EXPERIMENTAL FERTILIZATION OF MICHIGAN TROUT LAKES

Thesis for the Degree of Ph. D.

MICHIGAN STATE COLLEGE

Howard Allen Tanner

1952

This is to certify that the

thesis entitled

Experimental Fertilization of

Michigan Trout Lakes

presented by

Howard A. Tanner

has been accepted towards fulfillment
of the requirements for

Ph. D. degree in Zoology

Robert C. Ball
Major professor

Date May 23, 1952.

O-169

H—057

EXPERIMENTAL FERTILIZATION OF MICHIGAN TROUT LAKES

by

Howard Allen Tanner

AN ABSTRACT

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

DOCTOR OF PHILOSOPHY

Department of Zoology

Year 1952

Approved Robert C Ball

Howard Allen Tanner

ABSTRACT

The data presented are from a program directed towards determining the feasibility of applying fertilizer to unproductive trout lakes and by so doing increase fish production. The program is the latest of several studies in Michigan all of which have been directed towards examining the advantages and disadvantages of fertilizing several types of natural and artificial waters. Six trout lakes lying in the generally unproductive pine plains of the north central portion of Michigan's lower peninsula were selected as the cite for the present study.

Biological sampling and measurement of certain chemical and thermal features of the environment in 1948 established the level of standing crops of several groups of organisms and the characteristics of each of the lakes prior to fertilization. Trash fish were removed by poison and brown trout planted in each of the lakes at the same number per acre. Fertilizer was applied to four of the six lakes at varied rates during the summers of 1949 and 1950. Data collections were continued during the period of fertilization and the effects have been evaluated by comparisons on the basis of before and during fertilization observations and between fertilized and unfertilized lakes.

Analysis of the data using statistical procedures re-

vealed that the position of the thermocline became shallower following fertilization and that the total hardness decreased in the fertilized lakes. Oxygen depletion occurred during summer and winter stagnation periods and was closely correlated with amounts of fertilizer added.

The biological sampling indicated increases in amount of plankton and bottom fauna organisms. Changes in the composition of the bottom fauna and in the depth distribution were observed and the degree of dependence of the trout on the bottom fauna for food was studied.

A complete creel census indicated the yield of trout to anglers and the total net production per acre was calculated from the creel census and a population estimate of the trout present at the end of the program. The trout were killed with a toxicant and estimates of the population were made on the basis of mark and recovery (Ball, ms.).

It was concluded that trout production could be stimulated with small applications of fertilizer. The small amounts of nutrient material used did not result in winterkill conditions. It was also concluded that the eutrophying effect of additional nutrients (Hasler, 1947) makes impracticable the fertilization of trout lakes with the exception of small lakes unproductive of trout because of extreme oligotrophic conditions.

Ball, Robert C.
---- Standing crop of brown trout based on recovery of marked fish following poisonings of six trout lakes. (In preparation.)

Hasler, Arthur D.
1947 Eutrophication of lakes by domestic drainage. Ecol. 28 (4): 383-394.

Frontispiece

Section-Four Lake

EXPERIMENTAL FERTILIZATION
OF MICHIGAN TROUT LAKES

by

Howard Allen Tanner

A THESIS

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

DOCTOR OF PHILOSOPHY

Department of Zoology

1952

ACKNOWLEDGMENTS

The writer wishes to express his gratitude to Dr. Robert C. Ball, Department of Zoology, Michigan State College. His generous cooperation and stimulating interest while directing the study has been a constant source of inspiration.

Appreciation is due The Institute for Fisheries Research of the Michigan Department of Conservation for the doctorate fellowship granted the writer in support of the program. The use of the facilities of the Institute and the cooperation of its staff, the director and staff of the Pigeon River Trout Research Station in particular, have been of great assistance.

Dr. Don W. Hayne, Zoology Department, Michigan State College, has been most helpful with the statistical portions of the paper.

Special thanks is due my wife, Helen, for her assistance throughout the program. Mr. Paul Barrett assisted in portions of the field work.

Howard Allen Tanner

candidate for the degree of

Doctor of Philosophy

Final examination, May 23, 1952, 1:00 P. M., Natural Science Building, Room 404

Dissertation: Experimental Fertilization of Michigan Trout Lakes

Doctorate committee: Chairman - Dr. R. C. Ball, Zoology, M. S. C.
Dr. G. W. Prescott, Botany, M.S.C.
Mr. W. F. Morofsky, Entomology, M. S. C.

Outline of studies

Major subject: Zoology
Minor subjects: Botany, Entomology

Biographical items

Born, Sept. 4, 1923, Kalamazoo, Michigan, English decent

Undergraduate studies, Western Michigan College, 1941-1943
Michigan State College, 1946-1947

Graduate studies, Michigan State College, 1947-1952

Master of Science degree, June, 1950

Major subject: Zoology
Minor subject: Aquatic Entomology

Thesis: The Biological Effects of Fertilizer on a Natural Lake

Experience: Graduate assistant Michigan State College, 1948. Member of U. S. Army 1942-1946. Research fellowship from The Institute for Fisheries Research of the Michigan Conservation Department in support of masters and doctorate research problems

Publication: Ball, Robert C. and Howard A. Tanner
1951 The effects of fertilizer on a warm-water lake. Michigan State College, Tech. Bul. 223.

Member of the Society of the Sigma Xi

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

INTRODUCTION

The energy from the sun and the allogenetic inorganic and organic nutrients from the surrounding soils provide the basis for the whole complex of biological activity within the lake basin. To the worker desiring to increase the production and yield from a lake, Ricker (1946) suggests two methods of approach. Either nutrient material can be added artificially and from the increased productivity greater production and yield may be possible or a more efficient use of the present nutrient supply may be encouraged as, for example, the removal of competing warm-water species from lakes to be managed as trout lakes.

Ricker's suggestion of artificial enrichment to increase the yield of fish from a body of water is not a new idea. An increase in the yield of one or more species of fish by the addition of nutrient material is made possible by the general productivity of the lake being stimulated, with larger standing crops being formed at each of the trophic levels upon which fish production is based.

Pond fertilization has been practiced in the orient since early in recorded history (Drew, 1951). Schaperclaus (1933) and Neess (1949), in reviewing practices of pond culture, noted the use of fertilizers in Central Europe several centuries ago. In spite of its antiquity, pond fertilization in this country is relatively new. The development of farm ponds and the pioneer work with fertilizers began in the southern states during the 1930s (Hogan, 1933; Meehean, 1933; Swingle and Smith, 1939). From this beginning, fertilization has spread throughout this country and Canada and applications have been tried on a variety of aquatic habitats, including natural lakes.

In Michigan, an experimental fertilization program has been underway since 1946. The work has encompassed many types of water and one phase has been the fertilization of natural lakes. Hasler (1947), in discussing the advisability of fertilizing natural waters, points out the absence of complete information on the effects of fertilization and points out the need for further experimental work. When the present study was begun in June of 1948, certain information from completed experiments served to guide the direction of the program. Heavy applications of fertilizer to a warm-water lake and to a trout lake had created winterkill conditions in both after two summers of fertilization (Ball, 1948; Ball and Tanner, 1950). Smith (1945), fertilizing trout lakes in Nova Scotia, discovered that enriched food supplies favored coarse fish entering through the outlet more than the trout population.

Evaluation of creel census reports has emphasized that fishermen do not harvest warm-water species and that increasing these fish by fertilization could not be economically justified. For these reasons landlocked trout lakes in which the rate of harvest has been shown to be high (Eschmeyer, 1938) were selected. The fertilization rates have been reduced.

Some workers have attacked artificial enrichment of natural lakes as unwise (Hasler, 1947 and 1948; Hayes, 1951). Their objections apply particularly to water areas with populations of salmonid or corrigonid fishes with their need for cold, well oxygenated water. These objections are, therefore, of particular importance in evaluating the present study.

Hayes (1951) discussed the subject in considerable detail and opposed the use of fertilizers on the basis of three major points: (1) the addition of nutrients to a lake speeds the process of eutrophication and extinction; (2) the eutrophication of the lake favors the coarse and less desirable species of fish and results in the elimination of trout; and (3) there is little or no carry over of the added nutrients necessitating a continual and, hence, uneconomic fertilization program. Hasler (1947) reviews the consequences of inadvertent enrichment of lakes in Europe with the accompanying disasterous results to the trout and whitefishes and concludes that a continuing addition of nutrients to trout lakes would have similar results. It is true that unless these objections can be met fertilization of trout waters must be considered undesirable. However, the possible rewards warrant investigations to determine if the objections which have been raised can be circumvented in a practical and economical manner.

The present study has been directed toward examining the effects of the fertilizer on biological productivity and production and providing additional information concerning the effects of fertilizer on certain of the physical and chemical factors of the environment. While other studies have shown general increases in productivity following application of fertilizer, the effects on the various trophic levels and on the chemical and physical environmental factors have remained unpredictable. The accurate prediction of fertilization results will become possible only with the complete understanding of the complex trophic-dynamic relationships as they exist in our natural waters. With this in mind, the present study was designed to measure not only changes in biological production but also the secondary effects on the chemical and physical features of the environment and, in so doing, provide certain of the information necessary to predict the total effects of fertilization on natural waters.

The study has been under the direction of Dr. Robert C. Ball of Michigan State College and has been supported by The Institute for Fisheries Research of the Michigan Conservation Department with a doctorate fellowship.

