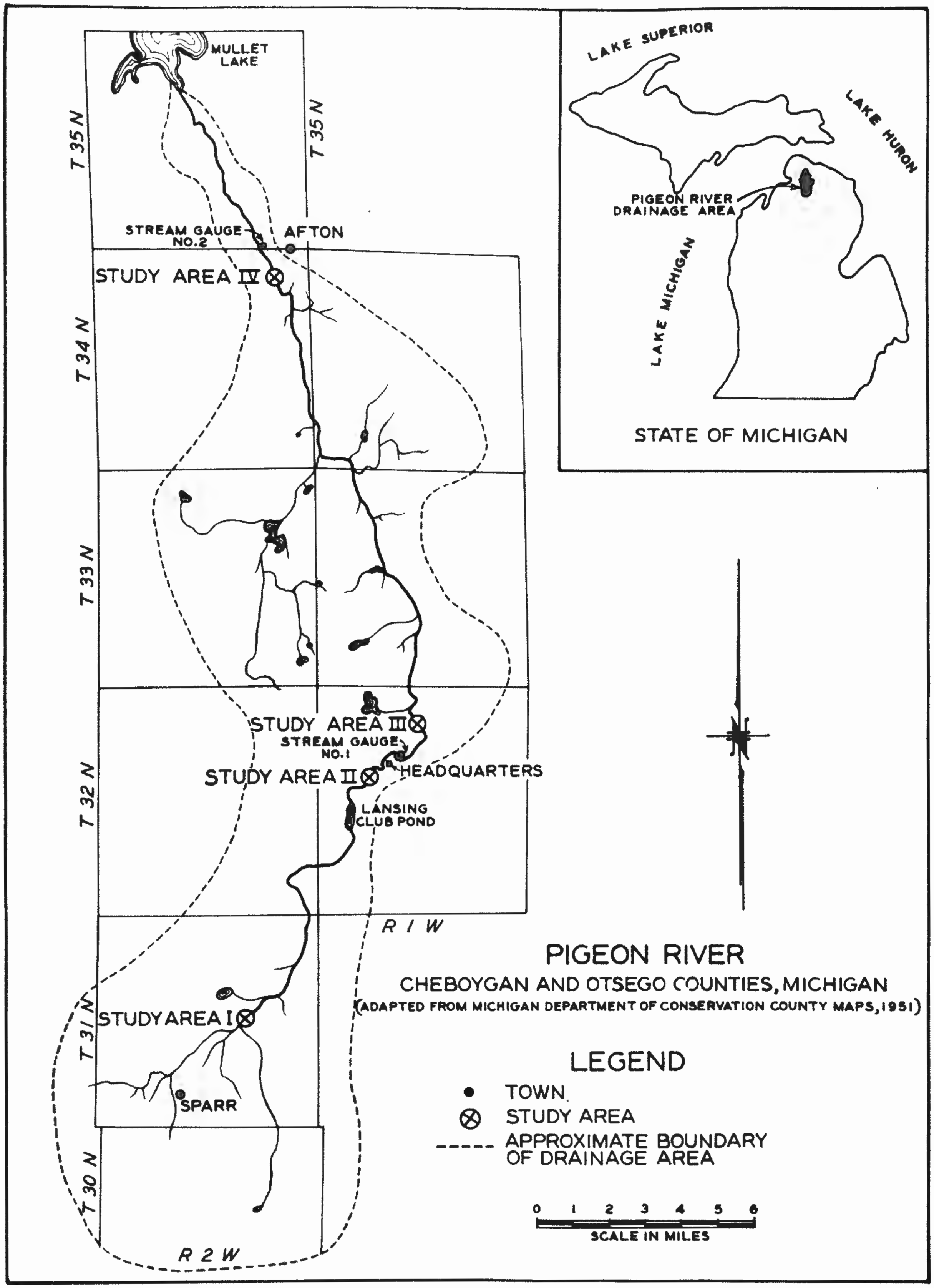
[1]Insofar as practicable, fish names correspond to those given in Special Publication No. 1 (1948) of the American Fisheries Society; common names are used in the text and their technical equivalents are given in an appendix (App. C, Table 1).

Fig. 1. Map of Pigeon River drainage system with study areas and stream gauges. In upper right is a map of the state of Michigan with the Pigeon River drainage area in black.



PIGEON RIVER
CHEBOYGAN AND OTSEGO COUNTIES, MICHIGAN
(ADAPTED FROM MICHIGAN DEPARTMENT OF CONSERVATION COUNTY MAPS, 1951)

It is not easy to recognize the significance of any single factor in nature (as mentioned by Allee et al., 1949). In the present study the abundance of wild trout was used as the sole measure of the relative importance of each factor. Leopold (1933) believed that limiting factors were the fundamental determinants of abundance and composition in game populations. Knowledge of this subject also appears to be basic in consideration of fish populations and hence, in their management. It is the aim of this study to increase information on this topic and, in so doing, to provide new methods and to develop new ideas applicable to trout surveys, stocking policies, and environmental improvement.

Acknowledgments

The writer is indebted to Drs. Edwin L. Cooper, Albert S. Hazzard, and Karl F. Lagler, under whose cooperative direction this work was accomplished. Messrs. Edward Bacon, Jan Fedely, Louis Horger, Gerald Myers, and Donald Tesman, of the Institute for Fisheries Research, Fish Division, Michigan Department of Conservation, helped in the collection of field data. Dr. Justin W. Leonard and his wife, Fannie A. Leonard, aided in the identification of stream insects. Dr. J. Speed Rogers checked the identification of certain tipulids. Mr. William Cristanelli prepared the figures from my rough drafts. Dr. Paul Barrett assisted in the phosphorus determinations. Mr. Dale Pettingill of the Water Resources Branch of the U. S. Geological Survey provided information on volume of stream flow in several streams of the region. Members of my doctoral committee, not mentioned here, have my thanks for the varied help they gave. I am, of course, indebted to the Michigan Department of Conservation for the opportunities and equipment so generously provided for this study; during the entire interval I was a member of the staff of the Pigeon River Trout Research Area of the Institute for Fisheries Research.

ANALYSES OF ECOLOGICAL FACTORS

The explanation for local differences in density of trout in a stream must lie in the interaction between the fish and one or more ecological factors. It was impossible to analyse all environmental determinants; the choice of those studied was largely governed by the following: (1) general utilisation of certain analyses in routine trout stream surveys (e.g., Davis, 1938; Needham, 1938; Lagler, 1949); (2) convenience and availability of instruments and services; and (3) desirability of the exploration of new possibilities. The analyses performed fall into the conventional broad categories: chemical, physical, and biological.

Chemical Factors

Each aspect of water chemistry studied is listed below. The reason for its inclusion in this investigation and the method employed are also given briefly. "Routine", as employed below, means that the determination of the ecological factor concerned is a standard procedure for most lake and stream surveys.

Phenolphthalein alkalinity

Routine. Standard Methods for the Examination of Water and Sewage, 1946.

Methyl Orange Alkalinity

Routine. Standard Methods for the Examination of Water and Sewage, 1946.

Dissolved Oxygen

Routine. Rapid Winkler, Ellis *et al.*, 1948.

Hydrogen Ion Concentration

Routine. Hellige glass comparator disks and indicator solutions; following manufacturer's instructions.

Phosphorus

Important in fertility studies of inland waters. Adapted from Ellis *et al.*, 1948.

Specific Conductance

Supplements methyl orange alkalinity data. Industrial instruments portable conductivity bridge Model RC, purchased in 1948; following manufacturer's instructions.

Stream Bottom Soils

Exploratory. Analyses performed by Department of Soil Science, Michigan State College.

Physical Factors

The physical factors, which might bear on fish distribution, were assayed in a manner similar to that described for the chemical factors. The reason for making each analysis, the method employed, and the source of the method, follow.

Morphometry of Stream Study Areas

Generally routine and fundamental in a study of this type. For each stream section, Dumpy level, steel tape, and yardstick were used to obtain; (1) surface configuration; (2) gradient; and (3) bottom topography.

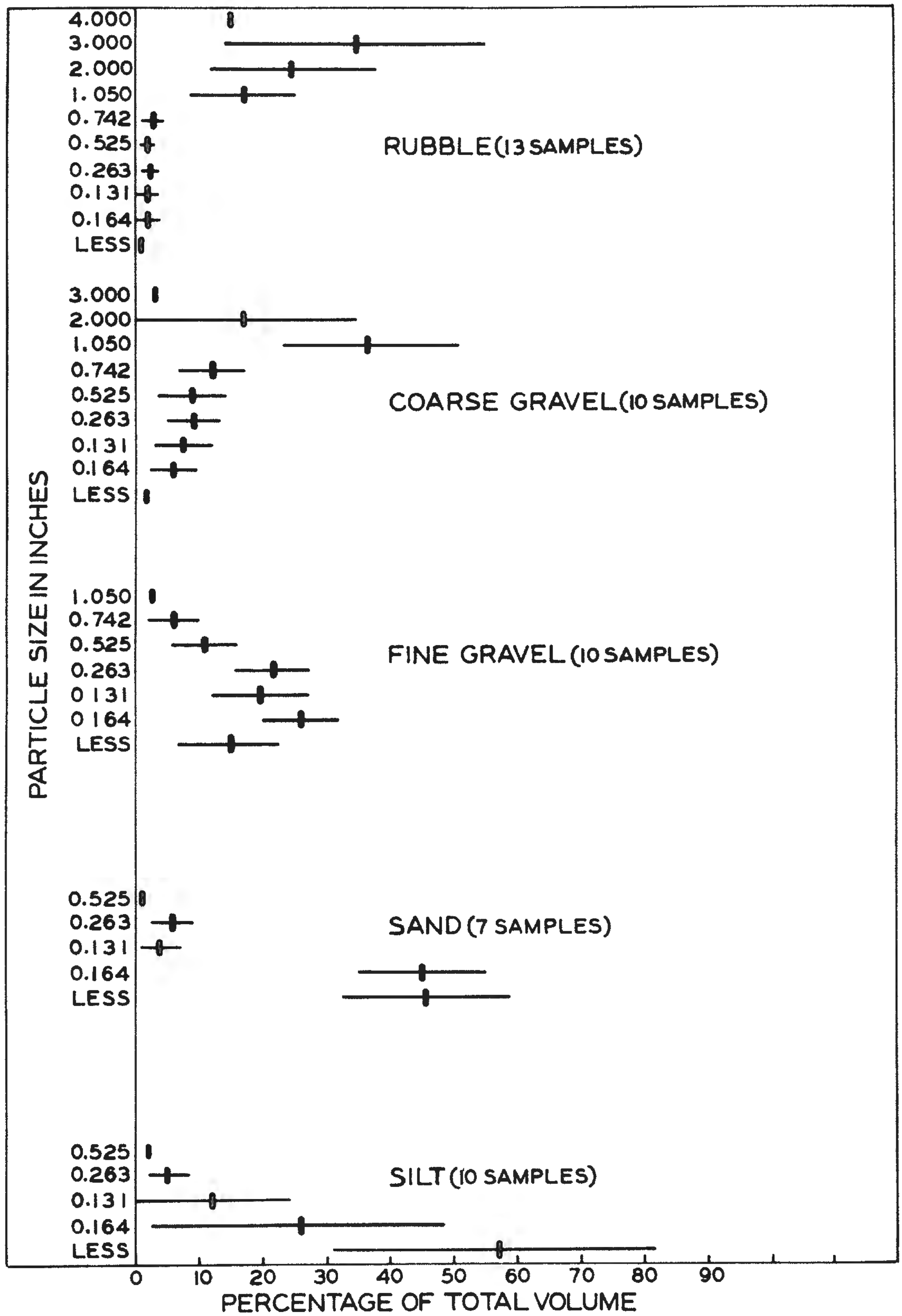
Stream Bottom Soils

Routinely subjective (e.g., Davis, 1938; Needham, 1938); here refined by use of U. S. Standard Sieve series (mesh sizes in inches: 2, 3, and 4) and Tyler Standard Screen scale (mesh sizes in inches:

1.050, 0.742, 0.525, 0.263, 0.131, and 0.0164). The procedure was to collect a sample of stream bottom soil with a bottom sampler (described by Surber, 1937) lined with cloth sheeting to prevent the loss of fine particles. In the laboratory, particles larger than 0.525 inches were washed free of sand and silt and then screened while still wet. All particles smaller than the previous maximum dimension were oven-dried (150° C.) before sieving. Comparison of wet and dry residues of larger particles following sieving showed insignificant differences in volume (less than 1.0 percent). The volumes of the materials in each particle size group were obtained by water displacement. Percentages of organic matter in silt and sand were determined by the method of Robinson (1927). On the basis of these methods it was possible to determine the composition of the stream bottom soil types. Those encountered in the Pigeon River were: rubble, coarse gravel, fine gravel, sand, and silt (generally conforming to the definitions of Davis, 1938). There was great variation in total volume of bottom samples obtained (500 cc. to 4000 cc.). Therefore, to describe the composition of each sample, the percentage of each particle size-group in the total volume of the sample was used (e.g., 4 in., 40 percent; 3 in., 30 percent; 1 in., 30 percent). The mean and standard deviation of volume of particle sizes in each bottom type were calculated to show the limits of reliability of this approach to the problem of bottom type variance (Fig. 2). An improved means of rapid classification for the five bottom types is now possible. In it I propose certain percentage limits within which specific size groups must fall. These bottom types are then defined as follows:

Rubble ---------- 60 percent of volume above 2 inches but less than 5 inches.

Fig. 2. Variation in composition of five bottom types in Pigeon River study areas. Sampling loci chosen by chance and gross inspection; bottom types conform generally to Davis (1938). Vertical line represents the mean percentage by volume of particle sizes; horizontal line represents one standard deviation above and below mean (Data from App. B, Table 5).


RUBBLE (13 SAMPLES)
4.000
3.000
2.000
1.050
0.742
0.525
0.263
0.131
0.164
LESS
COARSE GRAVEL (10 SAMPLES)
3.000
2.000
1.050
0.742
0.525
0.263
0.131
0.164
LESS
FINE GRAVEL (10 SAMPLES)
1.050
0.742
0.525
0.263
0.131
0.164
LESS
SAND (7 SAMPLES)
0.525
0.263
0.131
0.164
LESS
SILT (10 SAMPLES)
0.525
0.263
0.131
0.164
LESS
PARTICLE SIZE IN INCHES
0
10
20
30
40
50
60
70
80
90
PERCENTAGE OF TOTAL VOLUME

Coarse gravel --- 50 percent of volume above 0.525 inches but less than 2 inches.

Fine gravel ----- 60 percent of volume below 0.525 inches but greater than 0.0164 inches.

Sand ----------- 70 percent of volume below 0.131 inches with less than 4 percent organic matter.

Silt ----------- 70 percent of volume below 0.131 inches with more than 4 percent organic matter.

The names of bottom types, as just characterized, were used in the description of each study area.

Water Temperatures

Routine in summer; exploratory winter temperature data also taken. Thermal conditions in water were measured as follows: (1) weekly, with maximum-minimum thermometers (Taylor Instrument Company), one in each study area during the period when the stream was free from ice (about April through November); (2) periodically, with a Negretti-Zambra reversing thermometer or a Foxboro resistance thermometer; and (3) continually, at Gauge No. 1 (Headquarters, Pigeon River Trout Research Area), between my study areas II and III (Fig. 1) with a U. S. Geological Survey electrical recording thermometer. Since water temperatures in the winter vary within such a narrow range (32° F. to 36° F.) throughout the Pigeon River System, it was difficult to compare temperatures per se among the study areas. It was discovered, however, that the extent of surface ice cover depicted local water temperatures rather accurately. Those sections of the Pigeon River which were warmest in winter rarely froze over. Percentage of the stream surface covered by ice was, therefore, estimated periodically throughout the winters of

1950-51 and 1951-52 as an indicator of the location and effects of small differences in water temperatures. To clarify the method of estimation, aerial photographs were taken of the river on January 31, 1952.

<u>Ground Water Seepage</u>

Routinely subjective; here refined by additional proposed methods. Important in spawning (White, 1930; Hazzard, 1932). Ground water seepage was located by the following methods: (1) contribution to volume of flow; (2) summer water temperatures; (3) winter water temperatures; (4) surface ice cover; and (5) water temperatures in the bottom soils.

In order to determine the ground water contribution to volume of flow in various sections of the stream, serial estimates of stream discharges were made. These "seepage runs" served to show the amount of gain or loss of water within a section of stream. Any net gain not due to tributaries was considered to be the result of addition by ground water; no adjustment of loss by evaporation was necessary for present purposes. A Price Meter was used to measure the current velocity of the river. The discharge was computed by the Two-point Method (Corbett, <u>et al</u>., 1943). Volumes of tributary affluents were subtracted in computing net gains. The final analyses are presented as percentages of increase in volume per mile of stream (App. B, Table 4).

Methods for the determination of summer water temperatures, winter water temperatures, and surface ice cover were described earlier. Water temperatures in the bottom soils were found by placing the electrode of a Foxboro electrical resistance thermometer into the bottom soils from two to three inches.

Water Velocity and Flow

Routinely subjective. Important in flooding, and fixation of bottom types. Variations in water volume for the Pigeon River were obtained from two gauging stations operated by the U. S. Geological Survey (Fig. 1).

Stream Bed Topography

Routine. Pool-riffle ratio of Embody (1927).

Stream Cover

Cover has been described subjectively by many fishery workers including Davis (1938), Needham (1938), and Lagler (1949). To refine the gross estimation techniques used by these and other authors, I differentiated the cover into bank and midstream cover (adapted from Hoover, 1937). Bank cover was taken to consist of vegetation or overhanging soil slopes which shade the water at midday in the summer. Midstream cover was considered to be composed of logs, brush, large stones (over 2 feet in diameter), pools (greater than 3 feet deep in midsummer), dense acuatic plant beds, and artificial stream improvement structures in the stream channel. The results are expressed as the percentage of each study area which possessed the respective cover types.

Biological Factors

The biota of a stream obviously reflects the physical and chemical conditions present. It would, however, be impossible to make a complete inventory even of those factors which affect or may affect trout; thus, only certain components and aspects of the associated fauna and flora were studied.

Trout Populations

In order to study trout distribution and numbers, an accurate means of population assay is essential. An electric fish shocker provided the most practical and adequate means for the fish sampling procedures and stream population studies employed by me as well as by others (Haskell, 1940; Schuck, 1945; Shetter, 1950; Cooper, In press, a). Whereas most population assays with the electric shocker have utilized alternating current, recent studies (Elson, 1950; Virgil Pratt, personal communication) have shown direct current to be superior in streams. Direct current has the following advantages: (1) lower fish mortality (Pratt); (2) coverage of a larger field; and (3) conductance of fish to the anode, thus facilitating the capture. The equipment used included: (1) a direct current generator (Homelite Model 24, purchased in 1948); (2) a shocker boat with a sheet of copper attached to the bottom for a cathode (Myers, 1951); and (3) a set of two anodes which were heavy copper wires on five-foot long wooden poles.

Population estimates of trout in stream sections are calculations of total numbers. The mark-and-recapture method (as applied by Shetter, 1950) was employed here. For each estimate a three-man crew made two collecting trips through the study area. On the first trip, each trout obtained was measured to the nearest inch, marked by clipping off a small portion of the caudal fin, and returned immediately to the stream. On the second trip, made within an hour of the first, some fish previously marked were recaptured and some new or unmarked fish were also taken. The percentage of marked and unmarked fish by sizes and species was computed and formed the basis for an estimate of the total population by the application of the following formula:

$$P = \frac{A \times B}{C}$$

where: P = total population

A = total number of fish marked on the first trip

B = total number of fish collected on second trip

C = total number of recoveries of marked fish collected on second trip

Effectiveness of electric current in collecting fish depends on the voltage drop per unit of length over the body of the fish (Fisher, 1950). In general, large fish are thus more readily shocked and more easily collected than small fish; to prevent bias, population estimates were, therefore, broken down into size groups. In the study areas, such assays were made in April, May, June, and July, 1951. Single collections (one run through the section of stream) were also made in other months with the direct current shocker to provide comparative data when complete estimates could not be made.

<u>Spawning of Trout</u>

Suitability of spawning grounds has been held to be a factor influencing reproduction, and thus populations in trout streams (Hubbs *et al.*, 1932; Hobbs, 1948). I therefore counted the redds in each study area twice during the period from October 21 to November 10, in both 1951 and 1952. The connecting 400 yards on either side of the study areas were examined for the same purpose. All redds were marked (by notation and stakes) on the first trip and no redds were counted twice unless there were definite signs of continued spawning activity or re-use. Bottom type, temperatures, and current velocity were measured at redd sites to determine, if possible, the ecological features of trout spawning grounds.

Population Estimates of Non-trout Fish Species

The mark-and-recapture method of approximating population numbers, as described earlier, was also utilized for fish species other than trout in July, 1951. Estimates could be calculated only for those kinds which were sufficiently numerous and which could be collected with the electrical shocker to give credence to the results (over 10). No attempt was made to sample larval lampreys which burrow into silt beds. Certain collections of non-trout species were made at other periods of the year to determine the relative, rather than actual abundance.

Standing Crop of Fish

The numbers of trout and other fish in each study area as of July, 1951 were used to compute the standing crop per acre. A length-weight relationship curve for Pigeon River trout, from many collections, was employed to obtain the total weight of trout in a section of stream. Means, derived from a large series (between 300 and 400), were used to obtain conversions of numbers and length data to grams for other species.

Bottom Organisms

Macroscopic bottom organisms were collected during the winters of 1950-51 and 1951-52 with a square-foot bottom sampler (as described by Surber, 1937). Samples were screened through 20/inch wire mesh and placed in 70 percent alcohol. Ninety-seven preserved units were accumulated in the period from October 15 to February 28. Five silt samples from study area IV were collected on April 3, 1952. The organisms in each sample were sorted (after preservation), counted, and then measured volumetrically by water displacement. No attempt was made to include minute animals such as water mites or roundworms. The method of sampling the bottom was the stratified random type. Each bottom type was sampled at various depths and in various portions of the stream bed. An estimate of the total winter standing crop in each study area was computed by multiplying the mean standing crop of each bottom type by the area of that bottom type in the section.

Aquatic Plants

The location and approximate amount of bottom covered by higher aquatic plants in the channel of each study area was determined in the summer of 1951.

THE STUDY STREAM

In order to eliminate as many variables as possible in my search for environmental agencies affecting trout distribution, I concentrated my efforts on the Pigeon River as previously indicated. Preliminary appraisal of the river showed that trout populations varied greatly in different parts of the stream. Since it was impossible to study in detail the entire watercourse, four representative, but divergent linear units of the stream were chosen for intensive investigation. These sections, each 400 yards in length, when measured along midchannel, are designated as study areas I, II, III, and IV, progressively downstream (Fig. 1).

General Characteristics of the Pigeon River

The Pigeon River is one of several northern Michigan streams, which may have supported grayling and possibly brook trout. It now contains brook, brown, and rainbow trouts. The water is hard (methyl orange alkalinity range, 126 to 206 p.p.m.) and originates in a series of cedar swamps and springs near the village of Sparr, Michigan. The stream flows northward for approximately 60 miles and empties into Mullett Lake. The total drop, from source to mouth, is about 600 feet. Fairly rapid velocity throughout most of the stream course continually yields maximum or near maximum concentrations of dissolved oxygen in the water (above 8.0 p.p.m.). The drainage area covers approximately 180 square miles and is underlain with limestone and shales of Paleozoic origin (Allen _et al._, 1916). Most of the river flows over glacial till, but downstream sections traverse limestone outcrops. The stream bottom is composed principally of various forms of gravel and sand.

The soil of the watershed is generally sandy and unsuitable for cultivation. Several farms are present in the headwaters; however, their number is insufficient to influence greatly the stream proper. The dominant vegetation of the drainage basin is jack pine and poplar, with some maples on the ridges. Basically, the stream is unpolluted and affords sport fishing throughout much of its length.

The flow in cubic feet per second for June is approximately 40 in the headwaters and 130 in the lower reaches. The maximum volume (spring flood water) amounted to approximately eight times the minimum midsummer flow (1950) at gauges 1 and 2 (Fig. 1). The maximum midsummer temperature recorded in the headwaters was 67° F. and in the lower reaches, 81° F.