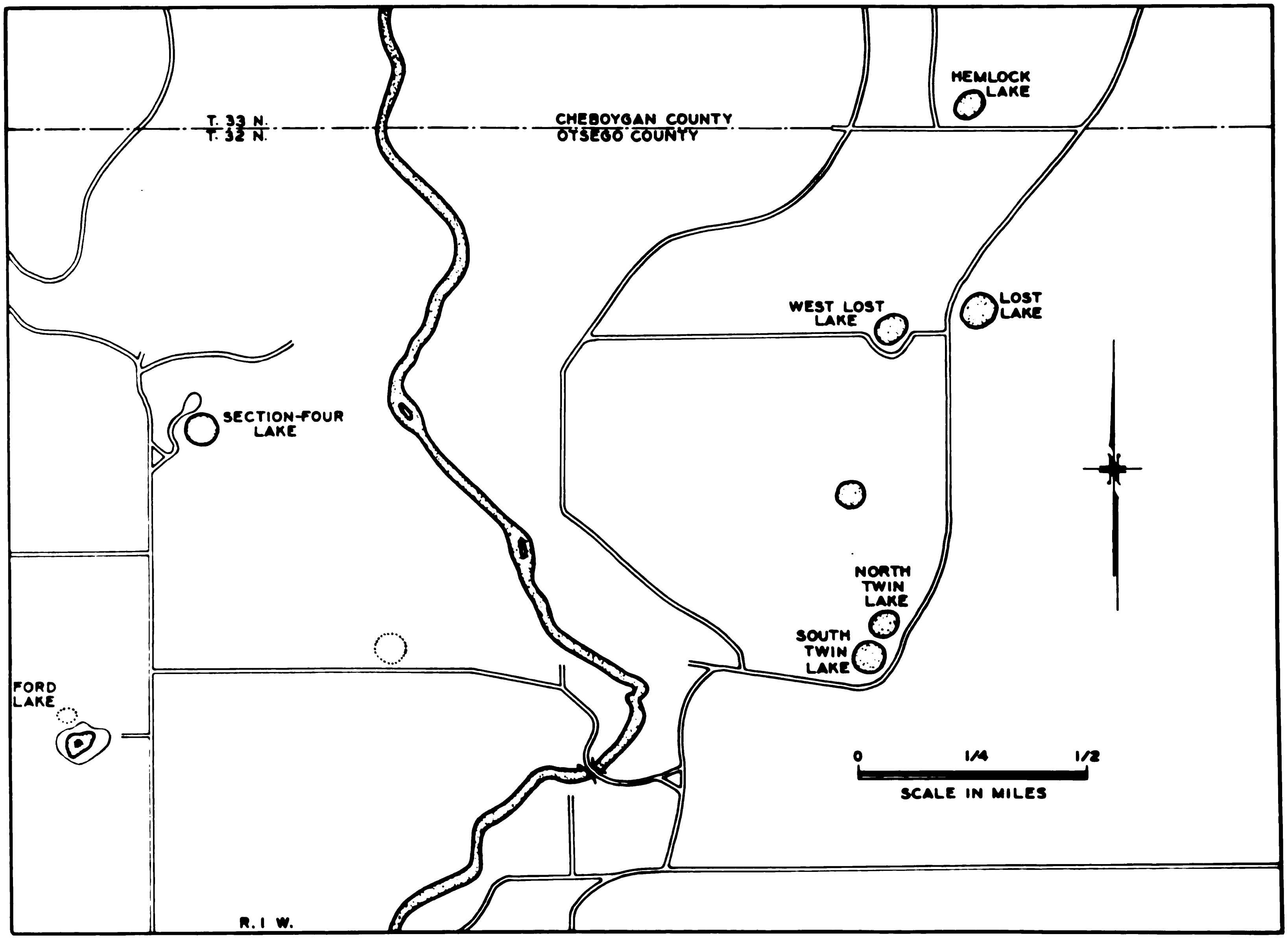
DESCRIPTION OF THE STUDY AREA

A group of six trout lakes lying in the Pigeon River State Forest was selected for use in the present study. These lakes, generally known as the Pigeon River "Pot-Hole" Lakes, were selected because of their small area, close proximity to one another, location on state owned lands, and general similarity. Two of the lakes had been used in a fertilization experiment by Ball (1948). Five of the six are in Otsego County (North Twin, South Twin, West Lost, Lost, and Section-Four Lakes) and Hemlock Lake is just over the line in Cheboygan County.

Prior to the second summer of field work the immediate area in which the lakes were located including five miles of the Pigeon River was designated as the Pigeon River Trout Research Area and placed under the administration of The Institute for Fisheries Research. The establishment of the Research Area made possible a compulsory creel census which aided greatly in the determination of fish production in the lakes. Figure 1 indicates the location of the area and the close proximity of the lakes to one another.

The soil and drainage are typical of the so-called pine plains of the north central lower peninsula. These plains are, properly speaking, a central upland, with a very acid sandy soil of low inherent fertility with a glaciated topography. The area is drained by the Pigeon River which runs

Figure 1. Map of the study area indicating position of the lakes in relation to the Pigeon River and to each other. Townlines, range and county lines define the location of the study area.


T. 33 N.
T. 32 N.
CHEBOYGAN COUNTY
OTSEGO COUNTY
HEMLOCK LAKE
WEST LOST LAKE
LOST LAKE
SECTION-FOUR LAKE
NORTH TWIN LAKE
SOUTH TWIN LAKE
FORD LAKE
0
1/4
1/2
SCALE IN MILES
R. I W.

northward through Mullet Lake to the Cheboygan River and into Lake Huron. The original forest cover was of white and red pine with isolated hardwood stands consisting largely of beech-maple and hemlock and which, in general, occupied a less sandy soil type. Hemlock Lake lies in one of these isolated hardwood stands where the soil type is an undulating phase of the Emmet-Nester association and the surface a sandy loam to fine sandy loam with a substrata of reddish sandy clay loam with occasional gravel pockets (55 percent Emmet sandy loam, 25 percent nester sandy loam). This soil is classed as moisture retentive. The soil types in which the other five lakes lie (Roselawn and Rubion sand) are considered to have an extremely rapid drainage and are the types occupied by the original pine forest. These soils have a surface of sand and a substrata of brownsih yellow sand with an occasional gravel pocket.

Following the logging of the pine near the close of the last century the region was repeatedly burned by fire. The establishment of adequate forest fire control in the early 1930s has permitted fast growing aspen, popular, fire cherry, and shad bush to become established. These transient species are in various stages of being replaced by jack, red, and in some areas white pine as a result of natural and artificial seeding. Small areas of white and red pines survived the fires either by chance or because of a protected location. The steep slopes of the lake basins provided a measure of protection for the trees and today some portions of each lake basin are covered by large pines providing erosion control and adding to the beauty of the lakes.

DESCRIPTION OF THE LAKES

The unusual physical characteristics of these six lakes with their nearly symmetrical outline, the water surface 40 to 60 feet below the surrounding terrain, and the steepness of the slopes which surround each lake, with the exception of Hemlock, have created considerable interest in their origin. In earlier investigations, Eschmeyer (1938) pointed out the similarity of these lakes to the glacial-pit type of lake as described by Scott (1921). In the intervening years, geologists of the state have become more familiar with the region and the lakes and are now in agreement that the lakes are limestone sinks, Bergquist (personal communication). The evidence that supports this contention is that the area is underlain by limestone formations and the presence of many other more typical limestone sinks both with and without water in the area. Dramatic proof of the correctness of this conclusion was presented when, in late May of 1950, the west shore of Section-Four Lake collapsed (Figure 2). Soundings of the lake indicated that the collapse of the bank was due to the settling of part of the lake bottom. It was concluded that further erosion of the limestone formation had occurred.

The general similarities of the salient physical and chemical characteristics have been tabulated (Table 1). Certain important differences existed and should be noted.

Figure 2. The west shore of Section-Four Lake showing the cave-in which occurred in May, 1950.

TABLE 1

PHYSICAL AND CHEMICAL CHARACTERISTICS PRIOR TO FERTILIZATION

Lakes[1]	Surface areas (acres)	Maximum depth	Average depth	Bottom Soil Type			Total hardness	Secchi	Thermocline	Percent shoal[2]	Aquatic vegetation
				Shoal	Sub-littoral	Depth					
South Twin	3.9	34	24	sand	peat	peat	74	12.7	12-30	15.3	extensive
North Twin	4.7	44	28	sand	peat	peat	2	15.1	15-36	13.0	limited
West Lost	3.7	44	29	sand	peat[4]	peat	138	23.7	18-33	11.0	rare
Lost	3.5	55	41	marl	marl	(peat marl	177	17.0	18-33	3.3	rare
Hemlock[3]	5.9	64	41	(peat marl	peat[4]	peat	163	11.1	12-30	4.2	limited
Section-Four	2.6	72	51	marl	marl	(peat marl	192	35.7	18-42	4.0	rare

1 - All landlocked.
2 - Shoal and littoral zone are considered synonymous.
3 - Hemlock formerly has had an outlet and it is shown on old maps. Records indicate no surface flow since prior to 1932.
4 - Small amounts of marl present.

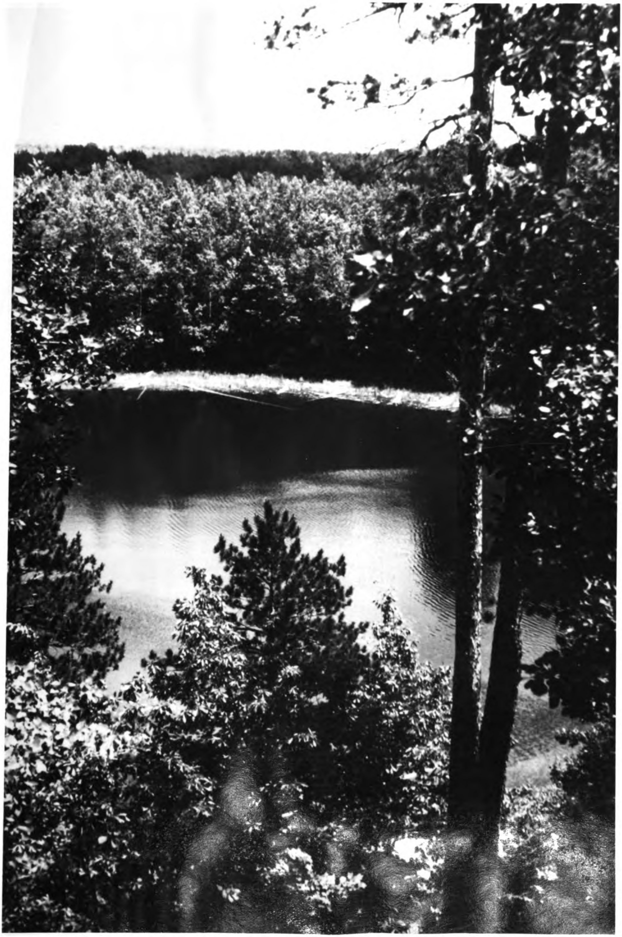
Section-Four Lake has much less shoal area than the average of the group. The secchi disk readings revealed that Hemlock Lake was considerably less clear than the others. South Twin Lake had beds of aquatic vegetation consisting of Potomogeton amplifolius at depths from 8 to 13 feet. In total hardness, North Twin Lake was the softest with an average in the lower epolimnion of 32 p.p.m. and Section-Four Lake was the hardest with an average of 192 p.p.m. The bottom soils of South Twin, North Twin, and West Lost Lakes are sand in the shoal and sub-littoral regions with peat in the depths. West Lost Lake has small amounts of marl present. Lost, Hemlock, and Section-Four Lakes are considerably deeper marl lakes with varying amounts of peat present in the depths.

The following pictures illustrate some of the physical features of the lakes.

Figure 3. Looking across Section-Four Lake towards the north shore. The steep basin slope is typical of the lakes in the study group.

Figure 4. View of the typical precipitous basin incline surrounding Section-Four Lake.