Brook, brown, and rainbow trouts have been introduced throughout the Pigeon River System.[2] At the present time, brook trout are very abundant in the headwaters and decrease in numbers downstream. Populations of brook trout become very low north of Township 32 North (T. 32 N., Fig. 1). Brown and rainbow trout enter the populations north of Lansing Club Pond, but never occur in large numbers. Rainbow trout were very sparse at all points observed. The number of non-trout species increases from eight in the headwaters to fifteen in the lower stretches of the stream. Suckers (Catostomidae), minnows (Cyprinidae), darters (Percidae), and muddlers (Cottidae), are present in all the sections of the stream. Sunfishes (Centrarchidae) enter the fauna in Township 32 North. Lower regions show an increase in numbers of species

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[2]All hatchery reared fish planted in the Pigeon River were marked by either fin-clipping or jaw-tagging and are not considered as integral parts of the trout populations in this study.

probably due to an upstream penetration of more characteristically lacustrine fishes from Mullett Lake. A few lake dwellers, e.g., centrarchids, may enter from small tributary lakes.

The bottom organisms are typically fast, hardwater forms. Mayflies (Ephemeroptera), caddis flies (Trichoptera), and true flies (Diptera), are the groups most commonly represented. Although aquatic plants are not abundant, stonewort (*Chara*), pondweeds (*Potamogeton*), and speedwell (*Veronica connata*) occur sparsely along much of the channel.

Special Characteristics of the Study Areas

The study areas were selected because they differed greatly from one another in numbers of trout. The ecological characteristics of each study area, which may influence trout populations, are presented below.

Study Area I

Location. This section of stream is located near the town of Sparr, and is characteristic of the headwaters type of habitat (T 31 N., R. 2 W., S. 23, Fig. 1).

Size. Mean width, 37.6 feet; mean depth, 9.8 inches; total area, 1.036 acres.

Gradient. 0.126 percent.

Flow. 43.2 cubic feet per second on July 14, 1951.

Pool-riffle ratio. Size 2, type 2 and frequency 2.

Cover. Bank cover: 58 percent alders (*Alnus incana*), 30 percent cedar (*Thuja occidentalis*), 3 percent red osier dogwood (*Cornus stolonifera*), 4 percent high bush cranberry (*Viburnum opulus*), and 5 percent open. Midstream cover; fallen logs and trees, 30 percent of length of stream.

Water temperature. This study area has summer temperatures (App. B, Table 1) which may be regarded as optimal for brook trout (maximum range recorded, 63° F. to 67° F.) The winter temperatures were warmer and were not recorded in the range of 32.0° F. to 33.0° F. as consistently as in the other study areas (App. B, Table 2). The winter surface ice never was observed to cover more than 20 percent of the study area (Fig. 14, App. B, Table 3). The small amount of surface ice is attributed to the warmer water temperatures.

Ground water seepage. December 14, 1951; 23.5 percent increase in volume per mile of stream. February 16, 1952; 18.9 percent increase in volume per mile of stream (App. B, Table 4).

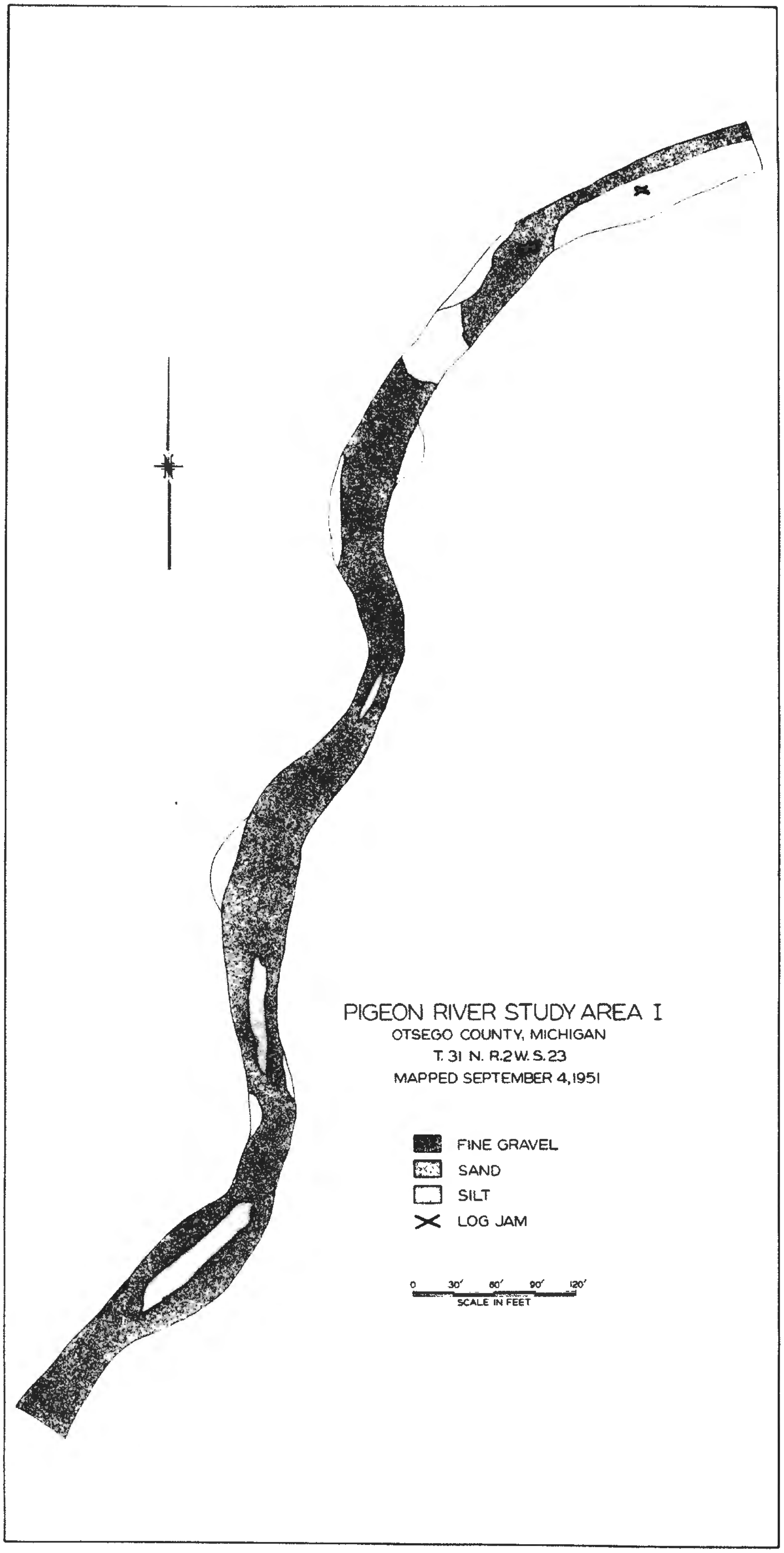
Bottom soil type. 74.0 percent fine gravel, 6.5 percent silt, and 19.5 percent sand (Fig. 3).

Bottom fauna. The total estimated winter standing crop of bottom organisms was 46,189 cc. (Table 15). Fine gravel was the most productive bottom type with a mean square-foot volume of 1.153 cc. The principal organisms were Brachycentrus lateralis, Atherix sp., Tipula sp., and Antocha sp. Silt was very flocculent and poor in production as compared to silt in other study areas. A large number of tubificid worms was present. Fauna in the sand was similar to that in fine gravel but present in fewer numbers (Table 12). Below is a partial list of bottom organisms collected:

Crustacea
- Cambarus sp.
- Hyalella sp.

Ephemeroptera
- Hexagenia limbata
- Ephemerella sp.

Fig. 3. Channel pattern and stream bottom soils in study area I.


PIGEON RIVER STUDY AREA I
OTSEGO COUNTY, MICHIGAN
T. 31 N. R.2W. S.23
MAPPED SEPTEMBER 4,1951
FINE GRAVEL
SAND
SILT
LOG JAM
SCALE IN FEET

Plecoptera
Isoperla sp.
F. Perlodidae (imm.)

Trichoptera
Brachycentrus lateralis
Glossosoma nigrior
Pycnopsyche sp.
Hydropsyche sparna
Hydropsyche sp.

Diptera
Tipula sp.
Eriocera sp.
Chrysops sp.
Dicronata sp. Dicranota
Atherix sp.
Ptychoptera sp.
Hemerodromia sp.
F. Ceratopogonidae

Trout populations. The numbers of trout in the population of this upstream section ranged from 200 in April, 1951 to 1440 in July, 1951 (Table 1). The greatest rise in this range occurred between June 15 and July 13 when a difference of 1017 fish was found. This increase is due to the young-of-the-year trout which were too small to be collected in the prior assays. Collections of trout in the fall showed the same relatively high numbers (App. C, Table 2). The standing crop of brook trout in July, 1951 was 45.77 pounds per acre (Table 16).

TABLE 1

POPULATION ESTIMATES OF BROOK TROUT IN STUDY AREA I IN 1951

Size group total length in inches	Number of fish			
	April 14	May 15	June 15	July 13
2.0 to 3.9	153	295	43	880
4.0 to 6.9	39	124	350	526
7.0 to 10.9	8	9	30	34
Total	200	428	423	1,440

Trout spawning. The number of redds observed in 1950 was 20 and in 1951 was 56 (Table 9). The redds were confined to fine gravel and grouped together in numbers of three to six. They were located in the same portions of the stream bed in both years of observations. In order to determine more exact ecological requirements for spawning, various studies were made. It was found that water over redds did not differ chemically or physically from that of the surrounding stream. Vertical current velocity curves were recorded over redds and did not differ significantly from adjacent areas with no spawning (Fig. 4). Because ground water has been regarded as important to brook trout spawning success (White, 1930; Hazzard, 1932; Greeley, 1932), temperatures were taken in the bottom soils with a resistance thermometer on April 11, 1952 and June 25, 1952. These temperatures were measured at points two to three inches beneath the surface of the stream bottom in various parts of the channel (Fig. 5). They show a definite relationship to the location of brook trout redds. The trout consistently chose portions of the stream bed for spawning that were warmer in winter and early spring and cooler in summer than nearby areas. Ground water appears to be the factor affecting this condition. A hypothetical cross-section of the stream channel has been constructed to illustrate the selection of ground water seepage by brook trout for spawning (Fig. 6).

Non-trout fish populations. Other fish species collected included: American brook lamprey, white sucker, longnosed dace, blacknosed dace, creek chub, red-bellied dace, slimy muddler, and the common muddler. On July 13, 1951, the population of slimy muddlers was 828 and that of white suckers was 127 (App. C, Table 4). The standing crop in July, 1951 of slimy muddlers was 6.35 pounds per acre and of white suckers, 3.60 pounds per acre (Table 16).

Fig. 4. Similarity of current velocities over sites of brook trout redds and over adjacent sites (within 11 feet of active redds).

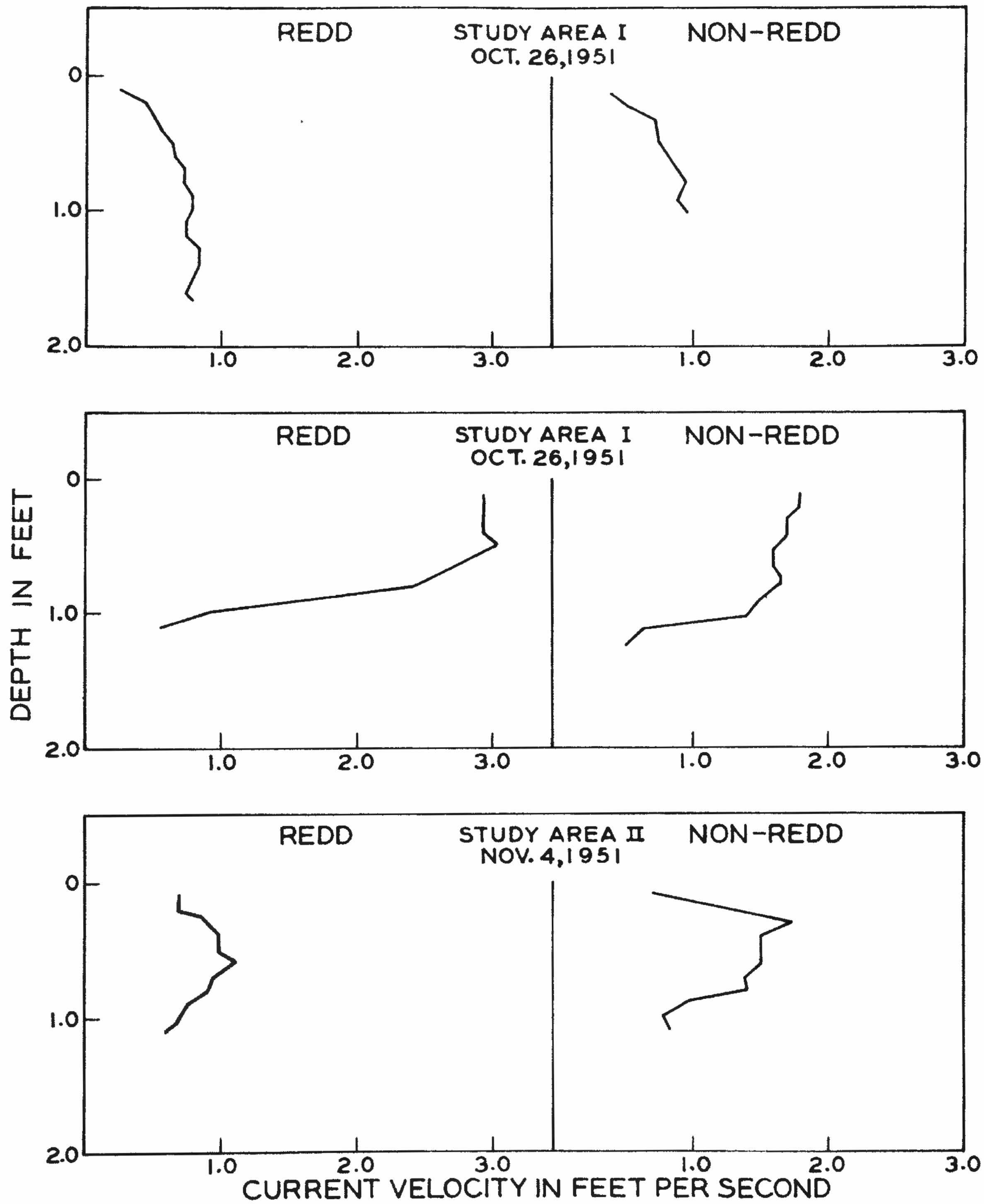

REDD
STUDY AREA I
OCT. 26,1951
NON-REDD
0
1.0
2.0
1.0
2.0
3.0
1.0
2.0
3.0
REDD
STUDY AREA I
OCT. 26,1951
NON-REDD
DEPTH IN FEET
0
1.0
2.0
1.0
2.0
3.0
1.0
2.0
3.0
REDD
STUDY AREA II
NOV. 4,1951
NON-REDD
0
1.0
2.0
1.0
2.0
3.0
1.0
2.0
3.0
CURRENT VELOCITY IN FEET PER SECOND

Fig. 5. Relationship between temperatures of water in stream channel and water in stream bottom soils (two to three inches below surface of stream bottom), and distribution of brook trout redds in Pigeon River, Michigan. Temperature data collected with a Foxboro resistance thermometer.

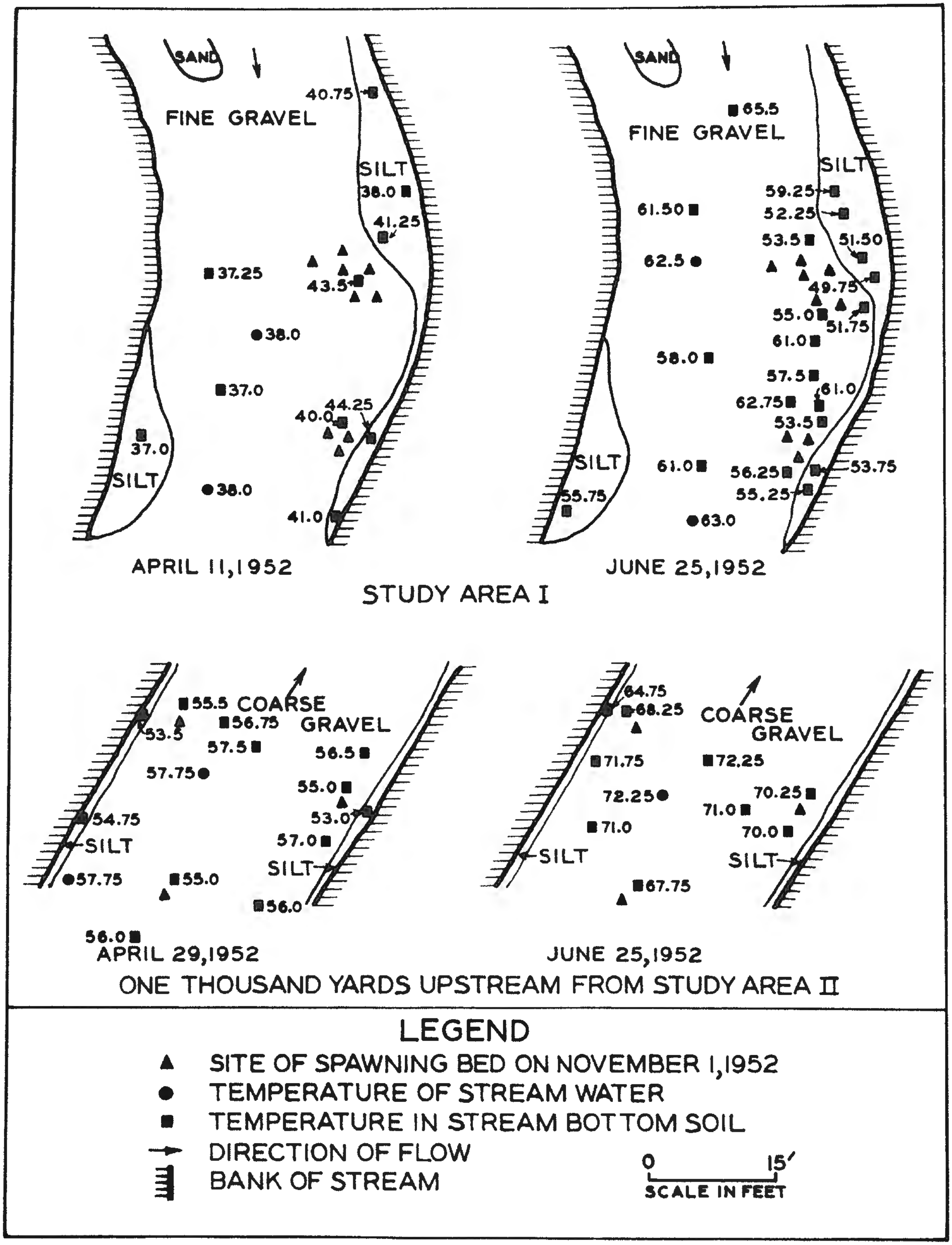
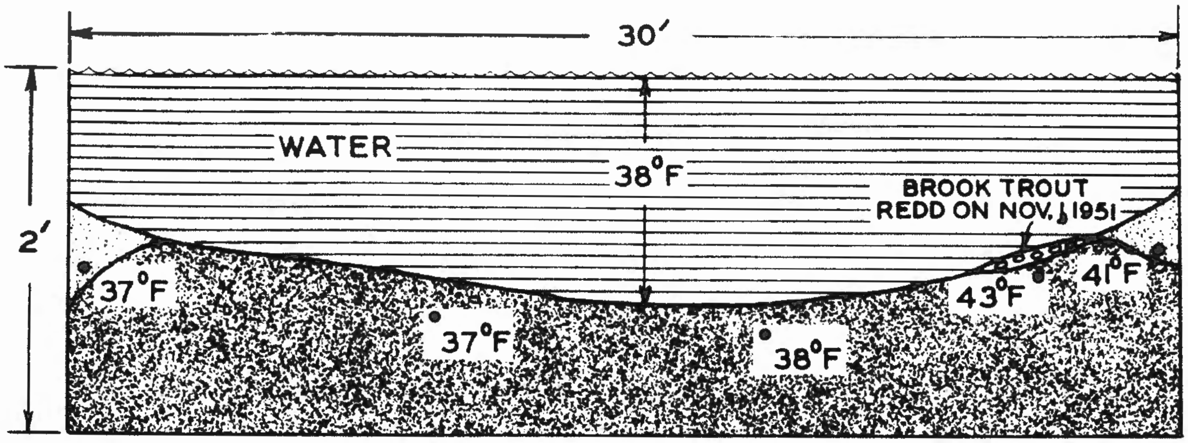
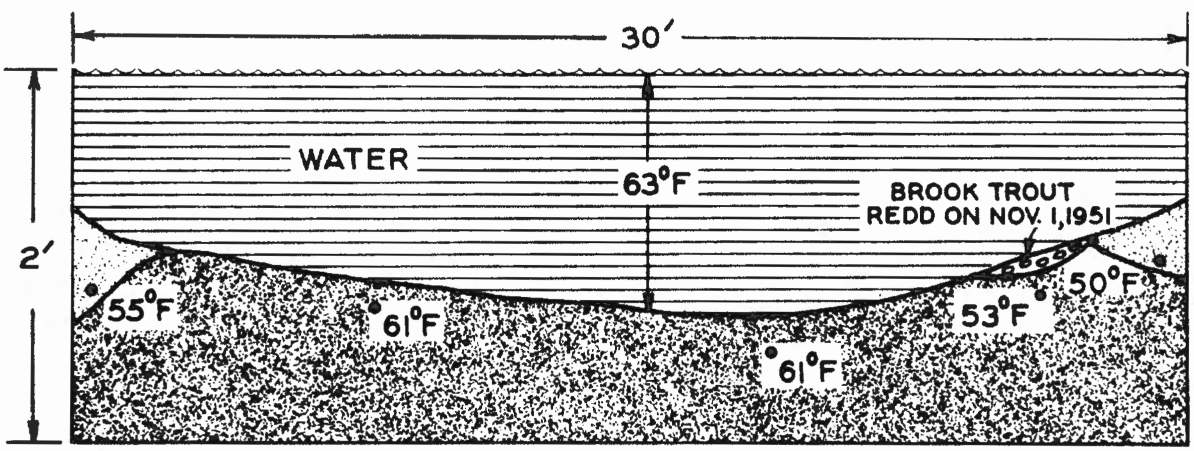

SAND
FINE GRAVEL
40.75
SILT
38.0
41.25
37.25
43.5
38.0
37.0
44.25
40.0
37.0
SILT
38.0
41.0
APRIL 11,1952
65.5
FINE GRAVEL
SILT
59.25
52.25
61.50
53.5
51.50
62.5
49.75
55.0
51.75
61.0
58.0
57.5
61.0
62.75
53.5
SILT
61.0
56.25
53.75
55.25
55.75
63.0
JUNE 25,1952
STUDY AREA I
55.5 COARSE
56.75 GRAVEL
53.5
57.5
56.5
57.75
55.0
53.0
54.75
57.0
SILT
SILT
57.75
55.0
56.0
56.0
APRIL 29,1952
64.75
68.25
COARSE
GRAVEL
71.75
72.25
72.25
70.25
71.0
71.0
70.0
SILT
SILT
67.75
JUNE 25,1952
ONE THOUSAND YARDS UPSTREAM FROM STUDY AREA II
LEGEND
SITE OF SPAWNING BED ON NOVEMBER 1,1952
TEMPERATURE OF STREAM WATER
TEMPERATURE IN STREAM BOTTOM SOIL
DIRECTION OF FLOW
BANK OF STREAM
0 15′
SCALE IN FEET

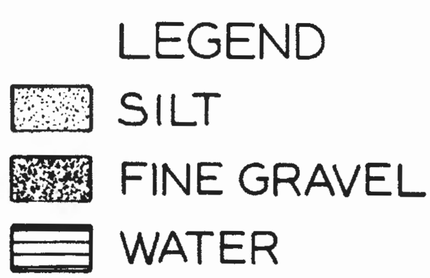
Fig. 6. Hypothetical cross-section of stream bed drawn to illustrate the effect of temperature of the water in bottom soils on the location of brook trout redds in the stream. Redds were located on November 1, 1951 and temperatures of the water in the channel and in the bottom soils were recorded on April 11, 1952 and June 25, 1952. Composite data from Pigeon River, Michigan.



APRIL 11, 1952



JUNE 25, 1952



Aquatic plants. The higher aquatic plants present included: Chara sp., Hippuris vulgaris, Potamogeton pectinatus, and Vallisneria americana. P. pectinatus was established in two large (approximately 3 by 15 ft.) beds in fast water in midstream. Chara sp. was scattered in several small patches (about one foot square). V. americana occurred sparsely in the shallows along the stream margin.

Study area II

Location. This section of stream is located within the Pigeon River Trout Research Area (T. 32 N., R. 1 W., S. 17) and is approximately halfway between the source and the mouth of the stream (Fig. 1).