Figure 5 Lost Lake shown far below the level of the surrounding terrain. This lake occupies the deepest depression of any of the group.



METHODS AND EQUIPMENT

General Work Pattern

The summer of 1948 was spent in collection of prefertilization data and the poisoning of those lakes which had trash fish. Fertilizer was applied to four of the lakes during the summers of 1949 and 1950. The remaining two were kept as controls.

Data were collected to facilitate comparison of physical, chemical and biological conditions before and during a period of fertilization. At the end of the summer of 1950 the lakes were again poisoned to obtain population estimates of the trout present.

Investigation of the problem of winterkill necessitated chemical examination of the lakes each winter. During the period adjudged to be the most critical, the lakes were visited and complete chemical series obtained.

The creel census station established just prior to the 1949 trout season collected a complete record of all trout removed from the lakes by angling. The checking station supplied a record of the daily weather which was of considerable value in evaluating the results of the program. The files of The Institute for Fisheries Research also were available to the writer.

A winter trip into the lakes during February of 1951 was the last date of collections.

Field Program

Selection and Preparation of Lakes

The six lakes selected for the program were examined early in the summer of 1948 to determine whether or not undesirable populations of warm-water fish were present. Application of a fish toxicant to North Twin, South Twin, West Lost, and Section-Four Lakes was decided upon in order to eliminate large populations of yellow perch (Perca flavescens) and common suckers (Catostomus c. commersonnii). In West Lost Lake, the pumpkinseed sunfish (Lepomis gibbosus) was present in addition to perch and suckers. Hemlock and Lost Lakes were apparently populated by only a few brook trout and limited populations of forage fish, so poisoning was considered unnecessary.

Known numbers of marked brook trout were released in each lake; in West Lost Lake known numbers of pumpkinseeds were caught, marked, and released. The percent return of these marked fish following poisoning was utilized to estimate the standing crop of fish (Ball, Ms.).

Chemical and Thermal Analysis of the Water

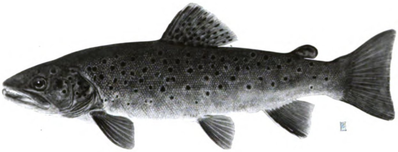
Using a Negretti and Zambra reversing thermometer, temperature readings were taken at weekly intervals throughout the three summers of the field investigations. Readings were taken from top to bottom in order to establish the position of the thermocline. After locating the thermocline, a chemical analysis of the water was determined from three vertical locations: chemical analyses were made at the mid-epilimnion, the mid-thermocline, and the mid-hypolimnion. All water samples were collected with a modified Kemmerer sampler. The rapid, unmodified Winkler method was used for oxygen determinations. Determinations of hardness and free carbon dioxide were made using methods outlined in Standard Methods for Examination of Water and Sewage (1946). The pH was determined using a Hellige colorimeter.

The objective of using the three vertical stations was to record changes in the chemistry of the three water layers. Additional samples were taken at three foot intervals to determine at what point the levels of dissolved oxygen fell below 4 p.p.m. It was deemed of particular importance to determine if oxygen supplies in the thermocline during the mid-summer stagnation period were depleted below the levels necessary for trout survival. Often the thermocline at this period is the only region of the lake suitable for trout from the standpoint of temperature and oxygen.

Stocking

After removal of trash fish populations from four of the lakes in 1948, brown trout (*Salmo trutta fario*, Figure 6) were stocked in all six lakes. The reason for using brown trout was that brook trout (*Salvelinus f. fontinalis*), the trout

Figure 6 The brown trout *Salmo trutta fario*.



most commonly stocked in Michigan lakes which are to be managed exclusively as trout lakes, were considered to be too vulnerable to angling. It was highly desirable that fish planted in 1948 be present in fair numbers at the end of the program to permit the evaluation of their growth under conditions of fertilization. The brown trout were planted as yearlings and at rates that were considered to be excessive so that a sufficient population might be present to exploit fully any increase in fish food resulting from the added nutrients. Through a misunderstanding, 500 brook trout fingerlings per acre were planted in South Twin, North Twin, West Lost, and Lost Lakes in addition to and at the same rate as the brown trout and at about the same time. These trout averaged 3.5 to 4 inches.

Numbers, average lengths, and average weights of the brown trout planted in each lake in the fall of 1948 are presented in Table 2.

In the fall of 1949, following the closing of the fishing season, the lakes were again stocked with brown trout. These trout had the left pectoral fin clipped making them distinguishable from the 1948 plant. Since populations of trout were present in all the lakes, the rate of stocking was cut from 500 per acre, the rate used in 1948, to 250 per acre. Trout planted in 1949 were larger than those planted in 1948. Their average length was 7.0 inches and they averaged 56.7 grams in weight as compared to a 5.65 inch and 34.4 gram average for the 1948 plant.

TABLE 2

1948 BROWN TROUT PLANTINGS

Lakes	No. fish planted	Average length (inches)	Average weight (grams)	Total weight (pounds)
South Twin	2,150	5.64	34.43	163
North Twin	2,850	"	"	217
Lost	2,300	"	"	175
West Lost	2,000	"	"	152
Section-Four	1,650	"	"	125
Hemlock	2,600	"	"	178
Totals	13,550			1,028

Application of Fertilizer

During 1946 to 1947 Dr. R. C. Ball, in fertilizing South Twin Lake, fertilized five times during each summer. In 1946 he used 400 pounds for each application and, failing to produce more than a moderate increase in phytoplankton, 600 pounds per application were used during the summer of 1947 for a total of 5,000 pounds on a lake with an area of 3.9 acres. Winterkill (Ball, 1948) occurred during the winter of 1947-48 which could be directly attributed to the addition of fertilizer. Taking his results as a starting point, it was decided to fertilize four of the six trout lakes at reduced rates. As originally planned, Section-Four was to receive 80 percent, Lost 60, Hemlock 40, and West Lost 20 percent as much fertilizer as did South Twin Lake in 1946-47. Several events occurred to modify these percentages: (1) a remapping of the lakes after they had been fertilized at rates based on the old areas, (2) a halt for fear of winterkill after only three applications produced spectacular blooms each summer, and (3) a change of fertilizer formula from one of a 10-6-4 N-P-K to 6-10-4 N-P-K dictated by availability. In general, these changes served to reduce the rates of application below the intended percentages.

The rates at which each lake was fertilized have been calculated on the basis of p.p.m. by weight (Table 3).

The fertilizer was placed in a tub on the rear seat of the boat and distributed over the surface of the shoal areas with a small dipper.

The four lakes were fertilized at different rates in order to determine if a rate of application low enough to avoid winterkill is enough to stimulate biological activity sufficiently to be reflected in increased growth of trout. The greatest amount of fertilizer was added to the lake with the greatest total hardness, Section-Four Lake, and the softer lakes received fertilizer at lower rates.

TABLE 3

RATES OF FERTILIZER APPLICATIONS

Lakes	Pounds		Total* p.p.m.	Actual percent	Planned percent
	1946	1947			
South Twin	2,000	3,000	28.5	100.	100
	1949	1950			
Section-Four	1,700	1,272	15.0	52.6	80
	1949	1950			
Lost	1,725	1,275	11.4	40.0	60
	1949	1950			
Hemlock	1,570	1,230	6.4	22.5	40
	1949	1950			
West Lost	400	300	3.9	13.7	20
	1949	1950			
North Twin	0	0	0	0	0

* - For the two summers.

Secchi Readings

The phytoplankton group is one of the basic converters of inorganic and organic nutrients to forms of energy useable by higher aquatic organisms. The phytoplankton is most responsive to the stimulus of added nutrients and the measure of this response has been used as an index of changes in biological activity during and following periods of fertilization (Swingle, 1939). Secchi readings were used to obtain a chronological record of the changes in amounts of plankton present. It has been shown (Van Dusen, 1947; Chu, 1943) that secchi disk readings provide a reasonably accurate estimate of changes occurring in amounts of plankton present. Plankton samples were collected periodically for species identification. Secchi readings were taken at least once a week during the summers of 1948, 1949, and 1950 and additional readings were taken as other duties permitted.

Bottom Fauna Collections

Bottom fauna samples were collected by means of a 6 inch by 6 inch Ekman Dredge. In sampling, the dredge was raised to the surface and a sifting screen of 30 wire mesh slipped beneath the dredge. The sample was then sifted to concentrate the invertebrate organisms. The organisms and the material not passing through the screen were placed in quart jars, numbered and removed to shore for examination in white bottom enameled pans. The organisms were removed and preserved in a solution of six parts water, three parts 95 percent alcohol and one part formalin. Each sample was labeled as to collection date and source and preserved in separate bottles.

The area of collection was confined to the region from shore to a depth of 30 feet. This area had been revealed by preliminary sampling to support over 95 percent of the invertebrate fauna inhabiting the lake bottoms. Samples were collected monthly and totaled 35 to 50 samples from each lake each summer.

The sampling was directed towards the evaluation of changes in quantity, quality, or depth distribution of the bottom fauna. The sampling program made possible comparisons of fertilized and unfertilized lakes and comparisons of bottom fauna populations of each lake prior to and following fertilization.

In each of the six lakes large numbers of sunken logs and other forest debris provided a protected habitat for many invertebrate groups (Figure 7). These groups included particularly Ephemerida, Odonata, Neuroptera and many crayfish, all important fish food organisms. This type of cover could not be sampled quantitatively with a dredge and estimates of this segment of the bottom fauna population were not possible. Collections for identification were made of the invertebrates living under the logs in the shallows.

Fish Sampling

Records of fish were secured from several sources. Early during the summer of 1948 fish were collected by hook and line, gill nets, minnow dip nets, and a few records were secured from a voluntary creel census. The purpose of this sampling was to determine which species were present in order to decide which lakes required poisoning. Data were taken concerning the fish removed by poison in 1948 from Section-

Figure 7 Section-Four Lake showing the tangle of sunken and floating logs present near the shore. Such cover is important as cover for trout and trout food organisms.

Four, South and North Twin, and West Lost Lakes. A population estimate was made on the basis of percentage recovery of marked fish. Prior to the 1949 season, the area was officially organized as a trout research area and through a compulsory creel census a complete record of the fish removed by anglers was secured. The fishing pressure during the 1949 season was light and, to suppliment the records of the creel census, samples were collected by gill nets. During the season of 1950, the heavier fishing pressure increased the number of catch records and the poisoning of all the lakes, which terminated the program in September of 1950, also provided a very large sample from each lake. An estimate of the fish populations present was made for each of the lakes on the basis of percent recovery of known numbers of marked fish planted in the lakes just prior to the 1950 poisoning (Ball, Ms.).

The creel census was conducted by the staff of the Pigeon River Trout Research Station.