Size. Mean width, 48.3 feet; mean depth, 12.5 inches; total area, 1.330 acres.

Gradient. 0.057 percent.

Flow. 60.8 cubic feet per second on July 13, 1951

Pool-riffle ratio. Size 2, type 2, and frequency 3.

Cover. Bank cover: 56 percent alder (Alnus incana), 9 percent red-osier dogwood (Cornus stolonifera), 7 percent willow (Salix sp.), 3 percent high bush cranberry (Viburnum opulus), and 25 percent open. Midstream cover: logs and artificial stream improvement structures, 20 percent of length of stream.

Water temperature. Generally the temperatures in area II run between 68° F. and 75° F. in the summer. The maximum in 1951 was 76° F. (Fig. 13; App. B, Table 1). Winter temperatures were not in the range of 32° F. to 33° F. as often as in study areas III and IV, but more often than in I. Consequently, the ice cover was never complete or persistent. Surface ice was greater in extent in II than in I, but much less than in the other areas (Fig. 14; App. B, Table 3). An aerial photograph of this section of stream was taken on January 31, 1952, and shows this section to be completely free of ice cover whereas other parts of the stream were variously frozen over (Fig. 8).

Ground water seepage. October 16, 1951: 6.7 percent increase in volume per mile of stream. February 17, 1952: 23.2 percent increase in volume per mile of stream.

Bottom soil type. 63.1 percent coarse gravel, 24.2 percent sand, 8.5 percent silt, and 4.2 percent fine gravel (Fig. 7).

Bottom fauna. The total estimated winter standing crop of microscopic bottom organisms was 31,529 cc. (Table 15) in study area II. Coarse gravel had a mean volume standing crop of 0.512 cc. per square foot. The principal organisms were *Ephemerella* sp. and *Hydropsyche* sp. Fine gravel had a low standing crop (0.238 cc.) probably due to heavy molar action at this point. Tipulids were fewer than in the fine gravel of study area I and *Brachycentrus lateralis* was absent. Sand was very unstable and supported practically no fauna. Silt in this study area was the most productive bottom type and was also the richest found in the Pigeon River. Burrowing mayflies (*Hexagenia limbata*) and midges (*Chironomidae*) were the most common organisms. Alderflies (*Sialis* sp.) were present in low numbers. A partial list of bottom organisms is presented below:

Annelida
- F. Tubificidae

Mollusca
- *Physa* sp.
- *Ferrissia* sp.
- *Sphaerium* sp.

Crustacea
- *Cambarus* sp.

Fig. 7. Channel pattern and stream bottom soils in study area II.

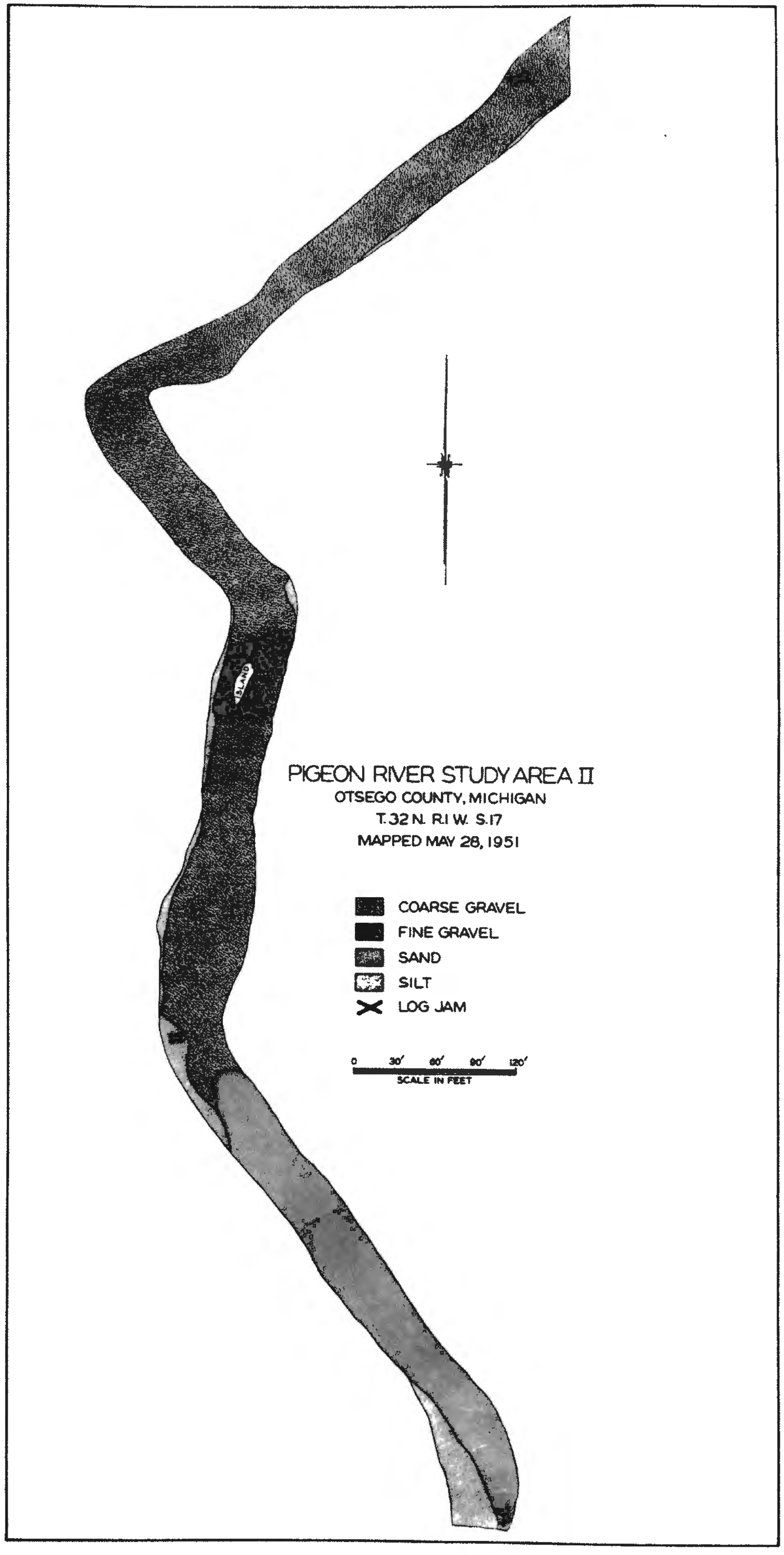
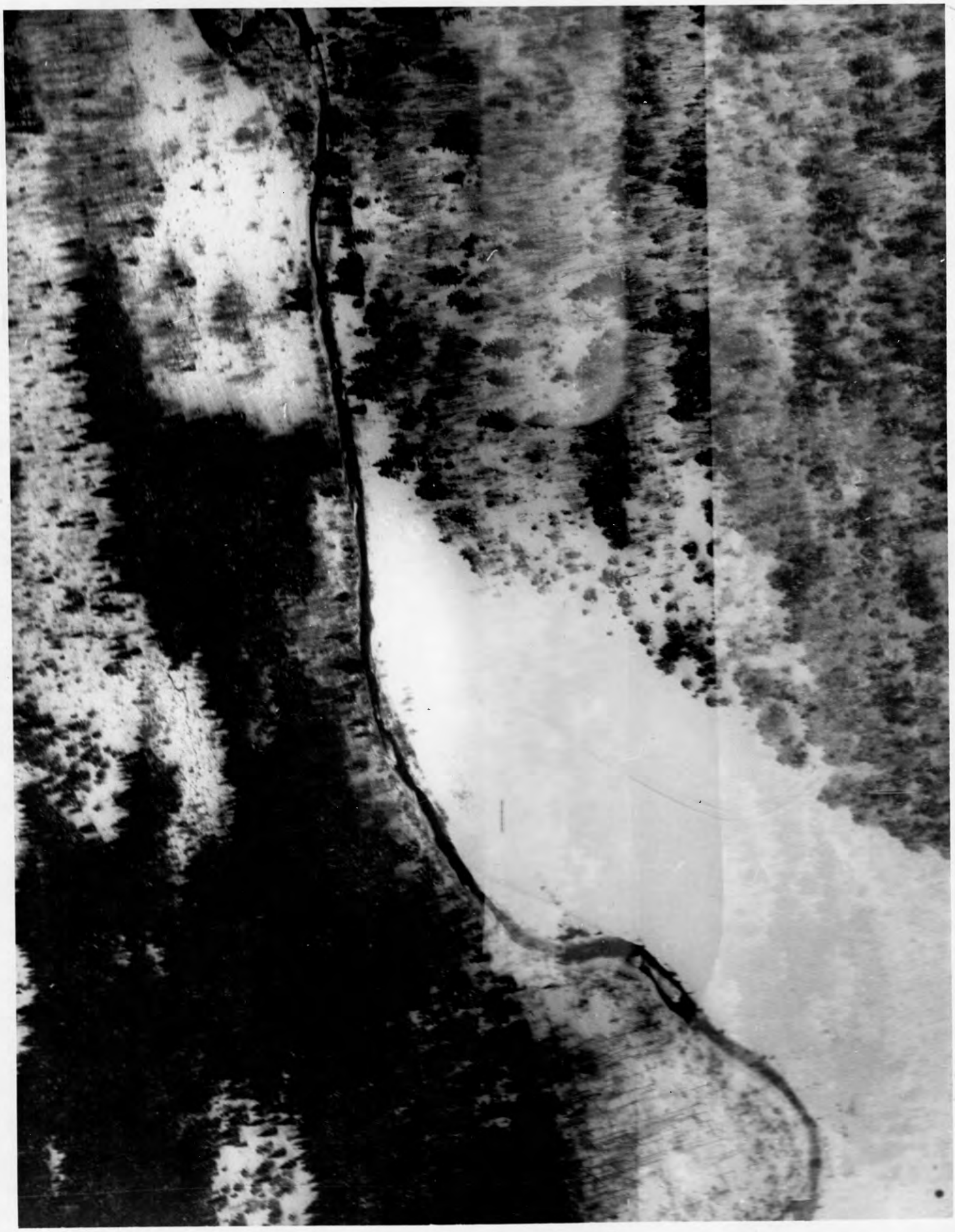

ISLAND
PIGEON RIVER STUDY AREA II
OTSEGO COUNTY, MICHIGAN
T. 32 N. R.I W. S.17
MAPPED MAY 28, 1951
COARSE GRAVEL
FINE GRAVEL
SAND
SILT
LOG JAM
0
30'
60'
90'
120'
SCALE IN FEET

Fig. 8. Aerial photograph of study area II on January 31, 1952. Note that entire stream is free of ice cover.



Ephemeroptera
Ephemerella subvaria
Hexagenia limbata
Ephemerella sp.

Plecoptera
Isoperla sp.
Acroneuria sp.

Odonata
Plathemis lydia
Lanthus sp.

Megaloptera
Sialis sp.

Trichoptera
Glossosoma nigrior
Glossosoma sp.
Brachycentrus lateralis
Hydropsyche sparna
Rhyacophila manistee
Hydropsyche sp.
Pycnopsyche sp.

Coleoptera
Elmis sp.

Diptera
Dicranota sp.
Dicranota sp., Sub-genus *Rhaphidolevis*
Atherix sp.
Tipula sp.
Simulium sp.
Antocha sp.
Chrysops sp.
F. Chironomidae = Tendipedidae
F. Ceratopogonidae = Heleidae

Trout populations. Study area II has a moderately large population of brown and brook trouts. The mark-and-recapture method, as previously described, could not always be used for all size groups of these species. This condition is due to the fact that in a 400-yard section of stream, it is sometimes impossible to get recoveries in populations so small that few fish were originally marked: e.g., if two 2.0- to 3.9-inch trout were marked, the chances of recovering these fish are small. In order to reach an approximation of the numbers of trout in these situations, a "derived recovery rate method" was employed (Table 2). To compute derived recovery rates, all fish which were marked and released in a particular size group were added together; recoveries from these marked fish were also totaled. The percentage recovery rate was then computed by dividing the number of recoveries by the total number of marked fish for each size group. To reach an estimate of the total trout population by this method, the number of trout collected on a shocking trip is divided by the derived recovery rate for a particular size group. In using these derived recovery rates the following possibilities must be considered: (1) recovery rates must not vary with density of population; (2) recovery rates must not vary with month of collection, e.g., April, May, June, and July; and (3) recovery rates must not vary between brook and brown trout.

TABLE 2

DERIVED RECOVERY RATES IN PERCENT OF BROOK AND BROWN TROUT IN ALL STUDY AREAS, PIGEON RIVER, MICHIGAN. DATA COLLECTED IN APRIL, MAY, JUNE, AND JULY, 1951, BY DIRECT CURRENT ELECTRICAL SHOCKER

Inch size groups	Number marked and released	Number recovered	Rate of recovery in percent
2.0 to 3.9	257	36	14.0
4.0 to 6.9	536	154	28.7
7.0 to 11.9	103	41	39.8

To analyze the variances in recovery rates among various trout densities, data from population estimates of four sections of the Pigeon River Trout Research Area, each about 1.2 miles in length, were utilized. The rates of recovery were tested by chi-square (Snedecor, 1946, Sec. 9.10) to determine the probability of occurrence for a larger value of chi-square with the data at hand (Table 3).

TABLE 3

SIMILARITY OF RECOVERY RATES IN THE MARK-AND-RECAPTURE METHOD OF ESTIMATING TROUT POPULATIONS IN FOUR DIFFERENT SECTIONS OF STREAM (EACH APPROXIMATELY 1.2 MILES IN LENGTH) OF CONTRASTING POPULATION DENSITIES IN THE PIGEON RIVER, MICHIGAN, IN SEPTEMBER, 1951. CHI-SQUARE (X^2) INDICATED WITH THE PROBABILITY (P) OF A LARGER VALUE

Trout species	Section of river	Size groups in inches					
		2.0 to 3.9		4.0 to 6.9		7.0 to 11.9	
		Number marked and released	Number recovered	Number marked and released	Number recovered	Number marked and released	Number recovered
Brook	A	64	17	65	26	44	13
	B	275	71	133	50	16	8
	C	225	47	184	78	40	15
	D	629	126	467	146	156	63
		x^2 = 4.748 P = 0.20		x^2 = 8.222 P = 0.05		x^2 = 2.625 P = 0.46	
Brown	A	9	1	20	4	37	18
	B	31	7	43	12	57	28
	C	17	3	21	9	51	15
	D	15	3	40	17	112	46
		x^2 = 0.696 P = 0.90		x^2 = 4.492 P = 0.23		x^2 = 5.227 P = 0.15	

The comparison of the recovery rates in various population densities can be summarised as follows: (1) brook trout in the 2.0- to 3.9-inch and 4.0- to 6.9-inch classes show similar recovery rates; (2) brook trout in the 7.0- to 11.9-inch category were too few in numbers due to heavy fishing pressure to get comparable results in all sections; (3) brown trout in the 2.0- to 3.9-inch group were too rare for adequate comparison; and (4) brown trout in the 4.0- to 6.9-inch and 7.0- to 11.9-inch groups gave similar recovery rates. These figures indicate that when enough brook or brown trout are marked (about 25 percent of the population), the recovery rate can be expected to be similar among populations of varying densities, at least in this stream.

To compare the recovery rates in different months, data were utilized on brook trout from population estimates in April, May, June, and July, 1951, in two study areas of this investigation (Table 4). The data signifies that the recovery rate of brook trout in the Pigeon River did not differ significantly among the months of April, May, June, and July, 1951.

Finally one must consider the possibility that the recovery rate may differ between brook and brown trout. Because brown trout were rare in all study areas of this investigation, data were used from a population study of four sections of the Pigeon River Trout Research Area (Table 5). These units were not identical to the study areas used in this investigation. The observed recovery rates between brook and brown trout were not distinctly different. Similar conclusions were reached by Cooper (1952).

On the basis of the foregoing evidence, the use of derived recovery rates is a valid method for estimating numbers of trout in the low populations in the Pigeon River. This system of estimating trout populations was used extensively in study areas III and IV for which it was developed.

TABLE 4

COMPARISON OF RECOVERY RATES IN THE MARK-AND-RECAPTURE METHOD OF ESTIMATING BROOK TROUT POPULATIONS IN STUDY AREAS I AND II IN THE MONTHS OF APRIL, MAY, JUNE, AND JULY, 1951. CHI-SQUARE (X^2) INDICATED WITH THE PROBABILITY (P) OF A LARGER VALUE

Study area	Month	Size groups in inches					
		2.0 to 3.9		4.0 to 6.9		7.0 to 11.9	
		Number marked and released	Number recovered	Number marked and released	Number recovered	Number marked and released	Number recovered
I	April	17	3	15	5	4	1
	May	60	12	79	30	4	3
	June	23	7	100	18	10	3
	July	88	7	151	38	11	8
		X^2 = 8.746 P = 0.05		X^2 = 9.559 P = 0.04		X^2 = 5.849 P = 0.15	
II	April	(too few fish)		38	11	4	0
	May			28	10	8	4
	June			37	7	17	11
	July			34	15	17	5
				X^2 = 5.572 P = 0.15		X^2 = 7.703 P = 0.05	

In 1951, the number of trout in study area II varied from 164 in May to 837 in July (Table 6). As in study area I, there is a large increase of numbers of 2.0- to 3.9-inch trout in July due to the fact that the young-of-the-year individuals have first become available for collecting with the methods used. This increase in population may be taken to indicate the amount of spawning both in, and close-by this study area. Only three young-of-the-year brown trout were collected in

July but their resistance to angler's exploitation (Cooper, In press, a) allows them to occupy a significant part of the larger size fish populations. Collections of trout in the fall showed the same relatively high populations as in the spring and summer (App. C, Table 2). The standing crop in pounds per acre in July, 1951 was 21.83 for brook trout and 7.40 for brown trout (Table 16).

TABLE 5

SIMILARITY OF RECOVERY RATES IN THE MARK-AND-RECAPTURE METHOD OF ESTIMATING TROUT POPULATIONS BETWEEN BROOK AND BROWN TROUT. DATA COLLECTED IN PIGEON RIVER TROUT RESEARCH AREA FROM SEPTEMBER 11 to 20, 1951. CHI-SQUARE (X^2) INDICATED WITH THE PROBABILITY OF A LARGER VALUE. P = PROBABILITY

Trout species	Size groups in inches					
	2.0 to 3.9		4.0 to 6.9		7.0 to 11.9	
	Number marked and released	Number recovered	Number marked and released	Number recovered	Number marked and released	Number recovered
Brook	1193	261	849	300	256	99
Brown	72	14	124	42	257	107
	X^2 = 0.154 P = 0.60		X^2 = 0.049 P = 0.80		X^2 = 0.198 P = 0.60	

<u>Trout spawning</u>. In area II, one redd was observed in 1950 and seven in 1951 (Table 9). The large number of such redds above and below this study area probably accounts for most of the young-of-the-year fish in July (Table 6). Various studies were made of spawning beds above this study area. The temperatures in the bottom soils at the sites of redds were higher in winter and lower in summer than in other portions of the stream channel (Fig. 5). The current velocities over spawning

beds showed no characteristics not present in other portions of the stream (Fig. 4). Local ground water seepage is the main determinant in the selection of spawning locations by brook trout.

TABLE 6

ESTIMATES OF TROUT POPULATIONS IN STUDY AREA II, PIGEON RIVER, MICHIGAN, IN 1951. SOME ESTIMATES ADJUSTED BY APPLICATION OF DERIVED RECOVERY RATES AND ARE INDICATED BY AN ASTERISK

Trout species and size group in inches	Number of trout			
	April 17	May 15	June 15	July 11
Brook				
2.0 to 3.9	18	7	7*	595
4.0 to 6.9	138	87	185	104
7.0 to 10.9	7*	20	36	78
Total	163	114	228	777
Brown				
2.0 to 3.9	25*	0	0	3
4.0 to 6.9	23	41	13	17
7.0 to 10.9	2	9	21	40
Total	50	50	34	60
Total for both species Brook and brown				
2.0 to 3.9	43	7	7	598
4.0 to 6.9	161	128	198	121
7.0 to 10.9	9	29	57	118
Total	213	164	262	837

<u>Non-trout fish populations</u>. Population estimates of 499 black-nosed dace and 372 creek chubs were found on July 13, 1951 (App. C,

Table 4). Other fish collected at various times included: white sucker, longnosed dace, mudminnow, Johnny darter, common muddler, and brook stickleback (App. C, Table 3). The standing crop of non-trout in pounds per acre in July, 1951 was 10.68 (Table 16).

Aquatic plants. Four small beds (approximately two by two feet) of Chara sp. were present in the middle of the stream. Potamogeton pectinatus, P. praelongus, and Veronica connata also occurred in small scattered beds. Vallisneria americana was scattered sparsely in the shallow areas.

Study Area III

Location. Study area III, like II, is located within the Pigeon River Trout Research Area and is about three miles downstream from the latter (Fig. 1).

Size. Mean width, 61.0 feet; mean depth, 9.9 inches; total area, 1.693 acres.

Gradient. 0.057 percent.

Flow. July 13, 1951: 61.5 cubic feet per second.

Pool-riffle ratio. Size 2, type 2, frequency 3.

Cover. Bank cover: 10 percent alders (Alnus incana), 10 percent willows (Salix sp.), and 80 percent open. Midstream cover: 4 percent of length of stream.

Water temperature. This section of stream shows great extremes in temperature throughout the year. For example, the summer temperature reached 78° F. for three consecutive weeks in 1951 (Fig. 13; App. B, Table 1). On July 27, 1949, 79° F. was recorded. Winter records were frequently found in the range of 32.0° F. to 33.0° F. (App. B, Table 2). In the winters of 1950-51 and 1951-52, surface ice formed much faster and more completely than in either study areas I or II (Fig. 14; App. B,

Table 3). Gradient was identical to area II and cannot explain the great differences in ice cover. An aerial photograph taken on January 31, 1952, showed this section of stream to be completely frozen except for one small patch of open water (Fig. 9).

Ground water seepage. October 16, 1951: 1.5 percent increase in volume per mile of stream. December 16, 1951: 6.4 percent increase in volume per mile of stream.

Bottom soil type. 46 percent sand, 42.0 percent coarse gravel, 8.3 percent rubble, and 3.7 percent silt (Fig. 10).

Bottom fauna. The total winter standing crop of bottom organisms was low (23,553 cc.), due to the large area of sand. The coarse gravel of the area had a predominant population of Hydropsyche sp. and chironomids with a mean standing crop of 0.412 cc. per square foot. Silt, with a mean standing crop of 1.162 cc. per square foot, contained mainly Hexagenia limbata, Ephemera simulans, and chironomids. Sand contained small numbers of all organisms. A partial list of the organisms collected follows:

Mollusca
- Physa sp.

Crustacea
- Cambarus sp.
- Hyalella sp.