Aquatic Vegetation and Filamentous Algae

Collections of aquatic plants were made from each lake. Changes in the conditions and amounts of aquatic vegetation present after fertilization were observed.

Since the formation of odorous and unsightly floating mats of filamentous algae resulted from the fertilization of

South Twin Lake (Figures 8 and 9) during the summers of 1946 and 1947, close watch was kept on all the lakes for its appearance during the present fertilization program. Only limited quantities of Spirogyra sp. appeared on one lake (Section-Four) during the present period of fertilization but mats covering large areas were present on South Twin Lake during 1948 and to a lesser extent during 1949, apparently from a residual effect from the 1946 and 1947 applications.

Lake Mapping

The maps on which the program was planned were constructed by crews from The Institute for Fisheries Research in 1931 and 1932. A remapping of all six lakes carried out in September of 1950 indicated that all of the six lakes were smaller than shown on the older maps. Changes in the lake areas are presented here (Table 4). These reductions in area and volume changed the rate of fertilization which had been established on the basis of the old maps.

Figures 8 & 9 Shoreline of South Twin Lake before and after 1946-1947 fertilization showing the algal mats which occurred. The reduced rates of fertilizing used in the present study avoided this nuisance.

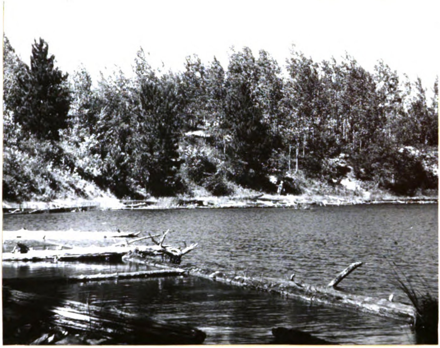


TABLE 4

AREA REDUCTIONS INDICATED BY REMAPPING (1950)

Lakes	Area indicated on old maps	New area (1950)	Change in area
South Twin	4.7 acres	3.9	.8
North Twin	5.4	4.7	.7
West Lost	4.3	3.7	.6
Lost	5.0	3.5	1.5
Hemlock	6.0	5.9	.1
Section-Four	3.3	2.6	.7

Laboratory Procedure

Bottom Fauna Samples

The laboratory procedure for examination of bottom samples consisted of identification of organisms and determination of numbers and volumes. Identification to species was not attempted. Had such identification been possible, the expenditure of time would not have been justified in this type of investigation. Numbers were determined by actual count and volumes by the displacement method described by Ball (1948). In obtaining the volumes of some of the smaller organisms it was necessary to accumulate large numbers and determine average individual volumes from the total volume and total number.

Stomach Analysis

Brown trout stomachs were collected from each lake. Examination procedure consisted of identifying food organisms present and obtaining a numerical count. Volume determinations were made on the entire stomach content and percent of total volume made up by each taxonomic group estimated. Brook trout stomachs were collected from South Twin Lake and examined for a comparison of feeding habits between brook and brown trout.

THE EVALUATION OF THE EFFECTS OF FERTILIZATION

Physical and Chemical Effects of Fertilization

Thermocline Changes

A weekly temperature series determined the thermocline position (Figures 10, 11, and 12). The thermoclines of the fertilized lakes (West Lost, Lost, Hemlock, and Section-Four) appear to have been in shallower positions in 1949 and 1950, the fertilized period, than in 1948, the year prior to fertilization. The thermoclines in North Twin and in South Twin Lakes (unfertilized) showed very little change during the same period. The changes in positions of the thermoclines were analysed statistically with an analysis of variance as described by Snedecor (1946). The mid-points of each thermocline determination were used as the sample value (Table 5). The thermocline position in 1948, prior to fertilization, is compared to the position occupied during fertilization, 1949 and 1950 (Appendix p. A). Thermoclines of the three lakes receiving the largest applications of fertilizer (Hemlock, Lost, and Section-Four) changed to a shallower position during 1949 and 1950. No real change occurred in the average position of the thermoclines in North or South Twin, the unfertilized lakes, or in West Lost Lake, the lake receiving the least amount of fertilizer.

Figure 10. North Twin and South Twin Lakes.

The vertical location of the thermocline and volume of water with less than 4 p.p.m. of oxygen.

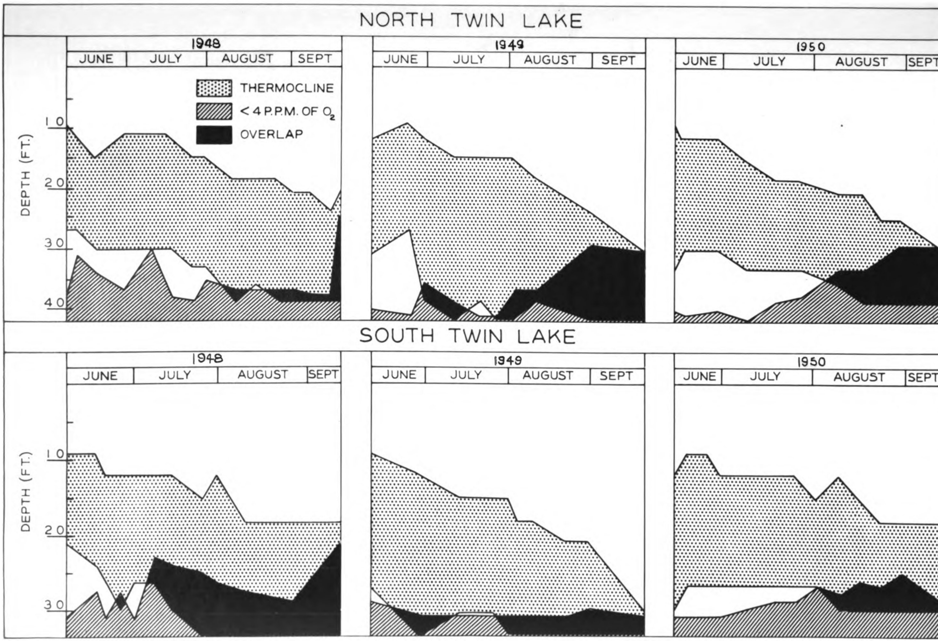

NORTH TWIN LAKE
1948
1949
1950
JUNE
JULY
AUGUST
SEPT
THERMOCLINE
< 4 P.P.M. OF O_2
OVERLAP
DEPTH (FT.)
1.0
2.0
3.0
4.0
SOUTH TWIN LAKE
1.0
2.0
3.0

Figure 11. West Lost and Lost Lakes.

The vertical location of the thermocline and volume of water with less than 4 p.p.m. of oxygen.

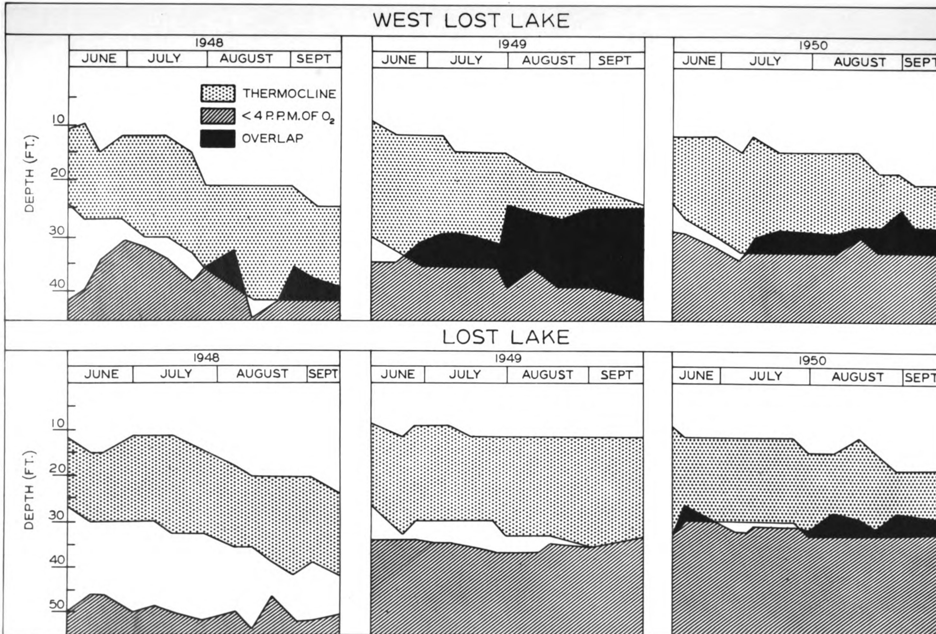

WEST LOST LAKE
1948
1949
1950
JUNE
JULY
AUGUST
SEPT
THERMOCLINE
< 4 P.P.M. OF O_2
OVERLAP
DEPTH (FT.)
10
20
30
40
LOST LAKE
50

Figure 12. Section-Four and Hemlock Lakes.

The vertical location of the thermocline and volume of water with less than 4 p.p.m. of oxygen.

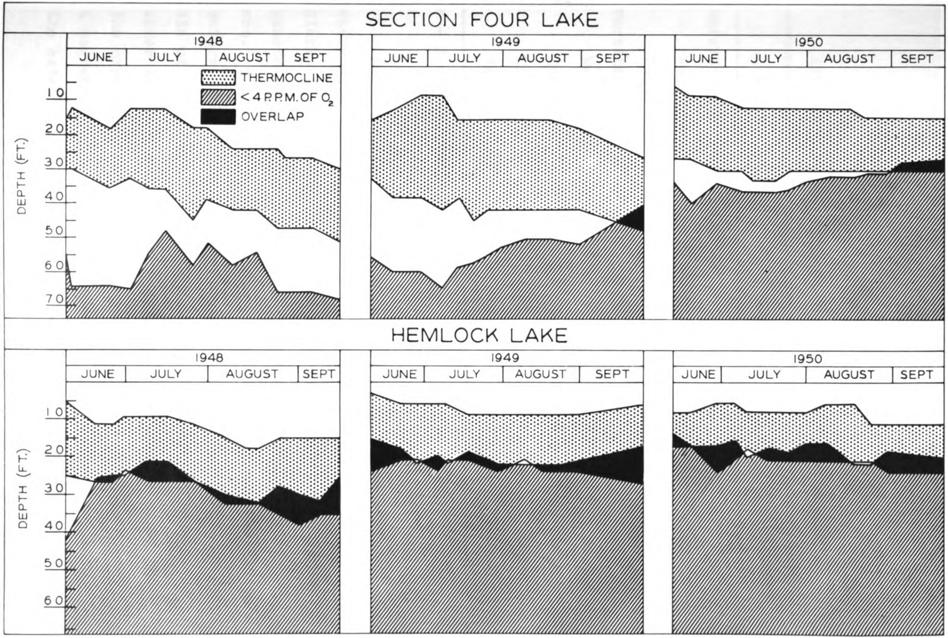

SECTION FOUR LAKE
HEMLOCK LAKE
1948
1949
1950
JUNE
JULY
AUGUST
SEPT
THERMOCLINE
< 4 P.P.M. OF O2
OVERLAP
DEPTH (FT.)
1.0
2.0
3.0
4.0
5.0
6.0
7.0

TABLE 5

AVERAGE DEPTH IN FEET OF THE THERMOCLINE MID-POINTS

Lakes	1948	1949*	1950*
Unfertilized			
North Twin	25.1	28.0	26.7
South Twin	21.6	24.6	21.2
Fertilized			
West Lost	25.8	26.0	23.4
Hemlock	22.0	15.2	14.9
Lost	25.6	21.5	22.4
Section-Four	30.1	27.6	21.0

* - Period of fertilization.