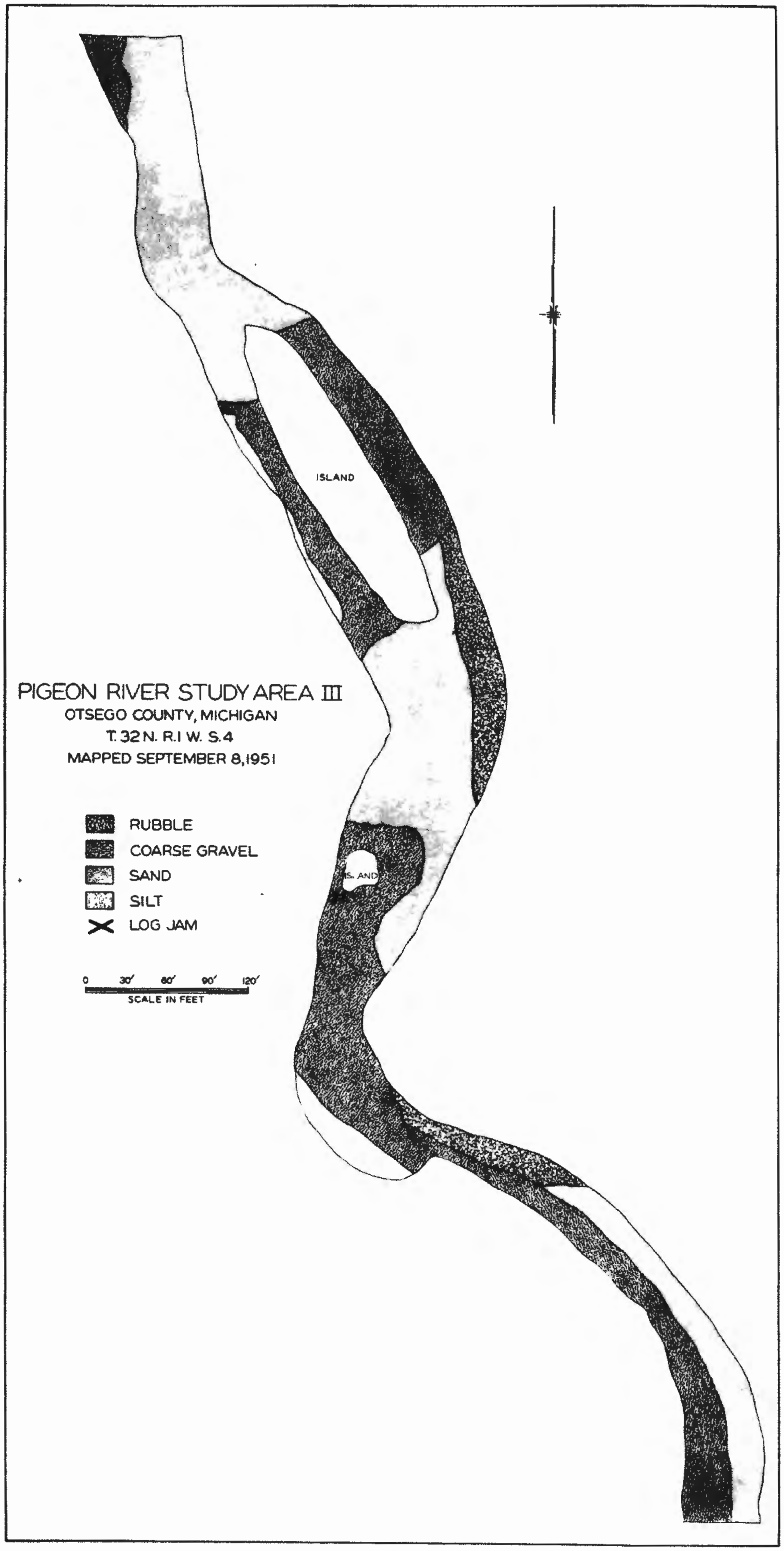
Ephemeroptera
- Ephemera simulans
- Hexagenia limbata
- Stenonema sp.
- Ephemerella sp.
- Baetisca laurentina
- Isonychia bicolor

Odonata
- Lanthus sp.

Plecoptera
- Isoperla sp.

Fig. 9. Aerial photograph of study area III on January 31, 1952. Note that ice covers the entire stream except for a small section marked by arrow.

Fig. 10. Channel pattern and stream bottom soils in study area III.


PIGEON RIVER STUDY AREA III
OTSEGO COUNTY, MICHIGAN
T. 32 N. R. I W. S. 4
MAPPED SEPTEMBER 8, 1951
RUBBLE
COARSE GRAVEL
SAND
SILT
LOG JAM
0 30' 60' 90' 120'
SCALE IN FEET
ISLAND
ISLAND

Hemiptera
F. Corixidae

Megaloptera
Sialis sp.

Trichoptera
Hydropsyche sparna
Hydropsyche bifida
Chimarra atterima
Pycnopsyche sp.

Coleoptera
Elmis sp.

Diptera
Chrysops sp.
Antocha sp.
Tipula sp.
Atherix sp.
F. Ceratopogonidae

Trout populations. This study area has a small population of both brook and brown trout. The total numbers varied from 19 in June to 89 in July, 1951 (Table 7). Due to the low populations, the derived recovery rates were often used as a basis in the estimates. Brook trout populations show an increase in 2.0- to 3.9-inch fish from 4 in June to 72 in July, 1951. Due to the lack of significant spawning in or nearby this study area, these young fish are believed to be produced upstream about 700 yards. Small numbers of trout were also found in the fall collections (App. C, Table 2). The standing crop in pounds per acre in July, 1951 amounted to 1.57 brook trout (Table 16).

Trout spawning. No spawning beds were ever found in study area II in 1950 or 1951. In 1951, however, three brown trout redds were found 300 yards upstream from the study section (Table 9). Adequate spawning sites are available as far as bottom type or gradient are concerned but the lack of seepage water, which allows great fluctuations in temperature, is believed to be the reason for the failure of trout to use this section of stream.

TABLE 7

ESTIMATES OF TROUT POPULATIONS IN STUDY AREA III, PIGEON RIVER, MICHIGAN, 1951. ESTIMATES ADJUSTED BY APPLICATION OF DERIVED RECOVERY RATES AND ARE INDICATED BY AN ASTERISK (*)

Species and size group	Numbers of trout			
	April 18	May 14	June 12	July 12
Brook				
2.0 to 3.9	0	0	4*	72
4.0 to 6.9	30	22	7*	11
7.0 to 10.9	9	4	6*	6*
Total	39	26	17	89
Brown				
2.0 to 3.9	0	0	0	0
4.0 to 6.9	0	2*	0	0
7.0 to 10.9	0	0	2*	0
Total	0	2	2	0
Brook and brown				
2.0 to 3.9	0	0	4	72
4.0 to 6.9	30	24	7*	11
7.0 to 10.9	9	4	8	6
Total	39	28	19	89

Non-trout fish populations. Population estimates of 261 white suckers, 923 blacknosed dace, 574 creek chubs, and 297 common muddlers were recorded on July 12, 1951. Other species collected at various periods were: American brook lamprey, longnosed dace, common shiner, mudminnow, logperch, Johnny darter, Iowa darter, and brook stickleback.

Aquatic plants. Higher aquatic plants were concentrated along the borders of the stream in this section but were rare in the current. Chara sp., Carex sp., Potamogeton praelongus, and Veronica connata were present in small amounts.

Study area IV

Location. Study area IV is located near the lower regions of the Pigeon River, outside the town of Afton (T. 34 N., R. 2 W., S. 1; Fig. 1).

Size. Mean width, 51.9 feet; mean depth, 19.5 inches; total area, 1.430 acres.

Gradient. 0.335 percent.

Flow. The discharge on July 14, 1951: 133.4 cubic feet per second.

Pool-riffle ratio. Size 3, type 3, and frequency 3.

Cover. 10 percent elm (Ulmus sp.) and ash (Fraxinus sp.), 5 percent cedar (Thuja occidentalis), 8 percent alders (Alnus incana), 9 percent willows (Salix sp.) and 68 percent open. Midstream cover: logs and boulders, 15 percent of length of stream.

Water temperatures. Temperatures in this section of stream showed great extremes in both summer and winter. In the summer of 1951, a maximum of 78° F. was recorded (Fig. 13; App. B, Table 1). On July 28, 1949, 81° F. was reported. Whereas study area IV did not show the consistently high temperatures that were reported in study area III, those recorded are marginal for trout. Winter stream temperatures were consistently near 32° F. The ice cover was greater in this area as compared to the other three (Fig. 14; App. B, Table 3). Surface ice remained all winter in 1951-52 once it had formed in early December. Heavy anchor ice was observed on the bottom before the stream froze over.

Ground water seepage. October 17, 1951, 0.3 percent increase in volume per mile of stream. February 19, 1952, 1.7 percent increase in volume per mile of stream.

Bottom soil type. 99.1 percent rubble and 0.9 percent silt (Fig. 11).

Bottom fauna. The winter standing crop of bottom organisms in rubble was 0.951 cc. per square foot. *Hydrosyche sp.*, *Chimarra sp.*, *Antocha sp.*, *Dicranota sp.*, and *Ephemerella sp.* were the most common organisms present. Due to severe ice conditions, silt samples were not collected until April 3, 1952 and thus may be slightly different from winter collections. Silt fauna was 90 percent chironomids and a few tubificids. No burrowing mayflies were present. A partial list of bottom organisms is below:

Annelida
- *Oligochaeta*
- F. Tubificidae

Ephemeroptera
- *Ephemerella invaria*
- *Ephemerella sp.*
- *Baetisca sp.*

Plecoptera
- *Neophasganophora capitata*
- *Allocapnia pygmaea*
- *Acroneuria lycorias*

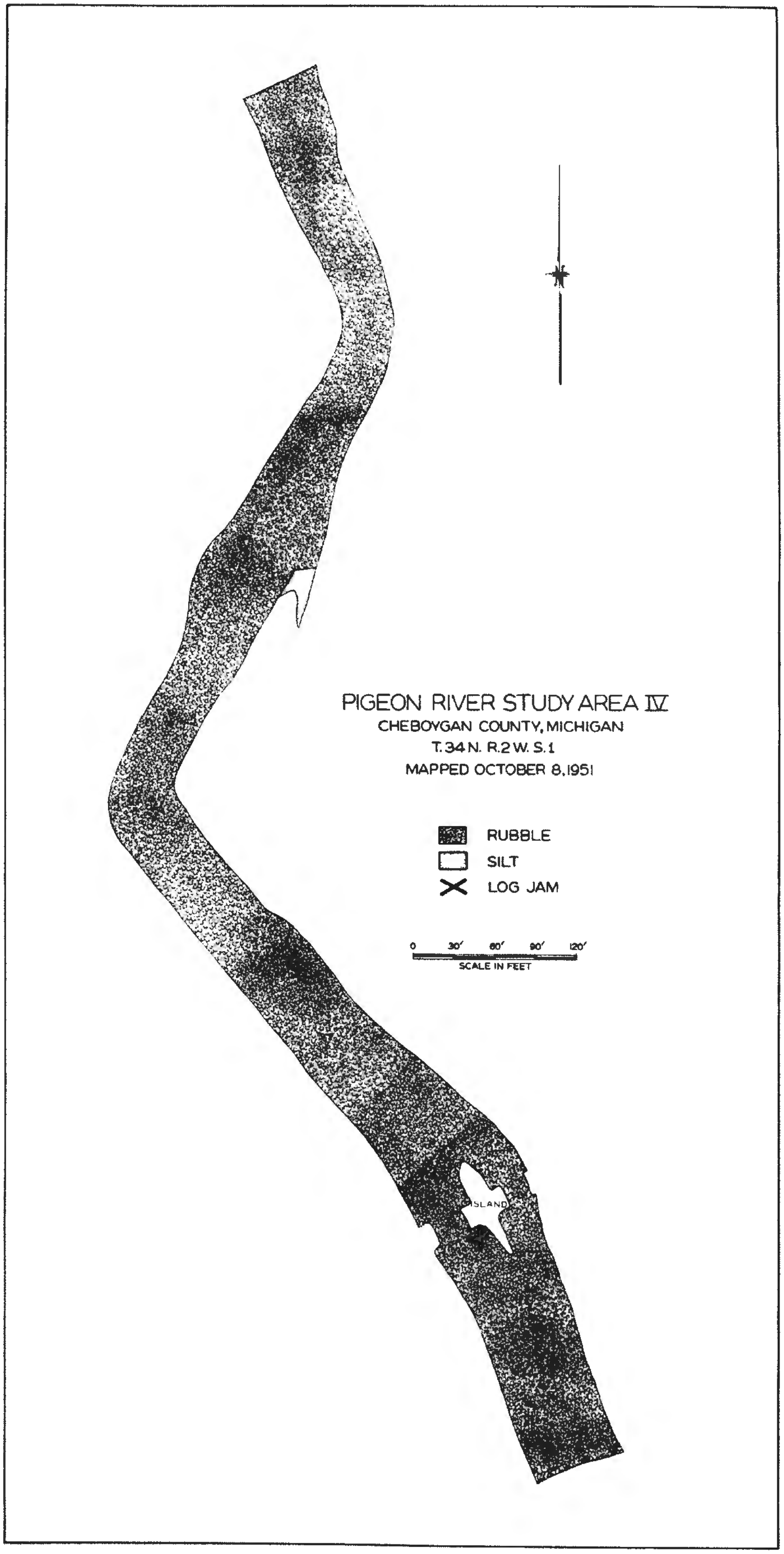
Odonata
- *Ophiogomphus sp.*

Megaloptera
- *Sialis sp.*

Coleoptera
- *Elmis sp.*

Trichoptera
- *Brachycentrus lateralis*
- *Hydrosyche Bifida*
- *Hydrosyche sparna*
- *Hydrosyche sp.*
- *Chimarra socia*
- *Glossosoma nigrior*

Fig. 11. Channel pattern and stream bottom soils in study area IV.


PIGEON RIVER STUDY AREA IV
CHEBOYGAN COUNTY, MICHIGAN
T. 34 N. R. 2 W. S. 1
MAPPED OCTOBER 8, 1951
RUBBLE
SILT
LOG JAM
0 30' 60' 90' 120'
SCALE IN FEET
ISLAND

Chimarra atterima
Agrypnia sp.

Diptera
Antocha sp.
Dicronata sp. Sub-genus *Rhaphidolevis*
Atherix sp.
Aphrosylus praedator
Tipula furka
Simulium sp.
Tipula sp.
Hemerodromia sp.
Eriocera sp.

Trout populations. The number of trout in this study area was small (never exceeding two) for all population estimates. The low number necessitated the use of derived recovery rates at all times (Table 8). Collections with the electric shocker other than at regular times of population estimates indicate low numbers of trout (App. C, Table 2). The largest number of trout collected was seven, in November, 1951.

TABLE 8

ESTIMATES OF BROOK TROUT POPULATIONS IN STUDY AREA IV, PIGEON RIVER, MICHIGAN, 1951. ESTIMATES ADJUSTED BY APPLICATION OF DERIVED RECOVERY RATES AND ARE INDICATED BY AN ASTERISK(*)

Brook trout size groups	Number of trout			
	April 27	May 14	June 12	July 12
2.0 to 3.9	0	0	0	0
4.0 to 6.9	0	0	0	0
7.0 to 10.9	0	2*	2*	1*
Total	0	2	2	1

Trout spawning. No redds were observed in study area IV or within the connecting 400 yards on either side. A survey was made in 1951 of five miles of the Pigeon River immediately upstream from this section of the river and a total of three redds was observed. The total absence of young-of-the-year trout in the population estimates attests to the absence of spawning (Table 9) and the relative immobility of trout produced elsewhere.

Non-trout populations. Calculated population estimates in July, 1951 showed 144 longnosed dace, 522 blacknosed dace, 208 creek chubs, and 160 blacksided darters (App. C, Table 4). Other species collected were: American brook lamprey, bluntnosed minnow, red-bellied dace, common shiner, log perch, Johnny darter, bluegill, rock bass, common muddler, and western banded killifish. The presence of large numbers of blacksided darters and longnosed dace is characteristic of this fast water habitat.

Aquatic plants. Higher aquatic plants were restricted to the shallows along the stream. Plants collected were: *Caltha palustris*, *Carex* sp., *Sagittaria latifolia*, *Sagittaria cuneata*, *Scirpus acutus*, and *Typha latifolia*. *Fissendens* sp., a moss, was common on rubble.

TABLE 9

NUMBER OF REDDS OBSERVED IN EACH STUDY AREA OF THE PIGEON RIVER, MICHIGAN, IN 1950 AND 1951. INCLUDED ARE SECTIONS OF STREAM BOTH 400 YARDS ABOVE AND BELOW EACH STUDY AREA

Study area	1950			1951		
	400 yds. above study area	Within study area	400 yds. below study area	400 yds. above study area	Within study area	400 yds. below study area
I	7	20	5	14	56	27
II	8	1	4	3	7	8
III	0	0	0	3	0	0
IV	0	0	0	0	0	0

ANALYSES OF ECOLOGICAL FACTORS IN RELATION TO TROUT POPULATIONS IN THE PIGEON RIVER

In attempting to evaluate the importance of various ecological factors in determining the size of the associated trout populations, it must be realised that these factors can operate individually and/or collectively. Only experimental evidence can settle the disputes concerning the relative importance of each on an individual or combined basis. In the Pigeon River, the size of the actual wild population of trout was used as the sole index in the appraisal of the effects of the ecological determinants. Survival rates and growth rates are obviously of great significance in this matter too, but data could not be collected to analyse adequately the effect of environment on these factors. Some data from other sections of the Pigeon River were utilised where data from the four study areas were inconclusive.

The ecological factors which influence trout populations may be classified into two categories on the basis of importance: (1) factor of greatest importance, i.e., it serves as a known limiting factor on trout populations in the Pigeon River; and (2) other factors, some of obvious importance, and others of no, or obscure relationship.

Factor of Greatest Importance

The most important limnological factor controlling the populations of brook and brown trout in the Pigeon River appears to be the seepage of ground water. It is the most significant determinant in the localisation of spawning fish and also affects distribution of all other size and age groups. The importance of ground water in the distribution of brook trout has been previously recognized. Ricker (1932) stated that spring water seepage explained the distribution of brook trout in Ontario. Other workers have pointed out the importance of cold water (a direct result of ground water in the Pigeon River) in the distribution of trout in streams and in the more practical considerations of locating trout hatcheries (Embody, 1921; Belding, 1928; Kendall and Dence, 1929; Creaser, 1930; White, 1930; Hassard, 1932; Ricker, 1934; Greeley, 1932; Cooper, 1939; Smith and Moyle, 1942). Brown trout can tolerate warmer temperatures in midsummer than brook trout (e.g., Embody, 1921; Hobbs, 1948) but evidence in the Pigeon River shows that they still require ground water influx of suitable thermal quality for spawning. Due to the importance of such a condition in the positioning of trout populations in this stream, certain methods of locating ground seepage are reviewed and their influences on trout populations are discussed.

Location of ground water seepage

Few fishery biologists have attempted to measure ground water seepage and a critical analysis of some means and their limitations seems advisable. The methods used in this investigation were: (1) seepage run, (2) summer water temperature, (3) winter water temperature, (4) winter ice cover, and (5) bottom soil temperature. As the use of each method was described previously, only certain limitations are presented below. Attempts to locate ground water by chemical methods in this stream were futile. Neel (1951) could not detect ground water in a Kentucky limestone stream by chemical means.

Seepage run. This method is only applicable if an accurate method of determining stream flow is possible on two points in the stream. Surface water influx must be determined and subtracted from the gain in volume of flow. The major limitation is that seepages cannot be determined for short stretches of stream (less than 700 yards in the Pigeon River) and ground water influx cannot be adequately localized as much as is necessary in some studies.

Summer water temperatures. Water temperatures were satisfactory as a measure of ground water seepage only during the hottest periods of summer. At these times the temperature effects are chiefly limited to sections of the stream where ground water is actually entering the channel. When the stream surface is exposed to high air temperatures, water temperatures will rise accordingly unless there is an appreciable amount of ground water to offset this influence. During hot periods, therefore, sections of stream with much seepage will have markedly lower temperatures than surrounding areas with little seepage. In the summer of 1951, the last two weeks in July were the warmest and most suitable periods in the Pigeon River region to demonstrate the presence of ground water (see air temperatures, Fig. 15). Study area I, with more seepage than the other sections, was much cooler with a maximum of 67° F. (Fig. 13; App. B, Table 1). Study area II, with a lower amount of ground water, reached 76° F. while III and IV, with very little seepage reached 78° F. Since the maximum temperature difference between study area II and areas III and IV was not great while the amount of ground water is much greater in II, some other factor is influencing the temperature of the water. One variable condition that could significantly affect water temperature is bank cover because it provides shade and prevents the maximum influence of sunlight. To check this condition, bank cover was surveyed for a mile of stream above each study area. Study area II is located below a section of stream with sparse bank cover and the water temperature reached 76° F. (a high temperature for trout) with ground water in some quantity. Study area I, however, had much bank cover both within the section and upstream from it and does not receive the full effect of sunlight. Study areas III and IV (both reached 78° F.) have small amounts of ground water seepage but they differ in respect to bank cover upstream. Above III is a large open meadow providing very little bank cover; above IV is a wooded area with five miles of continuous bank cover. Study area IV did not retain high temperatures over as long a period (1 week) as III (3 weeks) (see Fig. 13).

Another factor which might influence absorption of solar radiation in summer and, therefore, stream temperature, is the relationship between stream orientation and bank cover (as suggested by Dr. E. F. Brater). If a section of stream has an east-west orientation, the vegetation along the north bank will have practically no shading effect while the vegetation on the south bank will have considerable influence. This condition is due to the fact that the sun is never located directly overhead north of the Tropic of Cancer which is 23° 27' North of the equator. The latitude of the Pigeon River basin is 45° 12' North.

There is some evidence in study area II that the location of bank cover in relationship to stream orientation may be important. Above study area II the stream flows in an easterly direction. The bank cover, though sparse, was located principally on the north bank of the stream. Within study area II the stream temperature reached 76° F. with an appreciable amount of ground water seepage. More studies are needed to definitely relate stream orientation and bank cover. Thus, a lack of bank cover will allow water temperatures to rise appreciably even with seepage. In conclusion, whereas summer water temperatures may be used to indicate ground water, it is essential to consider bank cover as it is a limitation of the method.

Winter water temperatures. Ground water seepage can be identified by water temperatures in winter because of its warming influence on stream water. When air temperatures reach 10° F. or below for a period of several weeks a considerable amount of heat is necessary to prevent water from freezing, at least on the surface. Ground water is the main source of heat for a stream in this region. The use of winter water temperatures to identify seepage in the Pigeon River is limited, however, because the range of temperatures is small (32° F. to 36° F.) and it is difficult to compare small differences in temperature unless much data are collected. Since continuous winter temperatures were not taken in the study areas due to severe ice conditions, their value cannot be appraised fully.

If, however, ground water is an important influence in winter water temperature, an annual variation in ground water levels should influence annual water temperatures. Due to the fact that ground water data on the Pigeon River drainage are lacking, data were used from the Manistee, Au Sable, and Muskegon watersheds (Fig. 12). These streams are in the same general region as the Pigeon River and exhibit the same fluctuations. All these watersheds had higher ground water levels in the winter of 1951-52 than in the winter of 1950-51. Water temperatures of the Pigeon River at Gauge No. 1 (Fig. 1) show that the mean monthly winter water temperatures of 1950-51 were colder (frequently 32° F.) than in 1951-52 (never less than 34° F.). Air temperatures were not appreciably different for the two years and cannot account for the

Fig. 12. Mean monthly ground water levels above arbitrary data points at the following locations: Muskegon River watershed at Merritt, Manistee River watershed at Grayling, and Au Sable River watershed at Grayling. Data collected by U. S. Geological Survey.

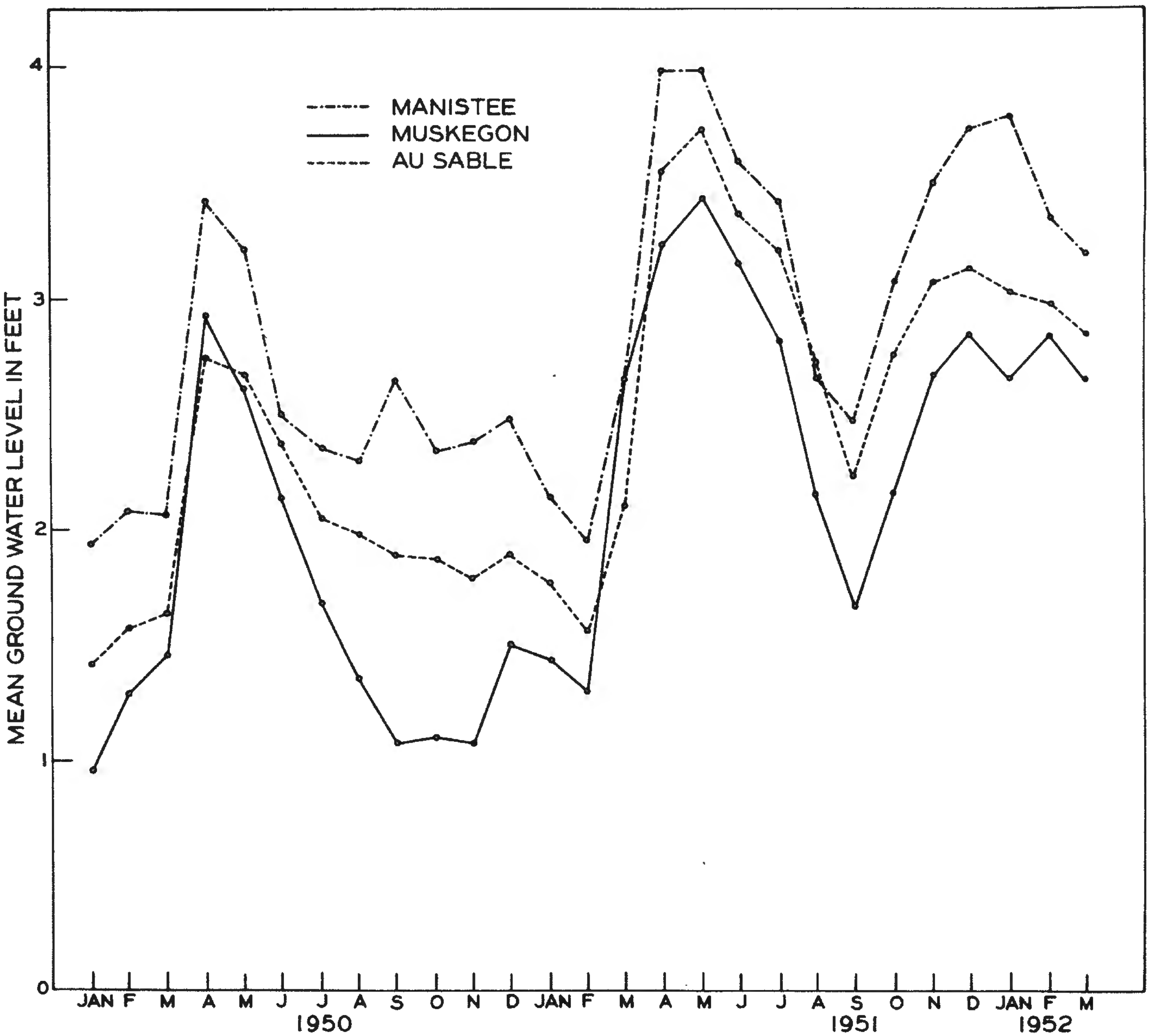
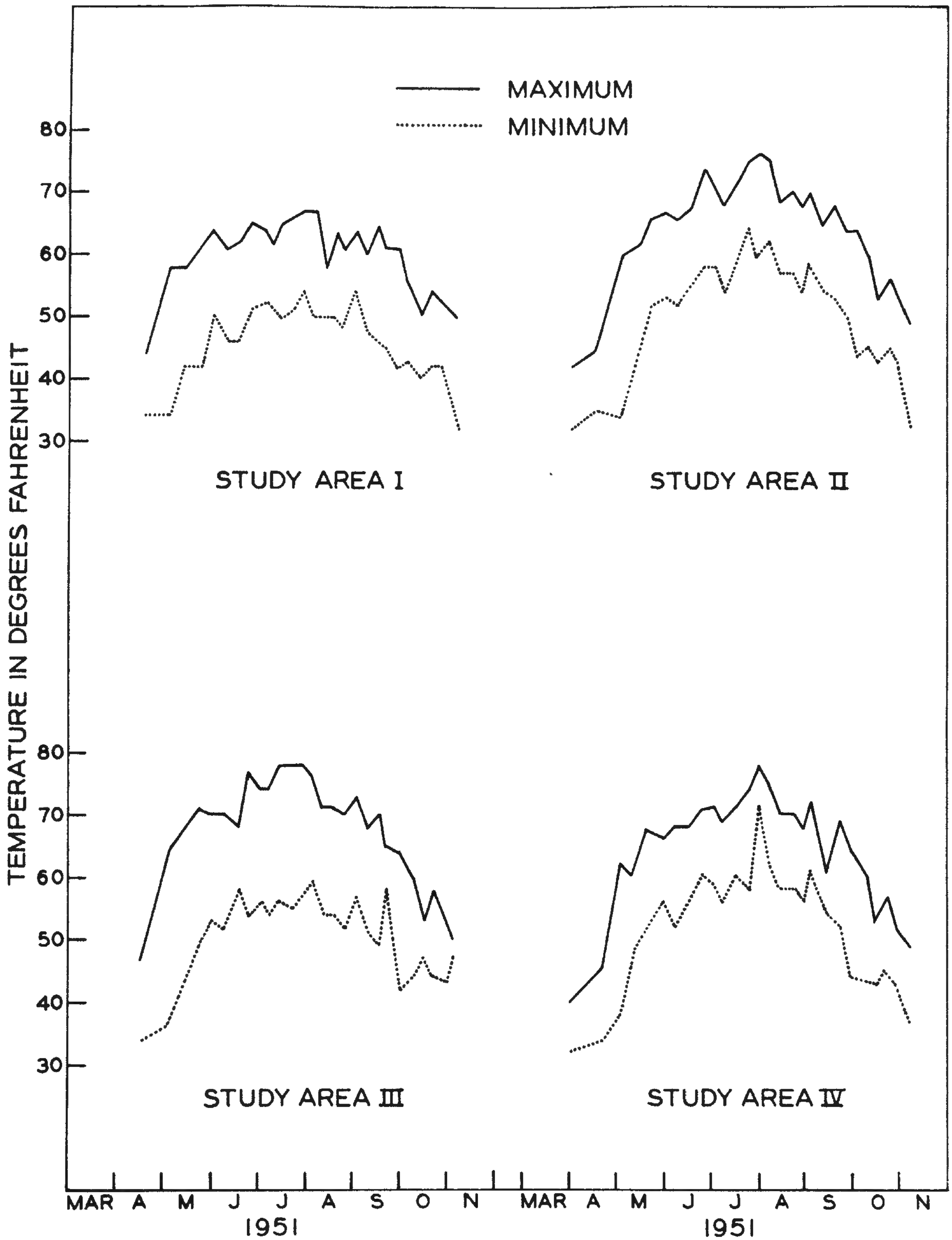

MANISTEE
MUSKEGON
AU SABLE
MEAN GROUND WATER LEVEL IN FEET
0
1
2
3
4
JAN F M A M J J A S O N D JAN F M A M J J A S O N D JAN F M
1950
1951
1952

Fig. 13. Weekly maximum and minimum water temperatures in the four study areas from March to November, 1951. Data collected with Taylor maximum-minimum thermometers.


MAXIMUM
MINIMUM
TEMPERATURE IN DEGREES FAHRENHEIT
80
70
60
50
40
30
STUDY AREA I
STUDY AREA II
STUDY AREA III
STUDY AREA IV
MAR A M J J A S O N
1951
MAR A M J J A S O N
1951

warmer temperatures in 1951-52 (Fig. 15); ground water level was the principal factor accountable.

Winter water temperatures are not affected by bank cover to any extent and are believed to be a more accurate method of locating ground water than summer temperatures if enough data can be collected. Winter surface ice cover is an index of winter water temperature and its use in this stream will be discussed in the next paragraph.

Surface ice cover. Surface ice cover was found to indicate ground water seepage by reflecting the winter water temperature. Those sections of the stream with significant seepage rarely reached 32° F. and therefore never froze at the surface. Other sections of the stream with little seepage froze over to some degree. Winter surface ice cover in this stream was mapped periodically in each study area (Fig. 14). Study area I rarely showed any ice cover in the two years of observations. Study area II froze over more completely than study area I but less than III or IV. The latter areas froze early and remained covered for a long time after each cold period. Gradient did not appear to significantly affect surface ice formation; study area IV with twice the gradient of the other areas had the greatest ice cover. Aerial photographs of study areas II and III (Figs. 8 and 9), taken on January 31, 1952, indicate the great difference in surface ice between these areas although they are only three miles apart. The value of using aerial photographs in winter to map trout habitat is great in this stream. An important limitation is that photographs must be taken during a very cold period. On January 31, 1952, the air temperature was at or near its winter minimum (Fig. 15). Regular winter photographs of study areas II, III, and IV indicate surface ice in a similar manner

Fig. 14. Observations of the percentage of surface ice cover in each study area during the winters of 1950-51 and 1951-52.

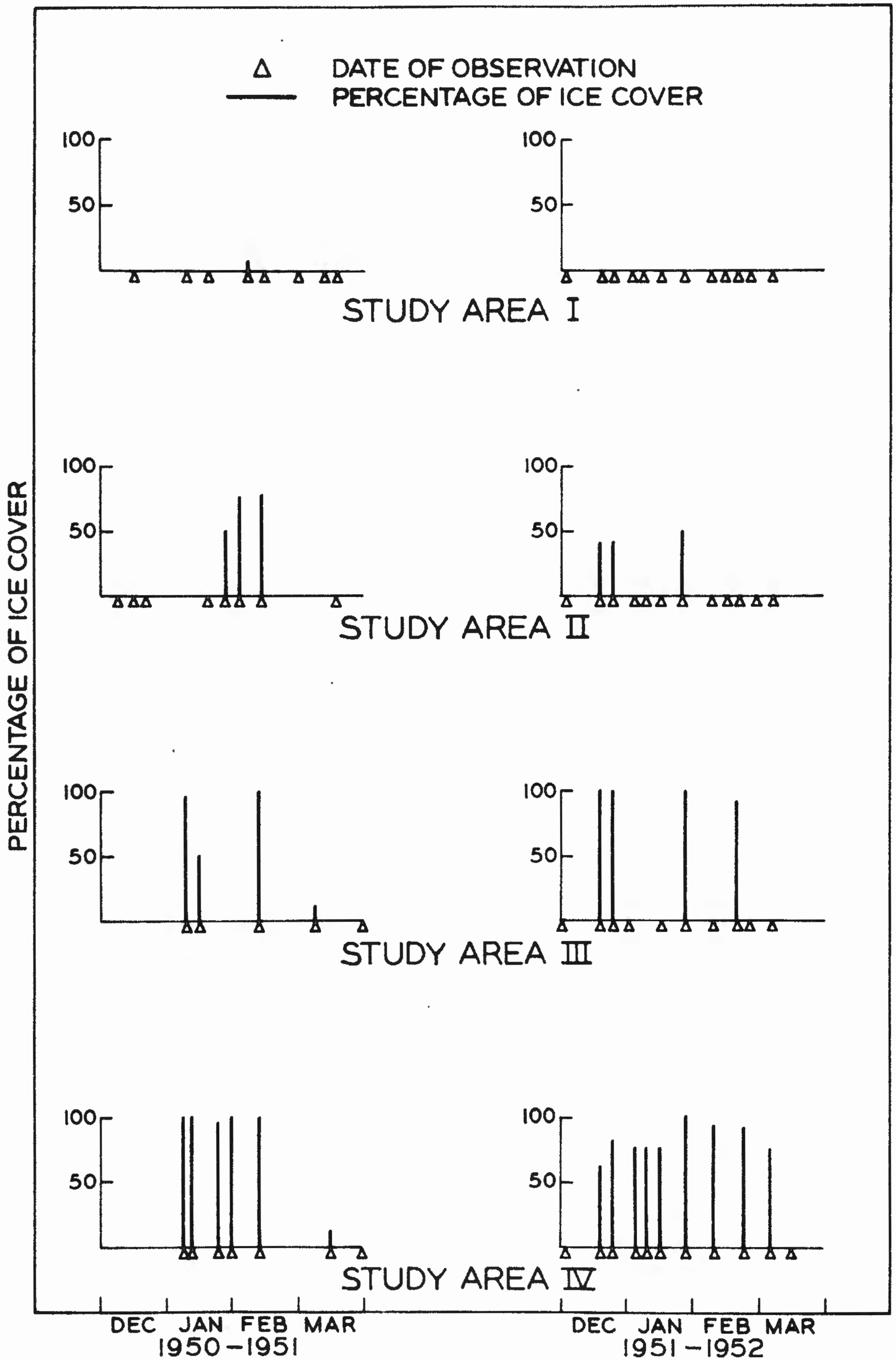
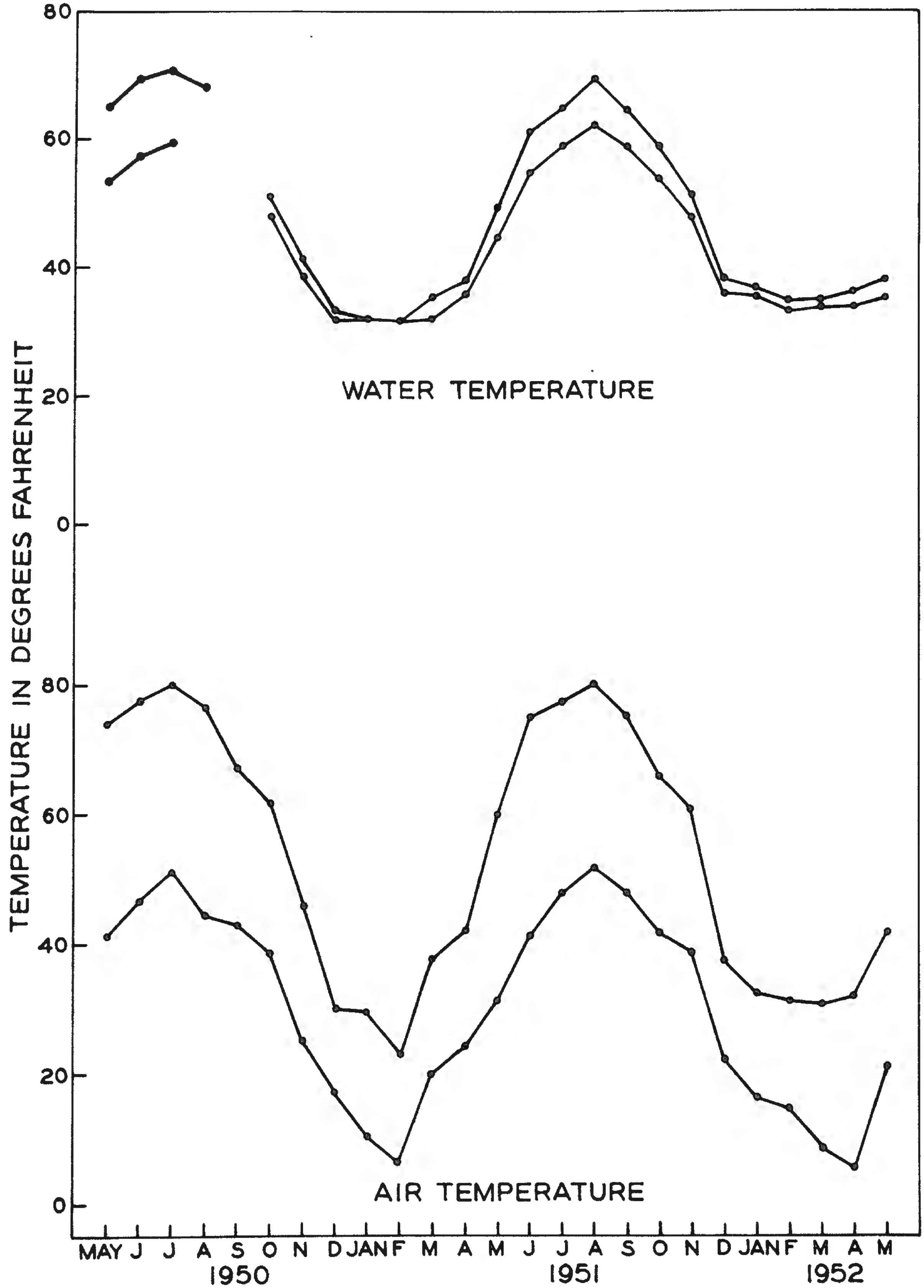

Δ DATE OF OBSERVATION
PERCENTAGE OF ICE COVER
PERCENTAGE OF ICE COVER
100
50
STUDY AREA I
STUDY AREA II
STUDY AREA III
STUDY AREA IV
DEC JAN FEB MAR
1950-1951
DEC JAN FEB MAR
1951-1952

Fig. 15. Maximum and minimum water temperatures of the Pigeon River at headquarters (See Fig. 1). Data prior to September, 1950 collected with a Taylor maximum-minimum thermometer; data after this date collected by an electrical recording thermometer. Maximum and minimum air temperatures collected with U. S. Weather Bureau thermometers at Headquarters.


80
60
40
20
0
WATER TEMPERATURE
TEMPERATURE IN DEGREES FAHRENHEIT
80
60
40
20
0
AIR TEMPERATURE
MAY J J A S O N D JAN F M A M J J A S O N D JAN F M A M
1950
1951
1952

(Figs. 16 and 17). In extremely cold periods (which do not occur annually) ground water may be mapped by ice cover more accurately than in the accompanying photographs. On February 2, 1951 the air temperature reached minus 40° F. and study area II was largely frozen while study area I was still open. The value of using winter ice cover to map ground water needs to be investigated on other streams before it can be used extensively. It proved to be very accurate in the Pigeon River.

Bottom soil temperature. Temperatures of the water in the bottom soils can be used to locate ground water seepage in a section of the stream channel because portions of the stream bottom with seepage are warmer than other parts of the stream bottom in winter and cooler in summer (see Figs. 5 and 6). This method would be difficult to use unless previous knowledge of the seepage in a stream were available. In this investigation it showed the importance of ground water in the location of brook trout spawning.

Influence of ground water seepage on trout populations

In the Pigeon River, spawning facilities of brook and brown trout correlated positively with the locales of ground water in the stream. Survival rates of young-of-the-year brook trout appear to be influenced by annual ground water levels.

Location of spawning. As previously described, the most important influence of ground water on trout populations in the Pigeon River is in the location of redds. Although spawning of brook trout was concentrated solely in sections of stream which showed ground water seepage, brown trout spawning areas were more widely scattered. The largest number of brown trout redds were, however, concentrated where ground water was present in quantity. Inventories indicated that the population density in a section of stream was directly correlated with the

Fig. 16. Upper photograph shows study area IV on January 9, 1951. Lower photograph shows study area III on February 13, 1951. Note complete ice cover in both photographs.

Fig. 17. Upper photograph shows study area II on February 14, 1952. Most of stream is frozen over. Lower photograph taken on December 19, 1951. Much of the stream is open.

amount of local spawning (Table 9). Study area I had a large number of redds (20 to 56) and a large permanent trout population (560 over 4 inches in July, 1951); study area II has a moderate number of redds (1 to 7) and a moderate trout population (239 over 4 inches in July, 1951); study areas III and IV have no redds and small trout populations (less than 20 over 4 inches in July, 1951).

In addition to ground water other ecological factors were considered in the location of brook trout redds but none carried as much significance. At the spawning locations, current velocity showed no special characteristics that were not present over other sites not used (Fig. 4). Bottom types of fine and coarse gravel were utilized for redds by brook trout. These substrata were present in study areas I, II, and III. They were not utilized, however, in area III and very little in area II. Numerous other sections of the Pigeon River were observed to have suitable bottom materials for spawning but lacked redds. Gradient may be a consideration in the location of brook trout redds because no spawning was observed in sections of the stream with a gradient over 0.2 percent. Study areas II and III have several sections of the channel with both suitable gradient and bottom type but they were not used for spawning. White (1930), Hazzard (1932), and Greeley (1932) all noted spring water and gravel at the spawning sites of brook trout. In the Pigeon, ground water appears to be the only limiting factor for spawning for most parts of the stream.

Hobbs (1937) mentions the following conditions as present at brown trout spawning sites in New Zealand: stable bottom, good diatomaceous growth on stones, lack of flooding, and slight gradient. In the Pigeon River, brown trout also chose stable bottom materials for nesting. Typically, they would spawn in coarse gravel and rubble, often downstream from brook trout redds which were predominantly in finer gravel. In part, this difference in habitat selection between the two species may be due to the fact that brown trout spawn at a larger size (usually above nine inches) than brook trout (usually above six inches) and thus may be able to handle larger stones in digging out redds. A good algal growth (partially diatomaceous) was generally present on the gravel in all study areas. All study areas had adequate gradient for spawning in some portions of the channel. Study areas II, III, and IV all had adequate spawning sites for brown trout but redds were only observed in study area II which had ground water seepage.

Several workers (Hubbs et al., 1932; Davis, 1934; Hazzard, 1937) mention that stream improvement structures will expose gravel and increase spawning areas. The evidence in this investigation indicates that ground water seepage is of much more importance than bottom type and should be investigated before environmental improvements to improve spawning are constructed.

As just shown, redds are an indication of the amount of spawning in a stretch of stream. Another index is the number of young-of-the-year trout present in midsummer. With the method of population estimation used, the month of July is the first month when a measure of young trout could be made. Prior to this period, trout are too small (generally less than 2 inches) to be collected by the electric shocker in a practical manner. Although it is possible that a limited migration of young trout may give a faulty impression in this regard, other workers (Shetter, 1937; Hoover and Morrill, undated; Watts et al., 1942; Schuck, 1945) have found little migration of young trout from the regions of spawning. My data also suggest little movement of this type. During the month of July, the number of young-of-the-year trout (2.0 to 3.9 inches) in study areas I and II was appreciably larger (500 or more fish) than in III or IV (Tables 1, 6, 7, and 8); some were collected in study area III but none in IV. Study area III is located 700 yards downstream from an active spawning ground and most young trout present are probably produced upstream. Only three redds were observed in five miles of stream above study area IV and none were found within a half mile of it; this fact accounts for the absence of young trout.

Shetter (1937) and Watts et al. (1942) found that brook trout do not migrate significantly throughout their entire lifetime. Schuck (1945) and Hobbs (1937) found similar results with the brown trout. Due to the lack of extensive migration of both brook and brown trout, the amount of spawning in a section of stream must strongly limit the population at any given site. Hobbs (1937 and 1940) found that brown trout populations in New Zealand agreed closely with the distribution of redds and that the development of populations has been possible only where satisfactory facilities for natural reproduction exist. My data support this contention for both brook and brown trout. Heavy fishing may, however, reduce the size of the spawning populations (Hobbs, 1937; Cooper, 1951). The amount of fishing pressure on the four study areas is only generally known. Nevertheless, fishermen were frequently observed in all sections of the stream and angling cannot explain the extreme differences in fish populations.

Survival rate of young-of-the-year trout. The survival rate of young trout is believed to be influenced by differences in ground water levels. As mentioned earlier, higher ground water levels are believed to have caused higher winter water temperatures in the winter of 1951-52 (monthly minimum of 34° F.) than in 1950-51 (monthly minimum of 32° F.). Several workers (Hubbs et al., 1932; Embody, 1934) reported that temperatures above freezing in winter are necessary to allow survival of trout eggs in gravel. Embody also states that temperatures below 34° F. may cause trout eggs to develop abnormally. In the same vein, Hayes (1949), working with salmon eggs, found that the conversion of yolk into embryonic tissue was 42 percent or less below 5° C. but ranged upward to 60 percent above this temperature. He also showed that other physiological processes were correspondingly slow at low temperatures. It is possible, therefore, that the warmer temperatures in winter (such as that of 1951-52) may permit a higher survival rate of young-of-the-year trout by allowing certain physiological processes to proceed more efficiently.

To determine this possible influence of ground water on trout, population data were used from the Pigeon River Trout Research Area. Although spawning populations of similar size were present in the reproductive seasons of 1949 and 1950, there was a conspicuous increase in the young-of-the-year brook trout in the fall of 1951 (9556) over that of 1950 (5468). Brown trout showed a decrease in survival rate which cannot be explained (Table 10). This is due possibly to the fact that brook trout spawn in areas of greater ground water seepage and may, therefore, be influenced to a larger extent by ground water levels. Since these population estimates were made in the fall, it is not possible to ascertain whether the ground water was most beneficial in the winter or in the summer. Air temperatures in the years of 1950 and 1951 were not of sufficient difference to account for the larger differences in water temperatures. More data over a longer period are necessary to definitely associate survival rate of young trout with ground water levels.

TABLE 10

SEPTEMBER POPULATION ESTIMATES OF BROOK AND BROWN TROUT IN 4.8 MILES OF THE PIGEON RIVER, MICHIGAN IN THE YEARS FROM 1949 to 1951. ARROW IN TABLE SIGNIFIES THE RESULTANT YOUNG-OF-THE-YEAR TROUT FROM THE PREVIOUS YEAR SPAWNING POPULATIONS*

Species and size group in inches	1949	1950	1951
Brook trout			
Spawning population (6.0 to 11.0)	1118 →	1247 →	
Young-of-the-year (2.0 to 3.9)		5468	9556
Brown trout			
Spawning population (9.0 to 18.0)	197 →	229 →	
Young-of-the-year (2.0 to 3.9)		1557	992

* Brook trout typically spawn at above six inches and brown trout at above nine inches in the Pigeon River.

Other Factors

The complete effect of certain environmental conditions on the density of Pigeon River trout populations could not be determined with assurance from the data taken in the study areas. The principal reason for this is that the influence of these factors on survival and growth rates could not be determined adequately. The obvious relationships of each ecological factor to the observed localization of trout populations in this stream, however, are presented.

Morphometry of the stream

The importance of stream channel morphometry in influencing the size of trout populations is minor in the Pigeon River. Factors considered in this investigation were width, mean depth, pool-riffle ratio, and gradient.

Width. In the four study areas the stream increased in width as the populations of trout decreased (Table 11). Width is not the significant reason for this relationship because collections of trout were made in several narrow sections of the Pigeon River (T. 33 N., R. 1 W., S. 33; T. 33 N., R. 2 W., S. 33) and few or no trout were found. Throughout the stream varying widths showed contrasting numbers of trout. Hoover and Morrill (undated) also found inconclusive evidence on the importance of stream width on trout populations in New Hampshire.