An explanation for the change in the position of the thermocline lies in the density of the plankton populations. Clarke (1946) presented data to show that the depth of light penetration was dependent on the amounts of plankton present. Since an increase in plankton occurred in the fertilized waters, the heat no longer penetrated to the depth that it did prior to fertilization but rather was absorbed in the water layers a short depth below the surface. The water of the hypolimnia remained at temperatures only slightly above 4 degrees C. The sheltered position of the lakes permitted the establishment of the thermocline in the shallower position. The importance of the upward shift of the thermocline is that, in lakes where oxygen is depleted in the hypolimnion during the summer stagnation period, the total volume of oxygenated water available to the trout populations is reduced. In a lake such as Hemlock, where the hypolimnion is already proportionally very large, this is an important factor. The thermocline in Hemlock Lake was at a level higher than that of the other five lakes prior to fertilization due to greater turbidity present.

Oxygen Depletion

The addition of fertilizer to lakes may reduce the amount of dissolved oxygen. Hasler (1947) has pointed out that inadvertant enrichment resulted in the exhaustion of oxygen from the hypolimnion of European lakes and caused the extinction of the whitefish and trout populations. Ball (1948) has reported the death of the fish and invertebrate populations caused by depletion of oxygen and accumulation of decomposition gases under the winter ice following application of fertilizer. That fertilizer increases the fish food organisms has been adequately demonstrated (Swingle and Smith, 1939; Patriarche and Ball, 1949). However, changes in oxygen levels may reduce fish production and prohibit artificial enrichment of natural waters.

During the present study attention was given to the detection of changes in the oxygen content of the lakes.

The average depth at which the amount of dissolved oxygen fell below 4 p.p.m. was determined by weekly observations during each summer of the investigation. The amount of oxygenated water present during the summer stagnation period was reduced in the fertilized lakes while little or no reduction occurred in the unfertilized lakes (Table 6).

TABLE 6

SUMMER OXYGEN LEVELS
AVERAGE DEPTH IN FEET WHERE OXYGEN CONTENT FELL BELOW 4 P.P.M.

Lakes	1948	1949*	1950*
Unfertilized			
North Twin	35.5	37.1	35.3
South Twin	27.0	30.7	28.7
Fertilized			
West Lost	37.1	29.0	29.0
Hemlock	27.1	20.0	18.4
Lost	49.5	35.3	30.5
Section-Four	59.9	54.7	33.2

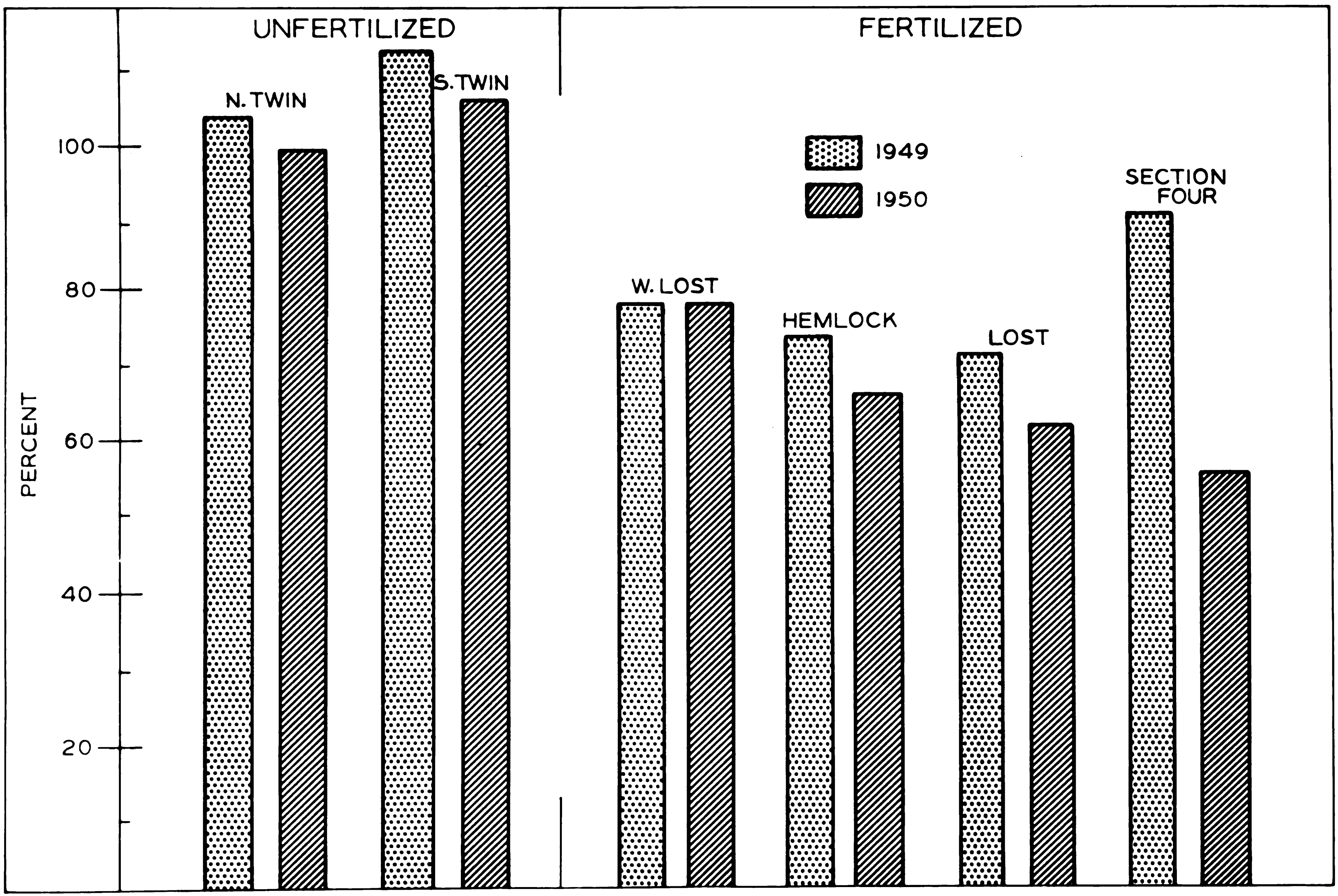
* - Period of fertilization.

An analysis of variance was applied to the data from each lake to determine if the differences in amounts of oxygenated water present in the prefertilization period and during the fertilization period were significantly different.

The amount of oxygenated water present during the period of fertilization in the fertilized lakes was significantly less than before fertilization. There was no change in the unfertilized lakes during the same period. From the analyses (Appendix p. B) it was concluded that the oxygen reduction was due to fertilization. In general, the oxygen reduction occurred only in the hypolimnion. Graphing depth at which the oxygen content fell below 4 p.p.m. chronologically (Figures 10, 11, and 12) indicates that the line of oxygen depletion after fertilization follows quite closely the bottom of the thermocline. Kusnetzow (1939) found that the respiration of bacteria is the primary agent of oxygen reduction in the hypolimnion. The stimulus of added nutrients increases the biological production and increased amounts of dead organic matter sink into the hypolimnion. The respiration of the bacteria growing upon it results in a more rapid oxygen depletion during the summer stagnation period. The average amount of oxygenated water present during the two summers of fertilization has been compared with the average amount present during the summer prior to fertilization (Figure 13). The prefertilization oxygen levels have been assigned the value of 100 percent. The percent of oxygenated water remaining during the period of fertilization is indicated by the graph. The more fertilizer added the greater the reduction of oxygenated water. The amount of oxygen depletion in Section-Four Lake was slight during

Figure 13. Depth of oxygenated water remaining (by percent) during period of fertilization.

(Prefertilization oxygen levels equal to 100 percent.)


UNFERTILIZED
FERTILIZED
N. TWIN
S. TWIN
W. LOST
HEMLOCK
LOST
SECTION FOUR
1949
1950
PERCENT
100
80
60
40
20

the first summer of fertilization in spite of the fact that it was receiving the most fertilizer. The very large volume of the hypolimnion in relation to the surface and littoral areas accounts for this lag in the oxygen being depleted in the hypolimnion.

In South Twin Lake a slight reverse trend can be observed. South Twin Lake was fertilized during the summers of 1946-47 and in 1948 there was a considerable volume of water in the thermocline and below in which there was less than 4 p.p.m. of oxygen. These data are an indication of carry over of the effects of the fertilizer added the previous summers. There was oxygen in excess of 4 p.p.m. throughout the entire lake volume during the summers of 1949 and 1950.

Several important physical and chemical differences existed between Hemlock Lake and the other lakes of the group. The thermocline occupied a very shallow position prior to fertilization and, as indicated previously, moved to an even shallower position during fertilization due to the increased turbidity. Prior to application of fertilizer, the proportionately large hypolimnion was completely devoid of oxygen during most of the summer stagnation period. The volume of the lake available to the trout during this period was not large originally and was reduced further when fertilization resulted in the repositioning of the thermocline. Thus, while the oxygen was not depleted from the zone of the thermocline by the effect of fertilizer, the water volume available for the trout was reduced. This may have contributed to the low production of trout from Hemlock Lake and should be considered when lakes are selected for fertilization in the future.

There is another quite different evaluation of the removal of oxygen from the hypolimnion. Einsele (1938) has indicated that, in general, when iron is present in the hypolimnion it combines with phosphorus as ferric phosphate in the presence of oxygen. The precipitate formed is insoluble and results in the removal of phosphorus from the nutrition of the lake. If, however, when the iron and phosphorus combine oxygen is absent the product is ferrous phosphate which is soluble and it can be presumed that some of it will be reused and will not be lost to the lake. Mortimer (1941) has indicated that, generally, the processes of reduction return the nutrient material in forms more useable by plants and bacteria than do the processes of oxidation. The process of eutrophication as described by Lindeman (1942) is extremely slow while the lake is oligotrophic. However, once the lake assumes the characteristics of an eutrophic lake which include lack of oxygen in the hypolimnion during the summer stagnation period the process of continued eutrophication and extinction becomes very rapid and, as Mortimer points out, the differences of the products of oxidation and reduction processes very likely account for this sudden quickening of the rate at which a lake becomes extinct.