TABLE 11

COMPARISON OF STANDING CROP OF TROUT IN JULY, 1951 WITH MEAN WIDTH, MEAN DEPTH, POOL-RIFFLE RATIO, AND GRADIENT IN THE PIGEON RIVER

	Study area I	Study area II	Study area III	Study area IV
Pounds of trout per acre	45.77	29.23	1.57	0.15
Number of trout	1440	837	89	1
Mean width in feet	37.6	48.3	61.0	51.9
Mean depth in inches	9.8	12.5	9.9	19.5
Percent gradient	0.126	0.057	0.057	0.335
Pool-riffle ratio	S2, T2, F2.	S2, T2, F3.	S2, T2, F3.	S3, T3, F3.

Mean depth. Mean depth, as a single factor, cannot explain the diversity of trout populations in the Pigeon River. This condition varied from a maximum of 19.5 inches to a minimum of 9.8 inches in the four sections of stream investigated (Table 11). Study areas II and III were nearly alike in mean depth and yet differed greatly in numbers of trout. Shetter and Hazzard (1939) found the largest numbers of trout with the mean depth over 14 inches. Hoover and Morrill (undated) found no correlation between brook trout production and mean depth in a New Hampshire stream.

Pool-riffle ratio. Pool-riffle relationships are believed important from a standpoint of biological productivity but form little relationship to differences in trout populations in my study areas in the Pigeon River. Neel (1951) states that riffles have a greater productivity of periphyton than pools; however, pools serve as a catch basin for debris which produces free carbon dioxide and bicarbonates on decomposition for use in photosynthesis on the riffles. In the Pigeon, decomposition probably takes place in shallow silt deposits and in some pools. Many pools observed had very small amounts of debris that were cleaned out during periods of high water. Davis (1938) observed that pools are necessary to trout in streams for concealment and for relief from the current. Collections of trout with the electric shocker in my study areas showed this to be true since pools in the better sections contained large numbers of all sizes of trout. Depth and size,however, do not appear to be as significant as shade and current velocity, in determining the suitability of pools. Large trout were frequently collected in pools less than one foot in depth, but which were well shaded and had a current velocity greater than 0.75 feet per second. Quiet waters deeper than three feet were more commonly occupied by blacknosed dace, white suckers, and creek chubs than by trout. Hoover and Morrill (undated) also found a definite correlation between the pool grade and standing crop of trout.

None of my study areas possessed ideal pool-riffle relationships (S1, T1, F1). Conditions were best in sections I and II, which also had the largest numbers of trout (Table 11). This channel attribute was tested further by shocking in several other sections of the Pigeon River (T. 33 N., R. 1 W., S. 33; T. 34 N., R. 2 W., S. 25; T. 34 N., R. 1 W., S. 31) which had near ideal pool-riffle conditions. Few or no trout, however, were found in these sections of stream and the importance of pool-riffle conditions as a limiting factor on trout populations in the Pigeon River was not believed great.

Gerking (1949) found a positive correlation between the average total weight of fish and the volume of water within the two foot contour in an Indiana warm-water stream. He was able to demonstrate that a stream with frequent, deep pools will be more productive than one with long stretches of shallow water. As mentioned previously, deep pools in the Pigeon River were often pre-empted by non-trout species (e.g., blacknosed dace, white suckers, and creek chubs). Although these fishes probably serve as food for larger trout, no substantial populations of trout were ever found associated with large numbers of other kinds of fish. Thus the value of deep pools in this stream is less than well-shaded pools with some current.

One possible effect of pools is that they may serve to increase the survival rates of trout (e.g., Shetter et al., 1949). The pool-riffle ratio cannot, however, influence a trout population unless spawning facilities are first available to build up a population.

Gradient. Gradients varied from 0.057 percent to 0.335 percent in the four study areas of the Pigeon River (Table 11). The percentage gradient is obviously not correlated with the numbers or weights of trout. Study areas II and III vary greatly in trout populations but have the same gradients (0.057 percent). King (1942) recorded trout in streams with gradients from three to five percent. Hobbs (1948) found the greatest concentrations of trout at a gradient of 0.003 percent. Allen (1951) does not consider gradients from 0.548 percent to 1.707 percent as detrimental to trout populations in the Horokiwi stream. High gradient, such as present in many streams of western United States, can influence trout populations by reducing spawning facilities (Hobbs, 1948). All sections of the Pigeon have many suitable spawning areas as far as gradient is concerned and the total effect of this factor is judged to be negligible.

Cover

The real importance of cover on trout is probably found in its beneficial influence on survival rate. In the Pigeon River, cover does not influence spawning facilities or the use of spawning grounds. There is some positive influence of both bank and midstream cover on the populations of trout.

Bank cover. The highest trout populations occurred in the Pigeon River in study areas I and II where bank cover was most complete; study areas III and IV were located in more open sites. However, bank cover as a single factor will not make a stream habitable for trout. Its value was tested by shocking in several other sections of the Pigeon River with 90 to 100 percent bank cover (T. 34 N., R. 2 W., S. 13; T. 33 N., R. 1 W., S. 33), both of which yielded less than five trout per hundred yards of stream. Hoover and Morrill (undated) could find no correlation between the number of brook trout and bank cover in New Hampshire. Shade is desirable, nevertheless, in controlling high stream temperatures in midsummer as pointed out earlier.

Midstream cover. Midstream cover often influences a stream bed by controlling the current which, in turn, digs pools and alters bottom type. Most of the artificial stream improvement structures are forms of midstream cover. Although study areas I and II in the Pigeon River have the most midstream cover and the highest production of trout, other fish collections made from zones of continuous midstream cover (T. 33 N., R. 1 W., S. 33; T. 34 N., R. 1 W., S. 30) showed few trout. Shetter et al. (1949) reported an increased fish population in a portion of Hunt Creek due to the installation of deflectors, a form of midstream cover. The number of fingerling trout in this study did not increase appreciably (430 in 1941 to 438 in 1944) but the larger trout (above 4 inches) showed a significant increase (99 in 1941 to 145 in 1944). These stream improvement structures may, therefore, influence the survival rate rather than the amount of spawning or they may alter the habitat to make it more desirable to fishes of one size range than to those of another. The total value of midstream cover appears to be insignificant unless spawning facilities are available.

Chemistry of the stream water

Several field studies have been made on the chemistry of water in trout streams (Creaser and Brown, 1927; Creaser, 1930; Embody, 1927, a, 1927, b, 1928; Outsell, 1929; Powers, 1929; and Frost, 1945). In addition, controlled laboratory studies have been made on the effect of dissolved gases and hydrogen ion concentration on trout (Breder, 1927; Outsell, 1929). Findings to date indicate a wide tolerance of dissolved oxygen, dissolved carbon dioxide, methyl orange alkalinity, and hydrogen ion concentration for brook and brown trout.

Dissolved oxygen. The oxygen content of the Pigeon River was high (above 8.0 p.p.m.), approaching saturation at all periods (App. A, Table 1). Studies on dissolved oxygen requirements of brook trout

(Breder, 1927; Creaser, 1930; Cutsell, 1927; Embody, 1928) indicate little concern under ordinary conditions unless it is below 5.0 p.p.m. Ground water probably contains a low amount of oxygen when it enters the stream but it gains oxygen quickly because of rapid diffusion of dissolved gases in fast moving water. In summer the presence of ground water lowers the stream temperature and permits an increase in its oxygen holding capacity (e. g., study area I). Oxygen supply was adequate at all times and cannot be considered a detrimental factor to the Pigeon River trout populations. This fact was also true under several inches of loose gravel because eggs developed with virtually no mortality in one bed excavated.

Dissolved carbon dioxide and phenolphthalein alkalinity. Free carbon dioxide and half-bound carbonates were never found in Pigeon River waters although measurements were made at all periods of the year. Neel (1951) found free carbon dioxide in an unpolluted Kentucky limestone stream for only a brief period in autumn when the stream was filled with organic debris. Embody (1927a), however, recorded 20.5 p.p.m. from a small spring-fed tributary and free carbon dioxide is generally known to exist in organically polluted waters.

Methyl orange alkalinity and specific conductance. Methyl orange alkalinity was high (above 126 p.p.m.) in all study areas (App. A, Table 1). Study areas I and IV were, at some periods, slightly lower in alkalinity than study areas II or III. All showed lower readings in March and April due to dilution by melting snow and ice. Specific conductance of the water is closely related to methyl orange alkalinity and was high (185 to 213 reciprocal megohms) throughout the drainage system (App. A, Table 2). Neither the total alkalinity nor the specific conductance varied greatly from the source to the mouth of the Pigeon River. Because of its uniformity, these habitat items must be of no significance in determining fish distribution.

Hydrogen ion concentration. Many studies have attempted to correlate hydrogen ion concentration and trout distribution (Coker, 1925; Davis, 1926; Creaser and Brown, 1927; Creaser, 1930). All these investigations suggest that brook and brown trout can tolerate a wide range (pH from 5.0 to 9.0) of hydrogen ion concentration. The Pigeon River varied only slightly in pH from the source to the mouth and I conclude that this factor has no relation to the numbers of trout in various sections of the stream.

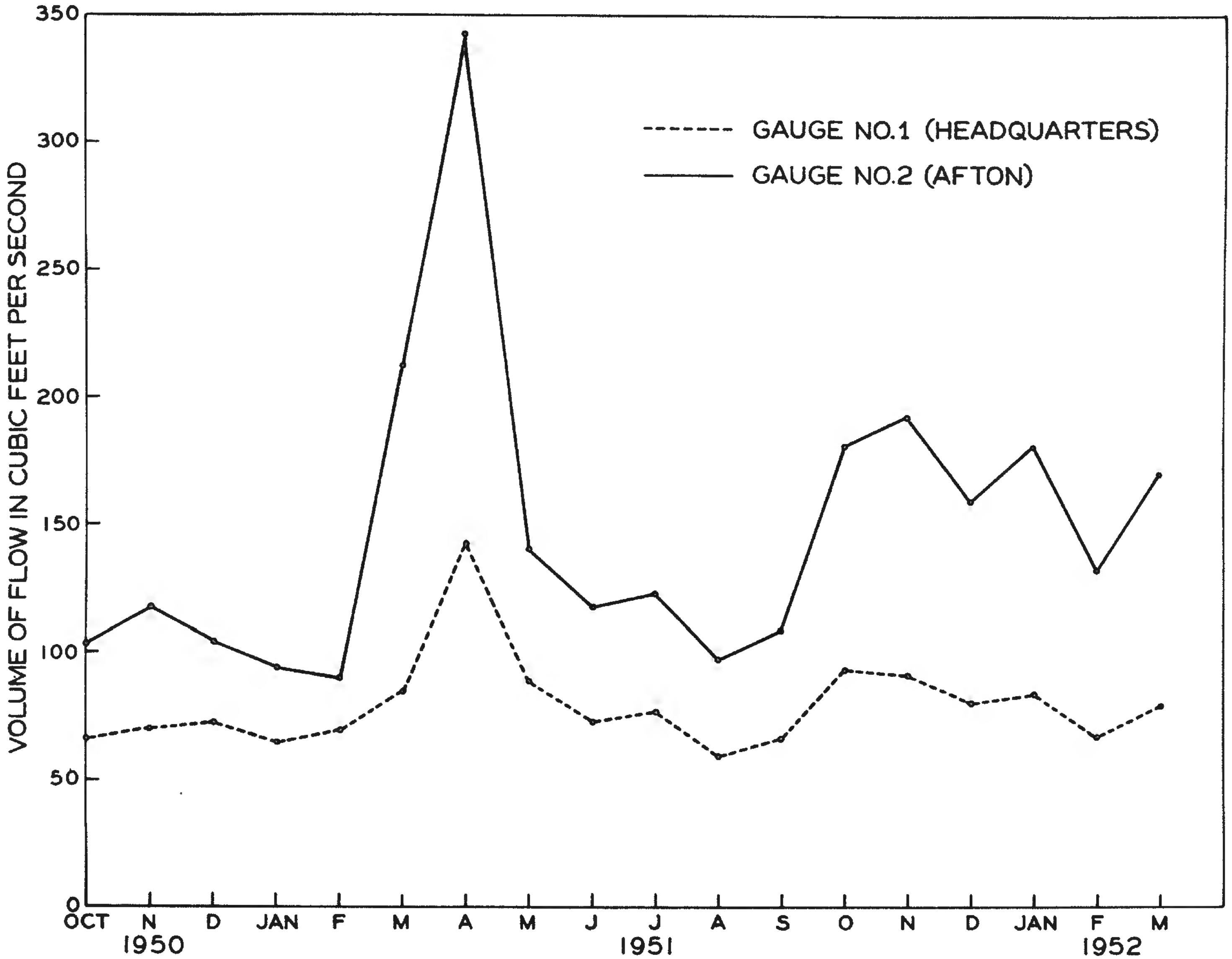
Phosphorus. Both dissolved inorganic and total phosphorus increased from the headwaters downstream (App. A, Table 5). Phosphorus was higher during August than during March. Berg (1943) recorded similar results from the River Susaa. Although the amount of phosphorus increased as the populations of trout decreased, there is no known or suspected cause and effect relationship between the two.

Stabilization of stream flow

A minimum of fluctuation in volume of flow is desirable in a trout stream because both bottom soil types and stream bottom organisms are often adversely influenced by flooding (Hubbs, et al., 1932; Tarzwell, 1938). The variations in volume of flow which operate in different parts of the Pigeon River are believed to be caused by the type of drainage net and the amount of indirect drainage. The drainage net refers to the pattern of surface stream tributaries which have developed by natural causes in the watershed. If a watershed is well networked by tributaries, rainfall or melting snows will drain off quickly and some flooding will occur in the main stream; however, if the watershed is not well drained at the surface much of this water will enter the ground and then reach the main stream flow as ground water. Indirect drainage refers to the conditions where rainfall will contribute to the stream flow via the ground rather than through tributaries or surface runoff (Wisler and Brater, 1949). The desirable qualities of ground water in a trout stream were presented earlier in this paper. If fewer tributaries in a drainage system will increase the ground water flow, it should also make better trout habitat. Likewise, a minimum number of tributaries should decrease the annual fluctuation in volume of flow because the rainfall will not be drained off the watershed as rapidly.

The amount of fluctuation in flow on the Pigeon River was determined at two gauging stations. Gauge No. 1 is located at headquarters and gauge No. 2, downstream near the town of Afton (See Fig. 1). Upstream from headquarters the river has few tributaries except at the origin where it forms from a series of flowing springs in a large cedar swamp. Between gauges 1 and 2 the number of tributaries increases greatly and the effluents from several small ponds contribute to the flow of the main stream. From the appearance of the drainage pattern of the Pigeon River (Fig. 1), the expected fluctuation in volume of flow would be greater at gauge No. 2 than at No. 1. This is actually so; the fluctuation in mean monthly flow is much greater at gauge No. 2 (coefficient of variation, 41.9 percent) than at gauge No. 1 (coefficient of variation, 23.2 percent). During the spring runoff (April) the rise in volume of flow was naturally much greater at gauge No. 2 than gauge No. 1 (Fig. 18). Coincident with the greater fluctuation in volume of flow

Fig. 18. Mean monthly flow of Pigeon River at Gauges No. 1 and No. 2 (See Fig. 1) as determined by the U. S. Geological Survey.


GAUGE NO.1 (HEADQUARTERS)
GAUGE NO.2 (AFTON)
VOLUME OF FLOW IN CUBIC FEET PER SECOND
0
50
100
150
200
250
300
350
OCT
N
D
JAN
F
M
A
M
J
J
A
S
O
N
D
JAN
F
M
1950
1951
1952

is the fact that good trout populations become rare and extremely localized below gauge No. 1.

The hydrographs of three other waterways (the Au Sable, Manistee and Muskegon rivers) in this region show variations in flow similar to the Pigeon River (Fig. 19). The Au Sable and Manistee are good trout streams where the hydrographic data were collected; the Muskegon is poor trout water. The annual fluctuation in volume of flow is much greater in the latter than in either of the former. Two desirable conditions for trout streams can be associated with a minimum fluctuation in volume of flow: (1) bottom soils and stream bottom organisms are not subject to dislodgement; and (2) rainfall is contributing to stream flow via the ground rather than through surface runoff.

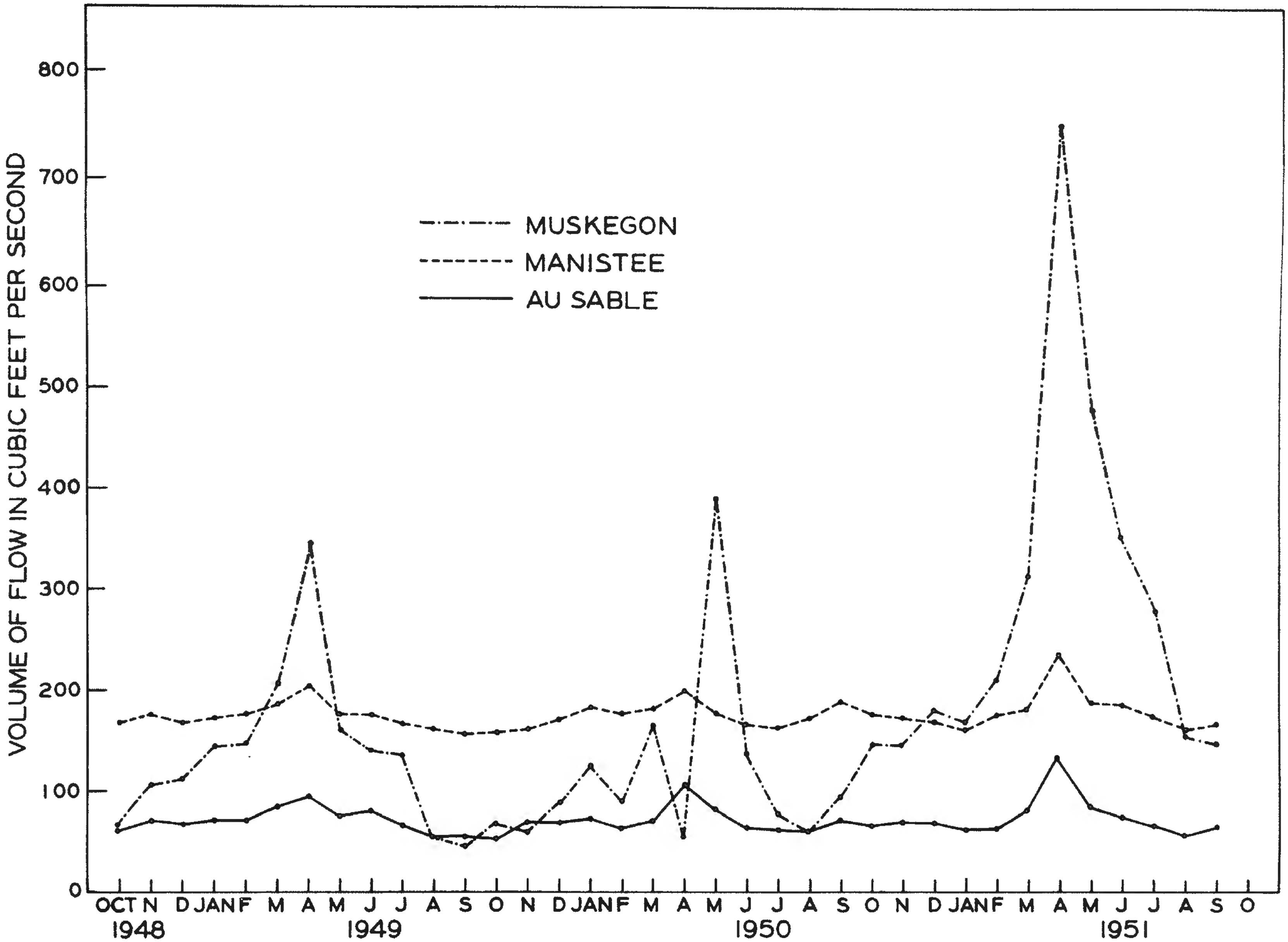
Bottom type

Type of bottom varied considerably in all four study areas and influenced both the amount of bottom fauna and trout spawning. The relationship of bottom materials to bottom fauna will be presented below. As shown previously, trout spawning was not limited by bottom type in any of the study areas.

Bottom fauna

Practically all trout stream survey procedures have considered bottom fauna production (Hoover, 1937; Needham, 1938; Davis, 1938; Lagler, 1949). I found that the winter volume of bottom fauna is related to the numbers of trout in a section of stream only to a minor extent. Hoover and Morrill (undated) also considered amount of bottom organisms to be a poor indicator of trout production in New Hampshire. However, abundance of bottom fauna is known to influence the growth rate of trout (Frost, 1945; Brown, 1946; Cooper, In press, c) and almost certainly affects the survival rate of certain age groups.

Fig. 19. Mean monthly volume of flow as determined by the U. S. Geological Survey on the Manistee drainage basin at Grayling, the Au Sable drainage basin at Grayling, and the Muskegon drainage basin at Merritt, all in Michigan.


MUSKEGON
MANISTEE
AU SABLE
VOLUME OF FLOW IN CUBIC FEET PER SECOND
800
700
600
500
400
300
200
100
0
OCT N D JAN F M A M J J A S O N D JAN F M A M J J A S O N D JAN F M A M J J A S O
1948
1949
1950
1951

In order to compare the bottom fauna production in the four study areas, all sampling was done in winter and the winter standing crop of bottom organisms was used as an index of the total food production (Table 12). At this period of the year there are few emergences and the fauna is relatively stable in volume and number of organisms.

The bottom fauna of the Pigeon River is principally mayflies (Ephemeroptera), caddis flies (Trichoptera), and true flies (Diptera). Ephemerella is a particularly common mayfly genus on the gravel. Hexagenia limbata was common in silt. Among the caddis flies, Brachycentrus lateralis, was most abundant in the cool headwaters but decreased in numbers downstream. Hydropsyche was most common in the fast water and on rubble and coarse gravel in study areas II, III, and IV. Glossosoma nigrior was present in moderate numbers on fine and coarse gravel in all sections of the stream. Diptera most often encountered were either chironomids or tipulids. Atherix, Eriocera, Dicranota, and Aphrocylus were common on coarse gravel and rubble in study areas II, III, and IV. Chironomids, for the most part, were concentrated in the silt. Stoneflies (Plecoptera) were represented principally by the Perlodidae but were not abundant in any portion of the stream. The coleopteran genus, Elmis, was found in all study areas but never formed a significant part of the fauna.

From the evidence in hand, it would be hazardous to use any species of bottom fauna as an indicator of trout habitat due to the wide ecological tolerance apparently possessed by most organisms concerned. Abundance of certain forms may be more indicative than mere presence. Brachycentrus lateralis was abundant in the headwaters with a large population of brook trout and decreased in numbers downstream. Needham (1938) also mentions this larva as typical of cool headwater streams.