Changes in the fish populations of a lake due to oxygen depletion during the summer stagnation period are, in general, long term ones and the final effects may take several years to evaluate. However, winter oxygen depletion and the resulting winterkill is an immediate proposition and the results plainly discernable. The winterkills resulting from previous fertilization attempts in Michigan were factors that prompted the present study. It was hoped that using several rates of fertilization would permit the determination of what was a safe rate of fertilization and what was not. Unfortunately, the lakes were very inaccessable during the critical period of late winter, however, one trip to the lakes during the period adjudged to be the most critical was made each of the three winters.

The results of the oxygen determinations at the time when snow and ice had been of the longest duration and the sun had not yet removed the snow cover from the ice are presented in Table 7. The level of dissolved oxygen is expressed as the depth in feet at which oxygen supplies fell below 2 p.p.m. Some oxygen depletion occurred in all the fertilized lakes and in Section-Four Lake, the lake receiving the most fertilizer, the amount of oxygenated water remaining was only four feet in depth on February 26, 1951. Considering that this was only one reading and conditions may have deteriorated before spring, winterkill conditions may have occurred later and remained undetected because of the absence of fish. It must be concluded that the rate at which fertilizer was applied to Section-Four Lake was excessive.

TABLE 7

WINTER OXYGEN LEVELS
DEPTH IN FEET WHERE OXYGEN CONTENT FELL BELOW 2 P.P.M.

Lakes	1949	1950*	1951*
Unfertilized			
North Twin	----	27	27
South Twin	12	8	23
Fertilized			
West Lost	27	18	22
Hemlock	22	11	18
Lost	35	30	24
Section-Four	----	36	4

* - Period of fertilization.

For the other lakes, winterkill conditions apparently were not approached. The small amount of fertilizer applied to West Lost Lake did not create conditions approaching a winterkill and could be used elsewhere on similar lakes without endangering fish life. The data also indicate that oxygen reduction due to fertilization tends to increase as fertilization is continued (Table 7). This is also discernable in the data for the summer oxygen levels (Table 6).

South Twin Lake which was fertilized heavily in 1946 and 1947 and which winterkilled during the winter of 1947-48, was observed carefully in order to detect any residual effect of fertilization on winter oxygen levels. The oxygen depletion during the winters of 1949 and 1950 was severe while in 1951 the volume of oxygenated water in South Twin Lake was comparable to the amount present in North Twin Lake, the unfertilized lake (Table 7). It was concluded that the oxygen depletion during the winters of 1949 and 1950 was a residual effect of fertilization.

Changes in total hardness

Included in the weekly water chemistries was the determination of the methyl orange hardness. In comparing the average methyl orange readings of prefertilization dates to the readings during fertilization (Table 8) it is apparent that there was a reduction of hardness in each of the six lakes during the three years of the study. The rate of reduction appeared to be greater for the fertilized lakes than in North Twin and South Twin, the unfertilized lakes.

TABLE 8

RATES OF REDUCTION IN TOTAL HARDNESS IN THE UNFERTILIZED AND FERTILIZED LAKES DURING THE FERTILIZATION PERIOD

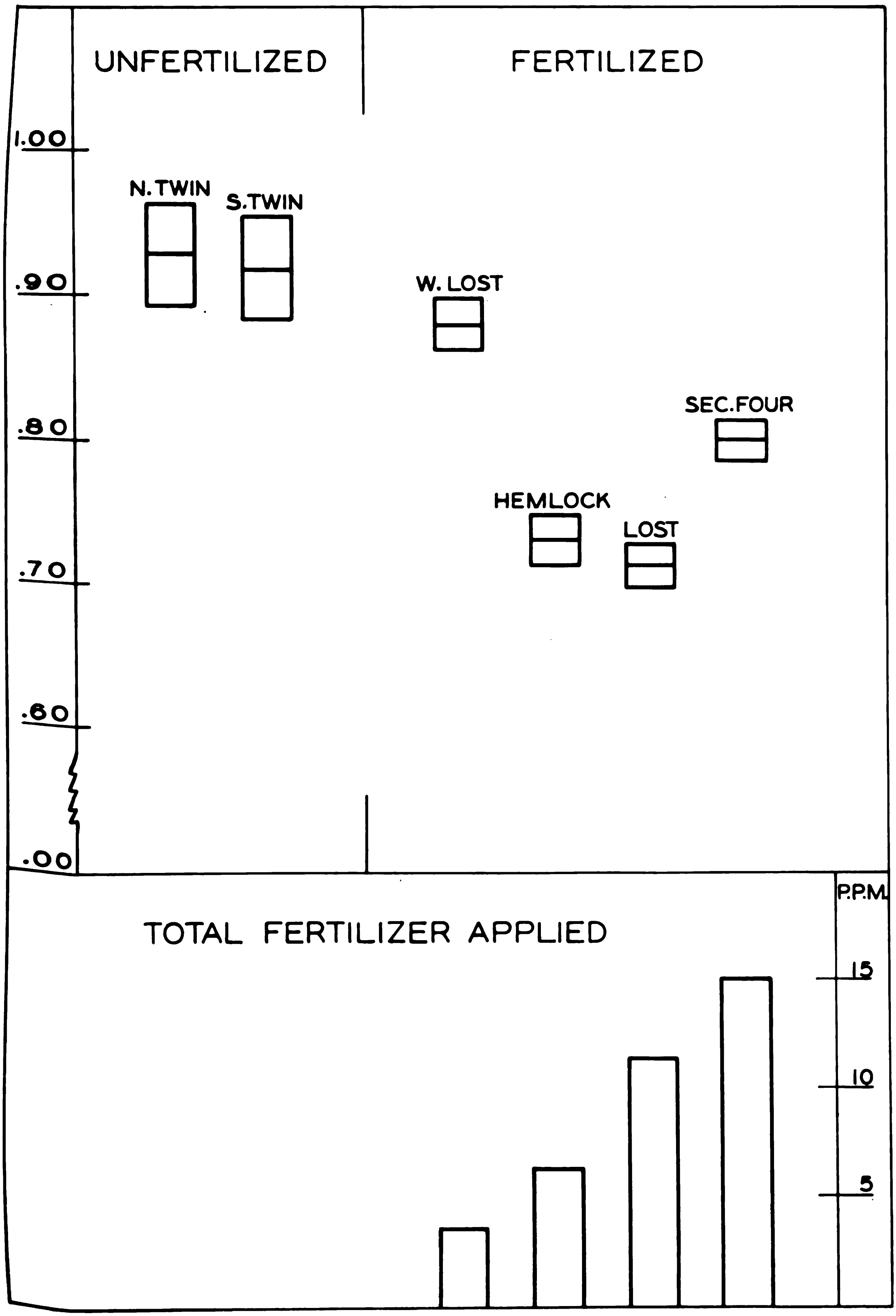
Lakes	Average total hardness 1949 and 1950		Average total hardness 1948		Quotient	Standard error of quotient
Unfertilized						
North Twin	29.5	./.*	31.7	=	.930	.016
South Twin	67.8	./.	74.0	=	.916	.033
Fertilized						
West Lost	120.3	./.	137.1	=	.875	.010
Hemlock	117.7	./.	161.3	=	.730	.009
Lost	126.2	./.	177.5	=	.713	.010
Section-Four	153.0	./.	191.9	=	.798	.006

* - Divided by.

To determine if there was a real difference in the rate of reduction in hardness between the fertilized lakes and unfertilized lakes during the period of fertilization the following statistical procedure was applied. The average hardness of each lake for the prefertilization period and for the period of fertilization were calculated, together with the standard error of their means. The value for the average total hardness of the period of fertilization was divided by the figure for the prefertilization period.

Since all the lakes were softer during the period of fertilization than previously, the quotients were all less than one and represented actually the percent of the prefertilization hardness present during the period of fertilization (Table 8). The standard error of the quotient (Baten, 1938) was used to determine confidence limits of the quotients. The quotients and plus and minus twice the standard error of each were plotted (Figure 14). This graphic method of statistical presentation (Dice and Leraas, 1936) enables one by observation, with some exceptions, to determine if a significant difference exists. Plus and minus twice the standard error is enclosed in a rectangle for each quotient. When the rectangles of the quotients overlap numerically there can be no significant difference in the values, when no overlapping occurs there exists a significant difference between the values of the quotients. Exceptions occur when overlapping is slight or overlapping is very closely approached. In these instances "t" tests must be employed (Walker, 1943). The quotients for West Lost and South Twin Lakes were tested with a "t" test and it was determined that there was no significant difference. Hemlock, Lost, and Section-Four, the lakes receiving the heavier applications of fertilizer, were reduced in hardness at a rate which was greater (highly significant) than for the two unfertilized lakes, North and South Twin (Figure 14). West Lost Lake was fertilized very lightly and did not differ signifi-

Figure 14. The quotients obtained by dividing the average total hardness during fertilization by average total hardness prior to fertilization for each lake. Graphed with $\pm$ twice the standard error of the quotient. Fertilization rates indicated by graph at base of chart.


UNFERTILIZED
FERTILIZED
1.00
.90
.80
.70
.60
.00
N. TWIN
S.TWIN
W. LOST
SEC.FOUR
HEMLOCK
LOST
TOTAL FERTILIZER APPLIED
P.P.M.
15
10
5

cantly from South Twin Lake, one of the unfertilized lakes, but was different from North Twin Lake. Also shown are the amounts of fertilizer added to each lake which indicates that the rate of hardness reduction was a function of the rate of fertilization.

The increased biological activity which occurred following the application of fertilizer was apparently the cause of the decrease in total hardness. The increase in the phytoplankton populations present resulted in an increase in the demand for carbon for the synthesis of carbohydrates during photosynthesis. The plants use the carbon present in the form of carbon dioxide and are capable of using the half-bound carbon present in the calcium bicarbonates. Further, the sudden reduction of the carbon dioxide present in the water has been observed to reduce the solubility of carbonates in the water and bring about their precipitation in crystalline form (Huber-Pestalozzi, 1938; Hasler, 1947 quotes Minder, 1922). These factors singly or in combination would result in a decrease in total hardness.

The importance of this reduction in total hardness should not be overlooked. When calcium carbonates and bicarbonates exceed a level of about 177 p.p.m. of methyl orange hardness, phosphorus combines with the calcium and is precipitated out in an insoluable compound and thus may be removed permanently from the nutrient cycle of the lake (Hubalt, 1943). Barrett (1952) suggests that the critical hardness level is lower. Two of the four fertilized lakes, Section-Four and Lost, had an average total hardness that exceeded 177 p.p.m. (Table 8) prior to the application of fertilizer. In both, the action of the fertilizer reduced the total hardness below the critical level. These results may offer a possible approach to the problem of increasing the productivity of marl lakes, many of which are very unproductive at the present time.

Biological Effects of Fertilization

The factors necessary to measure production are an estimate of the standing crop and the rate of turn over. The standing crop can be determ ned by a sampling program but rate of turn over is difficult to measure. Brujewica (1939), in a study to evaluate the dynamics of production in the Caspean Sea, describes methods of estimating rate of turn over. He determined the yearly P/B coefficient for the organism of each of the trophic levels of productivity by estimating production (P) and the biomass (B) obtaining the coefficient P/B as an estimate of the rate of turn over.

Since a high level of production requires either a large standing crop or rapid rate of turn over, or both, increases of the standing crop will be reflected in relative increases in production when there is little or no change in the rate of turn over (Clarke, 1946). In the present study the standing crops of organisms at several trophic levels have been measured periodically. Changes in the standing crop have been interpreted as reflecting a similar change in production.

Considerable confusion exists in the terminology used to describe various aspects of the dynamics of productivity and, as Clarke (1946) suggests, it is necessary to define there terms. Biological productivity as used here (Ivlev, 1945) is the capacity of a body of water to produce a given quantity of organic matter in some particular form. Production is the output or increase of the biomass of any group of organisms per unit of time. Biomass is synonomous with standing crop which has been defined by Clarke (1946) as the amount of organisms existing in the area at the time of observation. Yield is the amount removed by man per unit of time.

Plankton

Throughout the program emphasis has been placed on measurement of quantitative changes in various levels of the food pyramid. Qualitative examinations of plankton were not undertaken and frequent secchi disk readings were the only measure of changes in the planktonic populations. Several workers have evaluated the use of the secchi disk as a means of estimating changes in plankton levels (Van Duesen, 1947; Chu, 1943). It is believed that sufficient understanding of the relationships between light absorption and plankton concentration will permit general conclusion as to the effect of fertilization on the amounts of plankton present.

The secchi disk measures the rate of light absorption. Equal fractions of light are absorbed by successive layers of equal thickness of the light absorbing substance. If, for example, 20 percent of the light falling on the surface of the lake is absorbed in the first foot of water, then 20 percent of the remaining light is absorbed in the next foot of water. A secchi disk reading is approximately the point at which 85 percent of the light falling on the surface has been absorbed (Clarke, 1946). Changes in the transparency of the water change the readings in a geometric proportion and not a straight line or numerical proportion.

The concept of a direct relationship between amounts of plankton present and rate of light absorption has been investigated by many workers under a variety of conditions. Clarke (1938) found no correlation between plankton densities and changes in rates of light absorption. However, the same author (Clarke, 1946) showed that there was a relationship between depth of secchi readings and amounts of plankton present. Utterbank (1946), working in Puget Sound, found a considerable degree of correlation between levels of plankton populations and rates of light absorption in some areas of the Sound and not in others. He pointed out as factors reducing the degree of correlation, tide, surface disturbance, wind velocity and direction and amount of light falling on the surface of the water.

Depending on the degree of interference of other unmeasurable sources of variation, a correlation exists between rates of light absorption and quantities of plankton present which can be measured by secchi disk readings. The relationship is a geometric one, a factor that must be kept in mind when evaluating changes in secchi disk readings.

For example, if the rate of absorption (amount of plankton present) is increased five percent to 15 percent then the reading would be approximately 11 feet, a total change of seven feet. However, if the rate of absorption should be 30 percent with a secchi reading of 5 feet and a five percent increase in the rate of absorption (amount of plankton present) to 35 percent occurs then the change in the reading is only one foot. If the changes in rates of absorption were due entirely to plankton increases there was an increase of 5 percent in each instance. However, there was seven times as much change in one secchi reading over the other.

Because of the geometric nature of the relationship secchi disk readings cannot be used to compare the quantities of plankton present in bodies of water that differ in transparency due to other factors. Secchi disk readings should not be used to indicate changes in the amounts of plankton present in the same lake if turbidity is affected periodically by other factors. In the present study, the factors effecting the transparency of water other than plankton are alike for each of the bodies of water being compared. No other factors affecting transparency occur sporadically during the period of comparison and secchi disk readings may be used in evaluating changes in quantity of plankton present.

Many workers have indicated that increases in plankton will occur following the application of fertilizers (Swingle and Smith, 1939; Hogan, 1933; Meehean, 1936; Howell, 1942). In southern waters it is desirable to maintain a bloom of plankton throughout the growing period. However, during the summers of 1946 and 1947 Ball (1948), in fertilizing South Twin Lake, one of the group used in the present study, failed to achieve more than a moderate increase in plankton and yet winterkill conditions occurred during the winter of 1948-49. There was, therefore, some question if the reduced rates of application proposed for the present study would achieve any detectable increase in the amounts of plankton present.

Prior to fertilization frequent secchi readings served to establish the relative amounts of plankton present in each lake. The average secchi readings for each lake were calculated (Table 9) and the readings for each lake are charted chronologically (Figures 15, 16, and 17). Generally, the amount of plankton present was low. The low level of the plankton population in Section-Four Lake is emphasized by readings of greater than 40 feet. The secchi readings indicated slightly more plankton present in the other five lakes but all are considered to have been very low in plankton production prior to fertilization. The first fertilizer was applied in mid-June of 1949 and two more applications followed at three week intervals. There were greatly increased amounts of plankton present in each of the fertilized lakes. Fearing repetitions of the 1948 winterkill on South Twin Lake, fertilization was halted.

TABLE 9

AVERAGE SECCHI DISK READINGS
(DEPTH IN FEET)

Lakes	1948	1949*	1950*
Unfertilized			
North Twin	15.1	35.1	28.9
South Twin	12.7	21.6	17.1
Fertilized			
West Lost	23.7	13.5	13.8
Hemlock	11.1	4.1	4.1
Lost	17.0	9.9	7.6
Section-Four	35.7	13.7	12.2

* - Period of fertilization.

During the remainder of the summer there was little reduction in the amount of plankton present in the fertilized lakes with the exception of Section-Four Lake. The excessive hardness of this lake may have caused the rapid decline of the plankton population by combining with the nutrients, particularly phosphorus, to form in insoluble carbonate compounds (Barrett, 1952).

Applications of fertilizer in 1950 were begun on June 17 and three applications were made during the summer. The standing crop of plankton (Table 9) the second year (1950) did not greatly exceed those of 1949 in the fertilized lakes.

Figure 15. Record of secchi readings 1948, 1949 and 1950.

North Twin was not fertilized and South Twin Lake was fertilized during 1946 and 1947.

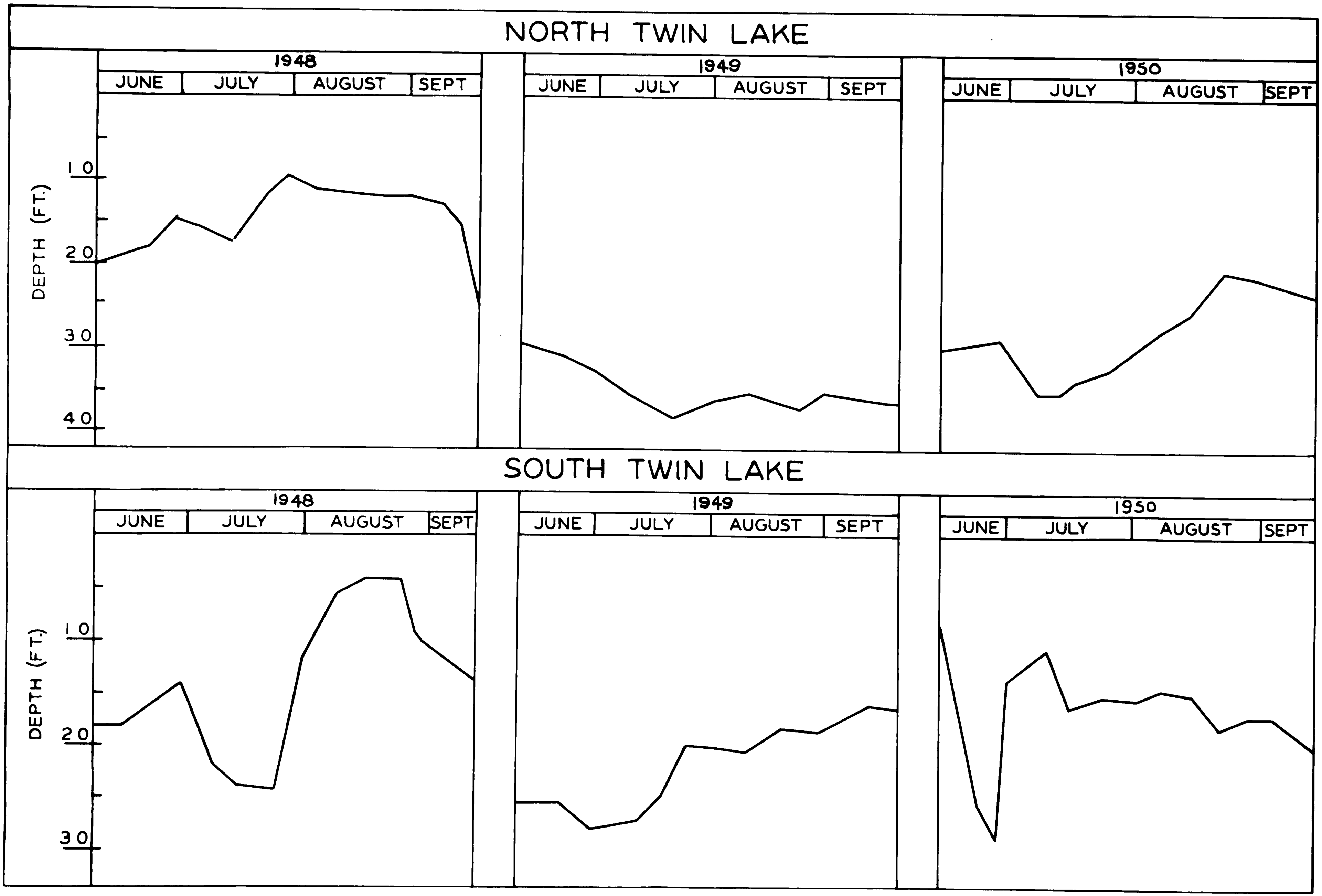

NORTH TWIN LAKE
1948
JUNE
JULY
AUGUST
SEPT
1949
JUNE
JULY
AUGUST
SEPT
1950
JUNE
JULY
AUGUST
SEPT
DEPTH (FT.)
1.0
2.0
3.0
4.0
SOUTH TWIN LAKE
1948
JUNE
JULY
AUGUST
SEPT
1949
JUNE
JULY
AUGUST
SEPT
1950
JUNE
JULY
AUGUST
SEPT
DEPTH (FT.)
1.0
2.0
3.0

Figure 16. Record of secchi readings 1948, 1949 and 1950.