TABLE 12

MEAN VOLUME IN CUBIC CENTIMETERS (V) AND NUMBER (N) OF BOTTOM ORGANISMS IN EACH BOTTOM TYPE OF EACH STUDY AREA, PIGEON RIVER, MICHIGAN. T EQUALS TRACE

Bottom type		Rubble		Coarse gravel		Fine gravel		Sand			Silt			
Study area		III	IV	II	III	I	II	I	II	III	I	II	III	IV
Number of samples		4	17	7	7	17	3	5	8	14	5	5	6	5
Nematoda	N											0.6		
	V											.005		
Annelida	N	0.5	0.6		1.1	4.8	3.0	0.4	0.2	0.1	37.0	11.6	9.7	27.0
	V	T	.023		.003	.029	T	.030	T	.003	.095	.010	.029	.075
Mollusca	N		0.1			0.6		0.2				0.6		0.6
	V		.012			.013		.025				.005		.090
Malacostraca	N	0.6	0.1	0.9	0.1				0.2				0.6	0.8
	V	.075	.124	.021	.128				.071				.004	.005
Arachnida	N		0.1											
	V		T											
Ephemeroptera	N	52.7	74.8	36.8	14.5	9.8	13.0	0.9	3.4	0.6	6.6	10.6	10.1	0.8
	V	.381	.123	.228	.132	.044	T	.070	.036	.007	.380	.805	.300	.010
Plecoptera	N	3.7	6.5	2.3	0.8	1.2	1.0	0.4	1.2		0.8	0.6	0.2	0.2
	V	.037	.082	.043	.007	.007	T	T	.011		.005	.005	T	T
Odonata	N		0.1	0.4	0.1	0.2	0.3	0.2		0.1	0.4	0.4	0.3	
	V		.009	.021	.003	.058	.030	.010		.041	.130	.240	.216	
Hemiptera	N											0.4	1.0	
	V											T	.100	
Megaloptera	N	0.7	1.2	3.1		4.6	0.3				0.4	6.0	0.5	0.8
	V	.037	.094	.014		.118	T				.010	.135	.008	.030
Coleoptera	N	4.2	8.8	7.1	0.1	9.9	3.0	9.4	0.8	0.1	8.0		0.2	
	V	.018	.031	.014	T	.041	.008	.040	.007	T	.020		T	
Trichoptera	N	64.0	66.0	38.7	6.4	43.2	6.3	7.6	0.6	0.2	1.8	0.6	0.5	0.6
	V	.181	.169	.389	.057	.466	.025	.205	.014	T	.037	.035	.017	.110
Diptera	N	35.7	55.5	13.7	11.4	33.3	184.7	32.0	16.0	7.8	50.0	150.2	169.8	211.0
	V	.039	.280	.082	.065	.374	.175	.225	.142	.051	.170	.330	.488	1.240
Mean number		162.1	231.7	103.0	34.5	107.6	211.6	51.1	22.4	8.9	105.0	181.6	192.9	241.8
Mean volume		.768	.947	.812	.395	1.150	.238	.605	.281	.102	.847	1.570	1.162	1.560

Needham (1938) states that the major factors in the distribution of bottom organisms in a stream are: (1) type of bottom, (2) velocity of current, (3) depth of water, (4) temperature of the water, and (5) materials in suspension and solution. I have data on each of these factors and offer the following comments regarding their influence on the production of bottom organisms in this stream. Silt contained more fish food organisms per unit area than any other bottom type encountered in the Pigeon River (Table 13). Sand was the only bottom type consistently low in production. It was the least stable and subjected the bottom organisms to the greatest molar action as indicated by the numbers of insect fragments and empty cases collected. The lack of any consistent communities of organisms in sand indicates that the occurrence of most of the organisms found was fortuitous. The sand in study area I was most productive because it occurred as small patches among stable areas of fine gravel. The influence of stability on volume production is also shown by comparing the fine gravel in study area I with that in study area II (Table 13). In the first area, fine gravel had a mean production of 1.150 cc. per square foot whereas the same bottom type in II had a mean of 0.283 cc. per square foot. The fine gravel in study area II was subject to severe molar action and was practically devoid of algal growth.

Current velocity and temperature influenced the species composition or communities of organisms more than it did the total volume production. Although no deep pools (over three feet deep in midsummer) were sampled, the influence of depth was apparently not great since the variances that were present in the study areas were so small. Little suspended matter was ever observed in the water of this stream.

TABLE 13

WINTER STANDING CROP OF BOTTOM ORGANISMS IN EACH BOTTOM TYPE WITH CORRESPONDING
T VALUES FOR COMPARING THE VARIOUS TYPES:
T = T VALUE   P = PROBABILITY OF A LARGER T

Bottom type	Number of samples	Mean volume in cc. per sq. ft.	Standard error of mean	Coarse gravel		Fine gravel		Sand		Silt	
				T	P	T	P	T	P	T	P
Rubble	21	0.972	0.173	1.44	.20	0.15	.20	3.74	.01	1.48	.20
Coarse gravel	14	0.620	0.171			1.05	.30	1.89	.10	3.09	.01
Fine gravel	20	0.927	0.237					2.66	.02	1.36	.20
Sand	26	0.262	0.080							6.45	.01
Silt	22	1.301	0.140								

The amount of inherent variation in both volume and number of organisms in any single bottom type of one study area was found to be great. Other workers found similar results unless precautions were used in sampling a restricted section of stream bottom (Needham, 1928; 1934; Pate, 1931, 1932, 1933; Surber, 1933, 1937; Mottley et al., 1939; Leonard, 1939; Allen, 1951). A coefficient of variation (Standard deviation/mean) of 50 percent can be normally expected in sampling one bottom type unless the sampling is restricted to a relatively small homogeneous section of stream bottom (as by Leonard, 1939). A large amount of variation was found in the bottom types in the Pigeon River (Table 14). The coefficient of variation of all bottom types in numbers of organisms varied from 39.6 to 251.7 percent and in volume from 41.6 to 283.3 percent. The amount of variation was greatest in sand probably due to the instability of the bottom and to the lack of a consistent fauna.

In order to estimate the standing crop of bottom fauna in each study area, the mean volume of organisms per square foot of each bottom type was multiplied by the number of square feet of bottom type (Table 15). The total production was then obtained by simple addition of the volumes for each kind of bottom material in the area. There is no constant relationship between the total volume of bottom fauna in winter and the standing crop of trout in summer. Study areas I and IV were nearly alike in regard to bottom fauna production per acre but they differ greatly in populations of trout. Bottom fauna production (i.e., total standing crop) was not correlated with total trout production in the Pigeon River.

TABLE 14

AMOUNT OF VARIATION IN NUMBERS AND VOLUME OF BOTTOM ORGANISMS IN EACH BOTTOM TYPE IN EACH STUDY AREA OF THE PIGEON RIVER, MICHIGAN

M = MEAN; S = STANDARD DEVIATION; C = COEFFICIENT OF VARIATION; N = NUMBER; V = VOLUME

Study area	Rubble		Coarse gravel		Fine gravel		Sand		Silt	
	N	V	N	V	N	V	N	V	N	V
I										
M					107.6	1.150	51.1	0.605	105.0	0.847
S					66.0	0.478	73.0	0.635	67.0	0.412
C					61.3	41.6	142.9	104.0	63.8	48.5
II										
M			103.0	0.812	211.6	0.238	8.9	0.102	181.6	1.570
S			67.0	0.712	280.0	0.161	22.4	0.289	133.0	0.665
C			65.0	88.8	132.3	67.6	251.7	283.3	73.2	43.6
III										
M	162.1	0.768	34.5	0.395			22.7	0.281	192.9	1.162
S	116.0	0.548	26.0	0.521			9.0	0.230	186.0	0.685
C	71.6	71.3	75.3	131.8			39.6	81.8	96.4	58.9
IV										
M	213.7	0.947							241.8	1.560
S	225.0	0.850							130.0	0.772
C	105.3	89.7							53.8	49.5

TABLE 15

WINTER STANDING CROP OF BOTTOM ORGANISMS IN EACH STUDY AREA. BASED ON MEAN VOLUME PRODUCTION (CC.) OF EACH BOTTOM TYPE IN EACH STUDY AREA AND THE TOTAL AREA OF THE RESPECTIVE BOTTOM TYPE

Bottom type	Volume of bottom organisms in cubic centimeters			
	Study area I	Study area II	Study area III	Study area IV
Rubble			4649	58440
Coarse gravel		29695	12238	
Fine gravel	38376	581		
Sand	5329	3933	3465	
Silt	2484	7725	3201	900
Total in all types	46189	41934	23553	59340
Volume in cc. per acre	44584	31529	13912	41496

Non-trout fish species

The importance of non-trout species in influencing brook and brown trout populations in the Pigeon River is believed to be minor. Populations of these species were never high where large numbers of trout were present. A large standing crop of fish is also dependent on a large trout population. The pounds per acre of all fish species in each study area in July, 1951, was as follows: study area I, 55.72; study area II, 39.91; study area III, 22.26; and study area IV, 11.13. The production of trout in study areas I and II was greater than non-trout whereas the opposite was true in study areas III and IV (Table 16).

The weight relationship in trout streams of trout to other species varies greatly in the literature. In summarizing published accounts of stream populations the following facts seem evident: (1) brook trout do not occur in large numbers with large populations of other fish, except for the slimy muddler; (2) brown and rainbow trout populations are found more frequently with larger populations of other fish species than are brook trout; (3) white suckers are the only large non-trout species commonly present in trout streams; and (4) warm-water streams are more productive of fish than cold-water streams. Hoover (1938) found in fished streams in New Hampshire that the highest trout populations were present with the highest non-trout populations; total fish standing crops varied from 1.3 to 97.47 pounds per acre with a mean of 27.8. In primitive brook trout streams at high altitudes the weight of trout far exceeded the other species (principally slimy muddlers) and the mean standing crop was 71.4 pounds per acre. Moore et al., (1934) working in Trammel Creek in New York recorded 62.7 pounds per acre of brook trout and 34.8 pounds per acre of other species. Smith et al. (1949) judged that trout dominated stream populations in Minnesota only when the total fish production was lowest (approximately 50 pounds per acre). Shetter and Hazzard (1939) found among several trout streams in Michigan that the highest standing crop of fish was in the South Branch of the Pine River where there was a much higher non-trout population. Shetter and Leonard (1943) determined the production in Hunt Creek to be 94.40 pounds per acre of brook trout and 9.68 pounds per acre of slimy muddlers. Gerking (1949) analysed a fish population in a warm-water stream in Indiana and, after reviewing the literature, concluded that such streams have a higher mean production (46 to 939 pounds per acre) than most trout streams.

TABLE 16

COMPARISON OF STANDING CROPS OF FISH IN POUNDS PER ACRE AMONG THE STUDY AREAS IN THE PIGEON RIVER, MICHIGAN, IN JULY, 1951. DATA FROM APP. C, TABLE 5 INCLUDES ONLY THOSE SPECIES THAT OCCURRED IN LARGE ENOUGH NUMBERS TO OBTAIN A POPULATION ESTIMATE WITH THE ELECTRIC SHOCKER

Fish species	Standing crop in pounds per acre			
	Study area I	Study area II	Study area III	Study area IV
Brook trout	45.77	21.83	1.57	0.15
Brown trout		7.40		
White sucker	3.60		4.53	
Longnosed dace				1.28
Blacknosed dace		3.39	4.94	3.31
Creek chub		7.29	8.85	3.79
Blacksided darter				1.63
Slimy muddler	6.35			
Common muddler			2.37	
Total trout	45.77	29.23	1.57	0.15
Total non-trout	9.95	10.68	20.69	10.01
Total fish	55.72	39.91	22.26	10.16

The data on the Pigeon River suggests that the resident population of trout and non-trout species denotes directly the percentage of trout habitat in a stream. The reason for this trout and non-trout habitat relationship is believed to be due to the fact that trout are very specific in their selection of spawning locations and most other species will not tolerate this type of habitat in numbers. A high weight percentage of trout reflects good trout habitat (e.g., study area I) and a high percentage of other fish species (e.g., study areas III and IV) indicates poor trout habitat. No large amount of trout spawning was ever observed in a section of stream with a high non-trout population. Most other species (e.g., blacknosed dace, creek chubs, and white suckers) also select quieter portions of the stream than do trout. No large populations of trout were ever found with large populations of other species and the latter do not appear to influence trout populations to any recognizable extent in the Pigeon River.

The use of relative abundance of non-trout species as an index of trout habitat is hazardous because of the broad ecological tolerance of most of them. The slimy muddler, however, is at least partly indicative of brook trout habitat (Greeley, 1932; Hoover, 1938; Shetter, 1949). A large population of this muddler, however, is not a sign of better trout water than a small population (Hoover and Morrill, undated).

Aquatic plants

Aquatic plants probably influence growth and survival rate but their presence is not believed to influence the density of populations significantly in this stream. Luxuriant growths of *Potamogeton pectinatus* and *Veronica connata* were found in sections of the Pigeon River both with high and very low populations. Frost (1945) noted a rapid growth of brown trout in a locality with a heavy moss fauna. Needham (1928) found greater bottom fauna production among plant beds. The total value of aquatic plants in the economy of this stream is not believed great.

Bottom soil nutrients

The bottom soils showed low readings in all nutrients except calcium (App. A, Table 4), the presence of which was also partially indicated by the high alkalinity of the water. The value of certain stream soil nutrients and their relationship to stream food production cannot be evaluated from the present data. Huntsman (1948) fertilized a small section of a stream in New Brunswick and concluded that the fertility of a stream is almost entirely derived from bottom materials. More work is necessary in this field before results will be meaningful. In this investigation there was little correlation between density of trout populations and discoverable differences in bottom soil fertility.

APPLICATIONS OF THIS INVESTIGATION TO THE MANAGEMENT OF TROUT STREAMS

The management of trout streams is commonly limited to the following methods: (1) regulation (e.g., limitation of size of fish, creel, season, and type of gear); (2) planting or stocking; (3) environmental improvement; and (4) public education. The basis for management under these headings is usually established by trout stream surveys to determine facts concerning the stream conditions and trout populations.

The principal contribution of my work was to demonstrate the paramount importance of ground water in the maintenance and localization of trout populations in the Pigeon River. Ground water was found to control spawning, population growth, and local density for both brook and brown trout. The present study also emphasizes the need for detailed investigational work as a foundation for management and provides new methods for use in stream and population appraisal, environmental improvement, and stocking.

Environmental Improvement

In Michigan, two types of trout stream improvement are being pursued currently. The first kind consists of constructing various types of midstream cover such as deflectors, rafts, and deep pools and was underway in the 1930's (Hubbs et al., 1932). Work of this type may possibly have an influence on the survival rate (e.g., Shetter et al., 1949) or growth rate of trout but it cannot affect natural trout populations unless spawning facilities are first available. The second type of environmental improvement is concerned with the management of the watershed and is a recent development. One of its aims is to divert rainfall into the ground where it may enter the stream as ground water rather than as surface runoff or via tributaries (Tody and Clark, 1951). Another is to stabilize stream flow by the construction of dams and small storage reservoirs. Any program which may increase ground water flow and minimize stream fluctuations would be of more value to trout populations in many sections of the Pigeon River than stream channel devices because it might make a larger portion of the stream bed available for spawning. Stream channel improvement may well have its place too, but further evidence is needed. In many parts of this stream the amount of ground water appears to be the only condition that is acting as a limiting factor on trout production. Adequate food, cover, and bottom type, were all present but trout populations were still very sparse.

Stocking

It is possible that if a section of stream has all the necessary requirements for trout populations except ground water for spawning, the stocking of fingerling trout would be a simple and economical method to correct this deficiency. However, as mentioned earlier in this paper, there was evidence, though limited, to support the possibility that such water also influences the survival rate of trout for the first year of life. This condition could be due to the fact that an area which lacks ground water will reach lower temperatures in winter and higher temperatures in summer than a section of stream with much ground water seepage. These extreme conditions may mean that such a portion of stream is unsuitable for young trout even though other ecological conditions such as food and cover are favorable. It is evident that planting experiments could be carried out where spawning facilities are lacking to test the feasibility of reverting to this management method. On the basis of preliminary experiments, Westerman and Hazzard (1945) concluded that in the great majority of Michigan streams, otherwise suitable for trout, enough or more than enough young are produced to fully seed the waters with all the fish which they can feed and house. Needham and Slater (1944) found in Convict Creek, California, that fingerling brown and rainbow trout survived very poorly when numerous wild trout were present. The latter workers suggested the stocking of trout fingerlings in waters barren of trout or lacking natural reproduction, providing that ecological conditions were adequate.

The planting of legal-sized trout has been employed as a management technique in parts of the Pigeon River which are deficient in spawning facilities. Such plantings are made on a strictly "put-and-take" basis and very few fish survive to the next angling season. This type of management generally produces trout which are often considered to be poor in both sporting qualities and palatability. Fingerling planted trout, however, are difficult to distinguish from wild fish by the time they reach legal size and escape this criticism. If we aim to retain the sporting values for which trout angling is famous, we may be obliged to depend principally on either wild trout or fingerling plantings.

Trout Stream Surveys

Trout stream surveys of varying degrees of thoroughness are instituted to determine the possible management techniques that can be used in a particular water course. Providing that trout have had an opportunity to inhabit a particular stream either naturally or by artificial introduction, the resident fish population is probably the best indicator of the suitability of any habitat for a particular species. In Michigan, Westerman (1926) states that all stream systems have been planted with brook trout at one time or another. Brown and rainbow trouts have also been planted at various times in most waters. In this state, therefore, it may be assumed that the existing salmonoid populations will represent the amount and condition of the trout habitat. Trout stream surveys should be planned with this fact in mind. The number of young-of-the-year trout will be a good indicator of spawning success for trout. A study of the growth rate will indicate the adequacy of food and possibly the degree of exploitation by angling (Frost, 1945; Cooper, In press, a). Annual survival rates can also be calculated generally from population estimates and the ages of the various size groups.

Ground water was found to be the main determinant of the size of trout populations in sections of the Pigeon River. Certain methods for the location of ground water are suggested. In summer, a seepage run of the stream is the most desirable method when water levels are not high. The use of summer water temperatures has limitations which were described earlier. Most stream surveys are conducted in summer when weather conditions are most suitable; winter conditions are neglected. The use of aerial photographs to determine the amount of surface ice cover was found to be a practicable and accurate method for the determination of locales of ground seepage in the Pigeon River and the areas of concentrated trout populations. A large section of a stream can be photographed in a short period of time and the location of ground water quickly assayed prior to actual field study.

In surveys, the drainage pattern of a stream system should be studied to determine whether the watershed is well drained on the surface or whether rainfall contributes to the stream flow as ground water. Any records of the U. S. Geological Survey or other similar agency on ground water levels and stream fluctuations can be extremely valuable. In repetition, although all types of data can be collected, the aim of a survey should be to determine the ecological factors which are actually limiting the production of trout for the angler. Only after these ecological conditions are determined can management be intelligently applied to correct these deficiencies.

SUMMARY AND CONCLUSIONS

The purpose of this investigation was to ascertain the ecological determinants of density of trout populations in the Pigeon River, Otsego and Cheboygan counties, Michigan.

Four study areas of the Pigeon River, each 400 yards in length, were selected for their varied concentrations of trout. Brook and brown trouts were studied. Rainbow trout, although present in the stream, were too sparse to be considered.

Chemical, physical, and biological data were collected in all months of the year during the period from June, 1950, to June, 1952.

Chemical factors studied were: phenolphthalein alkalinity, methyl orange alkalinity, dissolved oxygen, hydrogen ion concentration, phosphorus, and specific conductance. Accepted methods were used.

Morphometry (width, depth, gradient, pool-riffle ratio) of each study area was determined.

Composition of the stream bottom soils by particle size was determined with standardized sieves. A new method for classification of bottom types was suggested. Each study area was mapped as to bottom type.

Water temperatures in the summer were recorded by a Taylor maximum-minimum thermometer. Winter water temperatures were taken periodically. Temperatures in the stream bottom soils were measured with a Fembero resistance thermometer. Winter ice cover was also found to reflect water temperatures rather accurately, and each study area was, therefore, mapped periodically for ice cover. Aerial photographs were also taken of winter ice cover.

Ground water seepage was measured by determining its contribution to volume of stream flow with a Price current meter. Water temperatures in the stream (both summer and winter) and in the stream bottom soils (two to three inches below the stream bed) were also used to indicate ground water seepage.

Volume of flow at two points on the Pigeon River was determined by U. S. Geological Survey gauging stations.

Bank cover and midstream cover were defined and estimated in each study area.

Population estimates of trout species and non-trout species were made with a D. C. electrical shocker by the mark-and-recapture method. A modification of this latter method was used in sparse populations of trout.

The amount of trout spawning was determined by a count of the number of redds in each study area. The importance of stream bottom type, current velocity, and ground water seepage on the location of redds was noted.

Winter standing crops of macroscopic bottom organisms were estimated for each bottom type in each study area. An estimate of the total standing crop for each study area was computed by multiplying the mean standing crop of each bottom type by the area of that bottom type and adding the products.

Higher aquatic plants were mapped according to abundance and species.

The actual population of wild brook and brown trout was used as the sole index of the importance of each factor on the abundance of trout. No attempt was made to learn the effect of the various ecological factors on growth rates or survival rates.

Dissolved oxygen (8.0 to 13.5 p.p.m.), methyl orange alkalinity (126 to 215 p.p.m.), phenolphthalein alkalinity (none recorded), hydrogen ion concentration (7.4 to 8.8), or phosphorus (0.000 to 0.023 p.p.m.) did not vary significantly among the study areas. Mean depth (9.8 to 19.5 inches), mean width (37.6 to 61.0 feet), or percentage gradient (0.057 to 0.335 percent) did not vary in any definite relationship to trout populations. Pool-riffle ratio (S2, T2, F2, to S3, T3, F3) was most desirable with the greatest numbers of trout; however, it was not believed to be the basic reason for the larger trout populations.

Maximum water temperatures from March 14, to November 3, 1951, in the respective study areas were: I, 67° F.; II, 76° F.; III, 78° F.; and IV, 78° F. Percentage of surface ice cover was used to indicate winter water temperatures and was greater in study areas III and IV (maximum 100 percent) than in I (maximum, 20 percent) or in II (maximum of 75 percent). The maximum ground water seepages found in the respective study areas were: I, 23.5 percent; II, 23.2 percent; III, 6.4 percent; and IV, 1.7 percent.

Bank cover (20 to 95 percent) and midstream cover (4 to 30 percent) were greatest with the larger numbers of trout. Amount of cover was believed to influence survival rates but its exact relationship to population density was not determined.

The principal bottom types in each study area were: I, fine gravel; II, coarse gravel; III, sand and coarse gravel; and IV, rubble.

Estimated populations of trout in July, 1951 for each study area were: I, 1440; II, 737; III, 89; and IV, 1. These estimates included young-of-the-year trout and indicated the variances in amount of spawning among the study areas. Other population estimates at other periods of the year showed the same relative figures.

The mean numbers of redds in the respective study areas were: I, 36; II, 5; III, 0; and IV, 0. Ecological studies of spawning areas indicated that lack of ground water was the only factor that prevented spawning in most parts of the Pigeon River. Bottom soil type, current velocity, and depth were satisfactory for spawning in sections of all study areas.

Estimated winter standing crops of macroscopic bottom organisms in the respective study areas were: I, 49,189 cc.; II, 41,934 cc.; III, 23,553 cc.; and IV, 59,340 cc. Trichoptera, Ephemeroptera, and Diptera were the principal organisms found. A trichopterous larva, Brachycentrus lateralis, was the only organism which occurred in greatest numbers with a high population of brook trout. Type of bottom and amount of molar action were believed to be the main factors in bottom fauna production.

Large populations of non-trout species were never found with high trout populations. Standing crops in pounds per acre of non-salmonoid fishes in the respective study areas were: I, 9.95; II, 10.68; III, 20.65; and IV, 10.01. Common species present with low trout populations were: creek chubs (Semotilus a. atromaculatus), blacknosed dace (Rhinichthys atratulus meleagris), and white suckers (Catostomus c. commersoni). Slimy muddlers, (Cottus cognatus gracilis) were most abundant with large numbers of brook trout.

Aquatic plants were most abundant in study area I. They were relatively sparse, however, in the Pigeon River and did not appear to influence trout production significantly.

Lack of ground water seepage was found to be the only factor limiting trout populations. Trout required some ground water for spawning in the Pigeon River. Since apparently there was no significant migration from the spawning areas by either brook or brown trout, the amount of spawning controlled the numbers of all ages and size groups.

From a trout management standpoint, the following were discussed: (1) watershed management, which aims to increase ground water flow and minimize fluctuations of stream flow, was suggested as a method of habitat improvement for trout streams; (2) planting of fingerling trout to offset the lack of natural reproduction was suggested as a research project worthy of further study or consideration in certain parts of the Pigeon River; and (3) determinations of ground water seepage were indicated as essential features for inclusion in trout stream surveys.

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APPENDIX A

CHEMICAL DATA ON PIGEON RIVER, MICHIGAN

TABLE 1

DISSOLVED OXYGEN (O_2), METHYL ORANGE ALKALINITY (CO_3), AND HYDROGEN ION CONCENTRATION (pH) IN EACH STUDY AREA FROM OCTOBER, 1950 TO OCTOBER, 1951; DATA TAKEN IN MIDDLE OF EACH MONTH. NO DISSOLVED CARBON DIOXIDE OR PHENOLPHTHALEIN ALKALINITY WERE RECORDED AT ANY TIME. OXYGEN AND METHYL ORANGE ALKALINITY EXPRESSED IN PARTS PER MILLION.

Month and year	Study area											
	I			II			III			IV		
	O_2	CO_3	pH	O_2	CO_3	pH	O_2	CO_3	pH	O_2	CO_3	pH
10/50	8.0	126	8.8	8.7	199	8.8	12.3	187	8.8	9.4	126	8.0
11/50	9.7	144	8.0	8.7	199	8.8	10.6	199	8.8	12.0	135	8.0
1/51	12.5	190	7.9	12.7	215	8.0	13.0	194	8.0	12.8	179	8.0
2/51	13.5	186	8.0	12.6	192	7.8	12.8	192	7.7	11.7	191	7.4
3/51	13.0	195	8.0	12.8	178	8.0	12.8	187	8.0	13.7	178	8.0
4/51	12.0	165	8.0	11.8	160	8.0	12.2	165	8.0	11.2	150	8.0
5/51	10.8	197	8.0	9.5	192	8.0	9.0	178	8.0	10.5	193	8.0
6/51	9.6	185	8.1	9.6	191	8.0	9.5	190	8.0	9.5	190	8.0
7/51	8.7	203	8.1	9.0	201	8.2	9.1	191	8.2	8.7	190	8.2
8/51	9.1	195	8.1	9.8	199	8.1	9.1	200	8.1	9.1	195	8.1
9/51	10.4	203	8.1	10.2	175	8.0	9.7	193	8.1	10.6	191	8.1
10/51	10.2	169	8.4	10.6	182	7.9	11.5	189	8.0	11.0	168	8.0

TABLE 2

SPECIFIC CONDUCTANCE OF STREAM WATER IN RECIPROCAL MEGOHMS IN PIGEON RIVER, MICHIGAN

Date	Study area I	Study area II	Study area III	Study area IV
2/27/52	...	...	...	185
2/29/52	...	208	208	...
3/ 6/52	192	208	200	...
3/18/52	200	208	213	189

TABLE 9

INORGANIC DISSOLVED PHOSPHORUS AND TOTAL PHOSPHORUS IN THE STUDY AREAS OF THE PIGEON RIVER, MICHIGAN.
DATA IN PARTS PER MILLION
A = INORGANIC DISSOLVED PHOSPHORUS B = TOTAL PHOSPHORUS

Date	Study area I		Study area II		Study area III		Study area IV	
	A	B	A	B	A	B	A	B
8/23/51	0.005	0.006	0.006	0.017	0.006	0.006	0.020	0.023
3/28/52	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010

TABLE 4

CHEMICAL ANALYSES OF STREAM BOTTOM SOILS COLLECTED ON MARCH 28, 1952 IN EACH STUDY AREA AND EXPRESSED IN PARTS PER MILLION OF DRY SOIL. ANALYSES CONDUCTED BY DEPARTMENT OF SOIL SCIENCE, MICHIGAN STATE COLLEGE; SOIL TEST USED WAS SPURWAY ACTIVE (SPURWAY AND LAWTON, 1949)

Nutrients	Study area I	Study area II	Study area III	Study area IV
Phosphorus	1.0	1.5	1.0	0
Potassium	26	15	83	8
Nitrate	0	0	8	0
Ammonia	4	4	4	4
Calcium	600	800+	800+	600
Magnesium	24	16	16	16
Chlorine	Trace	Trace	Trace	Trace
Sulfates	Trace	Trace	Trace	Trace
Iron	Trace	Trace	Trace	Trace

APPENDIX B

PHYSICAL DATA ON PIGEON RIVER, MICHIGAN

TABLE 1

MAXIMUM AND MINIMUM TEMPERATURES (°F.) IN EACH STUDY AREA IN 1951 OF THE PIGEON RIVER, MICHIGAN; DATA COLLECTED WITH TAYLOR MAXIMUM-MINIMUM THERMOMETER

Study area I			Study area II			Study area III			Study area IV		
Date	Max.	Min.	Date	Max.	Min.	Date	Max.	Min.	Date	Max.	Min.
Mar. 31-Apr. 16	44	34	Mar. 14-Apr. 1	42	32	Mar. 16-Apr. 19	47	34	Mar. 23-Mar. 30	40	32
Apr. 16-May 2	58	34	Apr. 1-Apr. 17	45	35	Apr. 19-May 2	64	36	Mar. 30-Apr. 25	46	34
May 2-May 12	58	42	Apr. 17-May 2	60	34	May 2-May 25	71	50	Apr. 25-May 4	62	38
May 12-May 25	62	42	May 2-May 14	62	46	May 25-June 1	70	53	May 4-May 11	60	48
May 25-May 31	64	50	May 14-May 25	66	52	June 1-June 8	70	52	May 11-May 26	68	52
May 31-June 9	61	46	May 25-June 1	67	53	June 8-June 14	68	58	May 26-June 1	66	56
June 9-June 15	62	46	June 1-June 8	66	52	June 14-June 22	77	54	June 1-June 8	68	52
June 15-June 22	65	51	June 8-June 14	68	55	June 22-July 2	74	56	June 9-June 14	68	56
June 22-July 2	64	52	June 14-June 22	74	58	July 2-July 6	74	54	June 14-June 22	71	60
July 2-July 6	62	51	June 22-July 2	70	58	July 6-July 14	78	56	June 22-July 2	71	59
July 6-July 14	65	50	July 2-July 6	68	54	July 14-July 20	78	55	July 2-July 6	69	56
July 14-July 20	66	51	July 6-July 14	72	60	July 20-July 27	78	57	July 6-July 14	71	60
July 20-July 27	67	54	July 14-July 20	75	64	July 27-Aug. 3	76	59	July 14-July 20	74	58
July 27-Aug. 4	67	50	July 20-July 27	76	60	Aug. 3-Aug. 11	71	54	July 20-July 27	78	71
Aug. 4-Aug. 11	58	50	July 27-Aug. 3	75	62	Aug. 11-Aug. 17	71	54	July 27-Aug. 3	75	63
Aug. 11-Aug. 17	64	50	Aug. 3-Aug. 11	69	57	Aug. 17-Aug. 25	70	52	Aug. 3-Aug. 11	70	58
Aug. 17-Aug. 25	61	48	Aug. 11-Aug. 19	70	57	Aug. 25-Aug. 31	73	56	Aug. 11-Aug. 17	70	58
Aug. 25-Aug. 31	64	54	Aug. 19-Aug. 25	68	54	Aug. 31-Sept. 7	68	51	Aug. 17-Aug. 25	68	56
Aug. 31-Sept. 7	60	48	Aug. 25-Aug. 31	70	59	Sept. 7-Sept. 15	70	49	Aug. 25-Aug. 31	72	61
Sept. 7-Sept. 15	66	46	Aug. 31-Sept. 7	65	55	Sept. 15-Sept. 21	65	58	Aug. 31-Sept. 7	61	54
Sept. 15-Sept. 21	61	45	Sept. 7-Sept. 15	68	53	Sept. 21-Sept. 29	64	42	Sept. 7-Sept. 15	69	52
Sept. 21-Sept. 29	61	42	Sept. 15-Sept. 21	64	50	Sept. 29-Oct. 6	60	44	Sept. 15-Sept. 21	64	50
Sept. 29-Oct. 6	56	43	Sept. 21-Sept. 29	64	44	Oct. 6-Oct. 12	53	47	Sept. 21-Sept. 29	64	44
Oct. 6-Oct. 12	51	40	Sept. 29-Oct. 6	60	45	Oct. 12-Oct. 19	58	44	Sept. 29-Oct. 6	60	43
Oct. 12-Oct. 19	54	42	Oct. 6-Oct. 12	53	43	Oct. 19-Oct. 26	53	43	Oct. 6-Oct. 12	53	43
Oct. 19-Oct. 26	53	42	Oct. 12-Oct. 19	56	45	Oct. 26-Nov. 2	50	37	Oct. 12-Oct. 19	57	45
Oct. 26-Nov. 3	50	43	Oct. 19-Oct. 26	53	43				Oct. 19-Oct. 26	52	43
			Oct. 26-Nov. 3	49	33				Oct. 26-Nov. 2	49	37

TABLE 2

RECORDS OF WINTER WATER TEMPERATURES (°F.) IN EACH STUDY AREA OF PIGEON RIVER, MICHIGAN; DATA COLLECTED WITH NEGRETTI-ZAMBRA REVERSING THERMOMETER

Study area I		Study area II		Study area III		Study area IV	
Date	Temperature	Date	Temperature	Date	Temperature	Date	Temperature
11/ 6/50	42.0	11/11/50	51.0	11/11/50	50.0	11/ 7/50	41.0
1/11/51	34.1	1/18/51	35.0	1/15/51	33.1	1/ 8/51	32.0
1/19/51	35.0	1/25/51	32.5	1/28/51	32.1	1/20/51	32.0
2/ 6/51	34.2	2/ 2/51	32.5	2/16/51	32.9	1/24/51	32.0
2/16/51	32.7	2/14/51	32.5	12/ 2/51	36.0	2/ 2/51	34.2
3/19/51	38.0	3/14/51	38.0	12/19/51	32.2	2/13/51	32.7
12/19/51	38.0	12/ 2/51	36.0	1/ 5/52	36.0		
1/5 /52	33.5	12/19/51	32.1	1/28/52	32.1	12/19/51	32.1
1/ 7/52	32.9	1/ 7/52	32.8	2/18/52	32.2	12/26/51	32.0
1/28/52	32.2	1/28/52	32.1	2/29/52	33.0	1/16/52	35.0
2/ 9/52	33.0	2/20/52	33.2	3/18/52	39.2	2/18/52	32.0
2/20/52	34.6	3/18/52	38.0			3/18/52	33.8
3/19/52	37.4						

TABLE 3

FIELD OBSERVATIONS OF PERCENTAGE OF ICE COVER IN STUDY AREAS DURING WINTERS OF 1950-51 AND 1951-52

Date		Study area I	Study area II	Study area III	Study area IV
1950					
Dec.	10	0	0	...	...
	15	0	0	...	...
	20	...	0	...	...
1951					
Jan.	8	...	...	...	100
	9	...	...	95	...
	10	...	...	...	100
	11	0	...	...	...
	14	...	...	50	...
	19	0	0	...	...
	25	...	...	...	95
	29	...	50	...	...
Feb.	1	...	...	...	100
	2	...	75	...	...
	8	5	...	...	...
	13	3	...	100	100
	14	...	80	...	...
Mar.	1	0	...	...	...
	14	0	...	...	...
	15	...	...	...	10
	16	...	0	10	...
	17	0	...	...	...
	30	...	...	0	0
Dec.	2	0	0	0	0
	19	0	40	100	60
	24	0	40	100	80
Jan.	4	...	...	...	75
	5	0	0	0	...
	7	0	0	...	...
	8	...	...	...	75
	16	0	0	0	75
	28	20	50	100	100
Feb.	9	0	0	0	85
	17	...	0	...	...
	18	...	...	90	...
	19	...	...	...	90
	20	0	0	...	...
	26	...	...	...	90
	28	...	0	...	...
	29	0	...	0	...
Mar.	5	...	0	0	...
	6	0	...	...	75

TABLE 4

DETAILS OF DETERMINATIONS OF GROUND WATER SEEPAGE ENTERING SECTIONS OF THE PIGEON RIVER, MICHIGAN; EACH SECTION OF STREAM STUDIED ENCLOSES A STUDY AREA; DISCHARGE DETERMINATIONS WERE MADE WITH PRICE CURRENT METER

Date	Study area enclosed	Length of section of stream in yards	Discharge entering section in cfs.*	Discharge leaving section in cfs.	Surface water entering from tributaries in cfs.	Net increase in cfs.	Percent increase per mile
12/14/51	I	700	47.22	51.64	0.0	4.40	23.5
2/16/52	I	700	44.02	47.33	0.0	3.31	18.9
10/16/51	II	2000	68.90	76.16	2.00	7.26	6.7
2/17/52	II	1400	63.16	76.88	2.00	11.72	23.2
10/16/51	III	1760	78.69	79.87	1.0	1.18	1.5
12/14/52	III	1100	76.43	79.50	0.07	3.07	6.4
10/17/51	IV	5280	119.90	127.90	7.1	0.90	0.3
2/19/52	IV	5280	133.90	111.03	17.08	5.79	1.7

*cfs. = cubic feet per second.

TABLE 5

COMPOSITION OF BOTTOM TYPE SAMPLES IN THE PIGEON RIVER, MICHIGAN, TO SHOW VARIATION OF PARTICLE SIZE.
M = MEAN OF SEVERAL PERCENTAGE VOLUMES; S = STANDARD DEVIATION OF THE MEAN.*
NUMBER OF SAMPLES IN PARENTHESES

Mesh size in inches	Rubble (13)		Coarse gravel (10)		Fine gravel (10)		Sand (7)		Silt (10)	
	M	S	M	S	M	S	M	S	M	S
4	14.6									
3	34.5	21.0	2.6							
2	24.2	13.6	17.2	18.5						
1.050	15.9	8.5	36.5	13.0	2.1					
.742	3.3	2.0	12.0	5.6	5.9	4.2				
.525	1.9	1.5	6.3	5.2	10.6	5.3	0.7		1.3	
.263	2.1	1.6	8.7	4.2	21.5	6.3	5.5		4.9	4.0
.131	1.5	2.7	7.2	5.2	19.8	7.5	3.0	3.1	11.7	13.0
.0164	1.7	1.9	6.0	3.3	25.7	6.7	45.0	9.7	25.4	22.4
Less	0.3	0.3	1.5	2.5	14.4	8.7	45.8	13.7	56.7	25.0

*Standard deviation could not be reliably computed in some cases because this fraction did not occur in enough samples.

APPENDIX C

BIOLOGICAL DATA ON PIGEON RIVER, MICHIGAN

TABLE 1

COMMON AND TECHNICAL NAMES OF FISHES ENCOUNTERED IN THIS INVESTIGATION. COMMON NAMES CONFORM INSOFAR AS POSSIBLE TO SPECIAL PUBLICATION NO. 1 OF THE AMERICAN FISHERIES SOCIETY

PETROMYZONIDAE
- Entosphenus lamottei (LeSueur) - American brook lamprey

SALMONIDAE
- Salvelinus f. fontinalis (Mitchill) - Eastern brook trout
- Salmo trutta fario Linnaeus - Brown trout
- Salmo gairdneri irideus Gibbons - Rainbow trout

CATOSTOMIDAE
- Catostomus c. commersoni (Lacépède) - White sucker

CYPRINIDAE
- Rhinichthys atratulus meleagris Agassiz - Blacknose dace
- Rhinichthys c. cataractae (Valenciennes) - Longnose dace
- Semotilus a. atromaculatus (Mitchill) - Creek chub
- Hyborhynchus notatus (Rafinesque) - Bluntnosed minnow
- Chrosomus eos Cope - Redbelly dace
- Notropis cornutus frontalis (Agassiz) - Common shiner

UMBRIDAE
- Umbra limi (Kirkland) - Eastern mudminnow

CYPRINODONTIDAE
- Fundulus diaphanus menona Jordan and Copeland - Banded killifish

PERCIDAE
- Hadropterus maculatus (Girard) - Blacksided darter
- Percina caprodes semifasciata (DeKay) - Logperch
- Etheostoma n. nigrum Rafinesque - Johnny darter
- Poecilichthys exilis (Girard) - Iowa darter

CENTRARCHIDAE
- Lepomis m. machrochirus Rafinesque - Bluegill
- Lepomis gibbosus (Linnaeus) - Pumpkinseed
- Ambloplites rupestris (Rafinesque) - Rock bass

COTTIDAE
- Cottus cognatus gracilis Heckel - Slimy muddler
- Cottus b. bairdi Girard - Common muddler

GASTEROSTEIDAE
- Eucalia inconstans (Kirtland) - Brook stickleback

TABLE 2

NUMBER OF TROUT COLLECTED ON ONE DIRECT CURRENT ELECTRIC SHOCKER TRIP IN EACH STUDY AREA: OCTOBER, 1950; NOVEMBER, 1950; AND NOVEMBER, 1951

Species, and size group in inches	Study area											
	I			II			III			IV		
	Oct. 16 1950	Nov. 6 1950	Nov. 12 1951	Oct. 15 1950	Nov. 20 1950	Nov. 12 1951	Oct. 15 1950	Nov. 20 1950	Nov. 2 1951	Oct. 19 1950	Nov. 7 1950	Nov. 12 1951
Brook												
2.0 to 3.9	19	24	62	1	3	28	1	1	3	0	0	0
4.0 to 6.9	41	30	75	5	7	39	5	7	26	0	0	0
7.0 to 10.9	15	10	12	1	0	7	1	0	4	0	0	0
Total, brook	75	64	149	7	10	74	7	8	33	0	0	0
Brown												
2.0 to 3.9	0	0	0	3	2	3	1	1	0	0	0	0
4.0 to 6.9	0	0	0	3	4	1	0	0	4	0	0	6
7.0 to 10.9	0	0	0	4	2	15	1	1	0	1	1	1
Total, brown	0	0	0	10	8	19	2	2	4	1	1	7
Rainbow												
2.0 to 3.9	0	0	0	2	4	1	0	0	0	0	0	0
4.0 to 6.9	0	0	0	0	0	0	0	0	0	0	0	0
7.0 to 10.9	0	0	0	0	0	3	1	0	0	0	0	0
Total, rainbow	0	0	0	2	4	4	1	0	0	0	0	0
Total all species	75	64	149	19	22	97	10	10	37	1	1	7

TABLE 3

FIELD DATA ON NUMBERS OF FISHES OTHER THAN TROUT COLLECTED IN EACH STUDY AREA, PIGEON RIVER, MICHIGAN

Fish species	Study area I							Study area II							
	1950		1951					1950		1951					
	Oct. 16	Nov. 6	Feb. 6	Apr. 16	May 15	July 13	Nov. 12	Oct. 15	Nov. 20	Apr. 17	May 15	June 15	July 11	Nov. 12
White sucker	..	..	..	..	4	..	..	5	2	2	..	..	5	15
Blacknosed dace	..	..	..	1	2	..	..	2	3	10	27	10	..	46
Longnosed dace	..	..	..	..	3	..	..	1	..	..	1	1	3	..
Creek chub	..	..	..	..	5	1	1	..	2	5	13	7	..	49
Bluntnosed minnow	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Redbelly dace	..	..	..	..	2	..	..	..	..	..	..	..	..	..
Common shiner	..	..	..	..	..	..	..	..	1	..	..	3	..	..
Banded killifish	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Blacksided darter	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Logperch	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Johnny darter	..	..	..	..	..	..	..	9	8	6	..	..	13	4
Iowa darter	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Pumpkinseed	..	..	..	..	..	..	..	..	..	..	..	..	1	..
Rock bass	..	..	..	..	..	..	..	..	1	..	..	..	..	..
Bluegill	..	..	..	..	..	..	..	..	..	..	..	..	1	..
Slimy muddler	15	19	5	26	7	26	26	..	..	..	..	..	..	..
Common muddler	..	..	..	..	..	..	..	3	..	2	..	..	3	2
Brook stickleback	..	..	..	..	..	..	..	1	..	1	..	..	..	..
Mud minnow	..	..	..	..	..	..	..	..	..	..	..	..	..	..

(Continued on next page)

TABLE 3 (Continued)

FIELD DATA ON NUMBERS OF FISHES OTHER THAN TROUT COLLECTED IN EACH STUDY AREA, PIGEON RIVER, MICHIGAN

Fish species	Study area III							Study area IV						
	1950		1951					1950		1951				
	Oct. 15	Nov. 20	Apr. 18	May 14	June 12	July 12	Nov. 12	Oct. 19	Nov. 7	Apr. 27	May 14	June 12	July 12	Nov. 2
White sucker	12	5	4	3	7	..	14	2	3	2	5	1	6	2
Blacknosed dace	28	3	15	20	24	..	64	21	..	2	10	15	..	121
Longnosed dace	..	..	..	3	1	4	..	..	..	..	5	10	17	1
Creek chub	20	..	10	17	15	..	63	..	..	..	..	..	..	6
Bluntnosed minnow	..	..	..	..	..	..	..	..	1	..	..	..	..	..
Redbelly dace	..	..	..	..	..	..	..	..	..	..	..	..	..	1
Common shiner	5	..	1	4	6	9	90	..	1	..	..	..	2	..
Banded killifish	..	..	..	..	..	..	..	..	1	..	..	..	..	..
Blacksided darter	..	..	..	..	..	..	..	2	4	5	..	7	..	6
Logperch	..	..	..	..	1	..	..	1	..	..	..	..	2	1
Johnny darter	20	1	1	2	..	10	10	1	1	2	..	1	2	1
Iowa darter	..	..	..	1	..	..	..	..	..	..	..	..	..	..
Pumpkinseed	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Rock bass	..	..	..	..	..	..	..	..	..	..	..	..	2	..
Bluegill	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Slimy muddler	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Common muddler	10	10	2	..	..	..	14	..	..	..	..	2	..	..
Brook stickleback	..	..	..	..	..	1	1	..	..	..	..	..	..	..
Mud minnow	..	..	..	..	..	1	..	..	..	..	..	..	..	..

TABLE 4

POPULATION ESTIMATES OF NON-TROUT SPECIES ON JULY, 1951 IN EACH STUDY AREA OF PIGEON RIVER, MICHIGAN

Study area, date, and data of population estimates	Fish species						
	White sucker	Blacknosed dace	Creek chub	Blacksided darter	Slimy muddler	Common muddler	Longnosed dace
Study area I							
July 13, 1951							
Number on first run	17	..	..	..	46	..	..
Number on second run	15	..	..	..	36	..	..
Percent recovery	11.7	..	..	..	4.3	..	..
Population estimate	127	..	..	..	823	..	..
Study area II							
July 11, 1951							
Number on first run	..	57	31	..	..	..	..
Number on second run	..	70	48	..	..	..	..
Percent recovery	..	14.0	12.9	..	..	..	..
Population estimate	..	499	372	..	..	..	..
Study area III							
July 12, 1951							
Number on first run	..	105	41	..	..	33	..
Number on second run	..	123	42	..	..	27	..
Percent recovery	..	13.3	7.3	..	..	9.0	..
Population estimate	..	923	574	..	..	297	..
Study area IV							
July 12, 1951							
Number on first run	..	61	26	20	..	..	18
Number on second run	..	77	16	24	..	..	16
Percent recovery	..	14.7	7.7	15.0	..	..	11.1
Population estimate	..	522	208	160	..	..	144

TABLE 5

CALCULATION OF ESTIMATED STANDING CROPS OF FISH SPECIES IN EACH STUDY AREA IN JULY, 1951
N = NUMBER; TW = TOTAL WEIGHT IN GRAMS; SC = STANDING CROP IN POUNDS PER ACRE

Species and size group in inches	Study area											
	I			II			III			IV		
	N	TW	SC	N	TW	SC	N	TW	SC	N	TW	SC
Brook trout												
2.0 to 3.9	880	3,960	8.42	595	2,677	4.44	72	324	.42	..	..	..
4.0 to 6.9	526	14,254	30.33	104	2,818	4.78	11	298	.39	..	..	..
7.0 to 10.9	34	3,312	7.02	78	7,597	12.61	6	584	.76	1	97	.15
Brown trout												
2.0 to 3.9	..	..	..	3	13	.02	..	..	..	..	..	..
4.0 to 6.9	..	..	..	17	468	.77	..	..	..	..	..	..
7.0 to 10.9	..	..	..	40	3,984	6.61	..	..	..	..	..	..
White sucker												
3.0 to 6.0	127	1,689	3.60	..	..	..	261	3,471	4.53	..	..	..
Longnosed dace												
2.0 to 5.0	..	..	..	..	..	..	..	..	..	144	835	1.28
Blacknosed dace												
1.5 to 3.9	..	..	..	499	2,045	3.39	923	3,784	4.94	522	2,141	3.31
Creek chub												
1.5 to 5.4	..	..	..	372	4,389	7.29	574	6,774	8.85	208	2,454	3.79
Blacksided darter												
2.5 to 5.6	..	..	..	..	..	..	..	..	..	160	1,056	1.63
Slimy muddler												
1.5 to 3.5	828	2,981	6.35	..	..	..	..	..	..	..	..	..
Common muddler												
1.5 to 3.5	..	..	..	..	..	..	297	1,812	2.37	..	..	..
Total trout	1,440	21,526	45.77	837	17,557	29.23	89	1,206	1.57	1	97	.15
Total non-trout	955	4,670	9.95	871	6,434	10.68	2,055	15,841	20.69	1,065	7,116	10.01
Total fish	2,395	26,196	55.72	1,708	23,991	39.91	2,144	17,047	22.26	1,066	7,213	10.16

TABLE 6

WEIGHTS OF FISH USED IN COMPUTATION OF STANDING CROPS IN EACH STUDY AREA: TROUT WEIGHTS TAKEN FROM LENGTH-WEIGHT RELATIONSHIP CURVE OF PIGEON RIVER FISH. NON-TROUT WEIGHTS TAKEN FROM A MEAN OF 300 TO 400 SPECIMENS

Fish species and size range in inches	Weight in grams
Brook trout	
2.0 to 3.9	4.5
4.0 to 6.9	27.1
7.0 to 10.9	97.4
Brown trout	
2.0 to 3.9	4.3
4.0 to 6.9	27.5
7.0 to 10.9	99.6
White sucker	
3.0 to 6.0	13.3
Longnosed dace	
2.0 to 5.0	5.8
Blacknosed dace	
1.5 to 3.9	4.1
Creek chub	
1.5 to 5.4	11.8
Blacksided darter	
2.5 to 5.6	6.6
Slimy muddler	
1.5 to 3.5	3.6
Common muddler	
1.5 to 3.5	6.1