West Lost and Lost Lakes were both fertilized during 1949 and 1950.

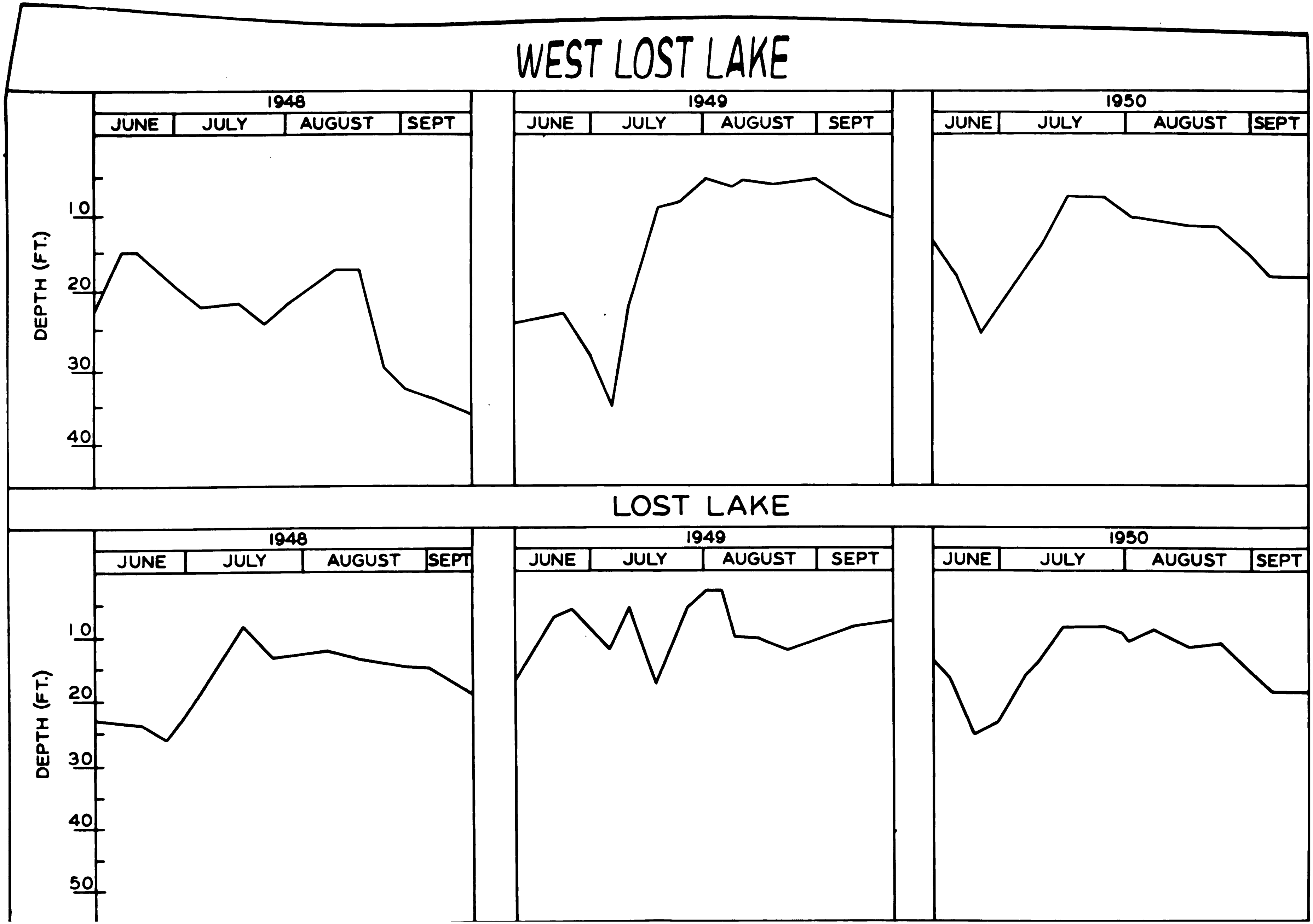
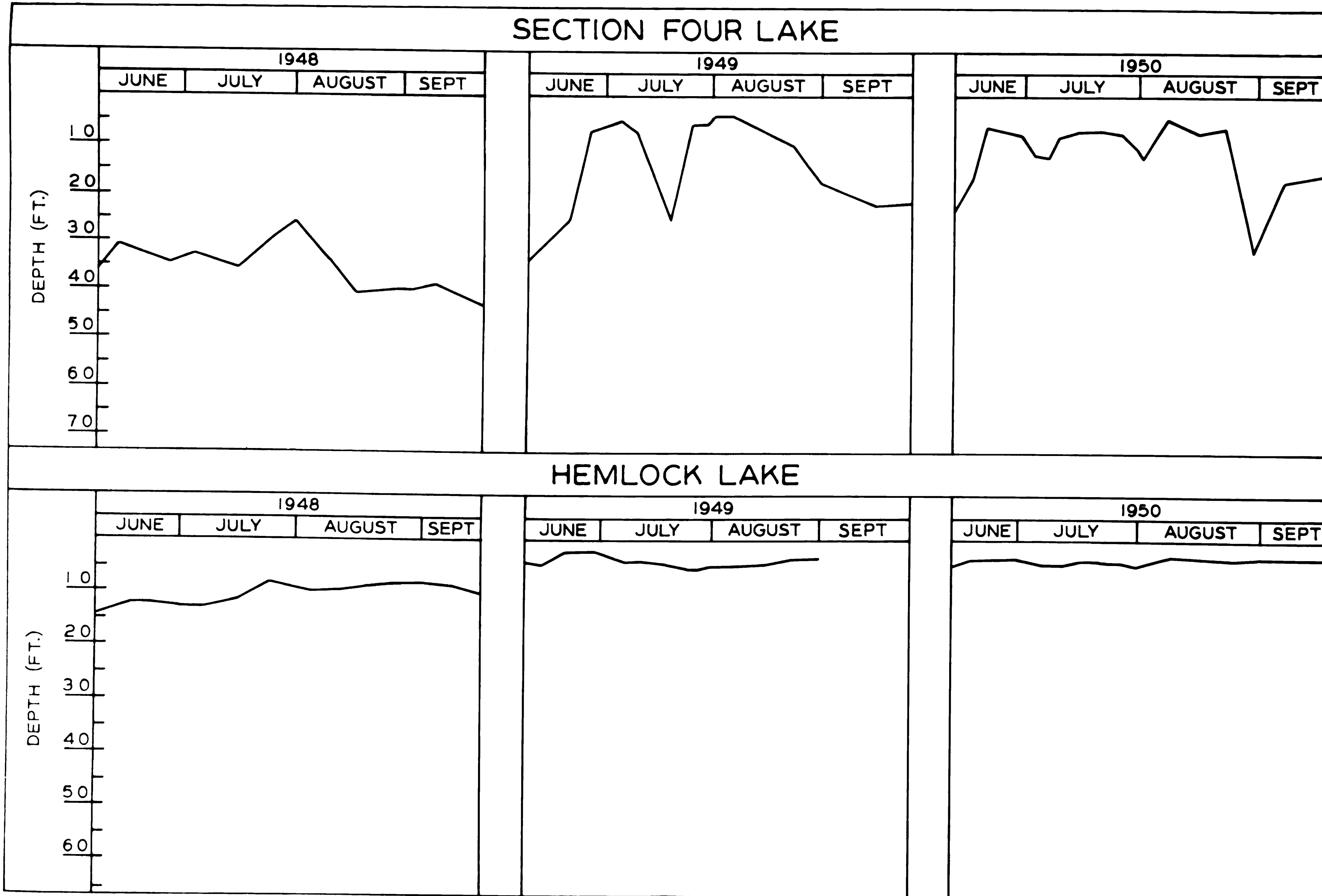

WEST LOST LAKE
1948
1949
1950
JUNE
JULY
AUGUST
SEPT
DEPTH (FT.)
10
20
30
40
LOST LAKE
1948
1949
1950
JUNE
JULY
AUGUST
SEPT
DEPTH (FT.)
10
20
30
40
50

Figure 17. Record of secchi readings 1948, 1949 and 1950.

Section-Four Lake and Hemlock Lake were both fertilized during 1949 and 1950.


SECTION FOUR LAKE
1948
1949
1950
JUNE
JULY
AUGUST
SEPT
DEPTH (FT.)
10
20
30
40
50
60
70
HEMLOCK LAKE
1948
1949
1950
JUNE
JULY
AUGUST
SEPT
DEPTH (FT.)
10
20
30
40
50
60

Only a slight decline of plankton concentrations in Section-Four Lake was noted before the end of the sampling period (Figure 15). It is believed that the corresponding reduction in total hardness during the same period may have resulted in the nutrient material remaining in a soluble form and available to the phytoplankton.

During the late summer of 1949 heavy concentrations of Daphnia sp. were noted in Section-Four Lake. Large swarms occurred chiefly in the partial shade of the floating and submerged logs which surrounded the lake perimeter. Examination of several trout taken in gill nets indicated that they were feeding on the Daphnia to the exclusion of all other food during the period of the extreme abundance of Daphnia. The only other concentration of zooplankton noted during the period of the field collections occurred in the lower thermocline of North Twin Lake. Here, also, large Daphnia were the dominate group. The zooplankton concentration in North Twin Lake was present continually during all three summers. Daphnia were an important item in the diet of the trout sampled from that lake.

Filamentous Algae and Higher Aquatic Plants

The heavy applications of fertilizer to South Twin Lake during 1946 and 1947 (Table 3) were followed by the formation of unsightly algal mats during the summers of 1947 and 1948 (Figures 8 and 9). The lower rates which were used during the present study did not result in the formation of similar mats. Filamentous algae was never conspicuous.

Extensive beds of potomogetons on the west and north shores of Hemlock Lake were eliminated by the increased turbidity which followed the applications of fertilizer.

Bottom Fauna

The size of the bottom fauna population supported by a body of water is generally accepted as one criteria of its potential fish production. The role of bottom fauna as an element in the Eltonian food pyramid is pointed out by Clarke (1946) and Lindeman (1942). Meehean (1936), Howell (1941), and Ball (1948) have related the quantity of bottom organisms to the production of fish in ponds and lakes.

The bottom fauna groups were the main food source for the brown trout in the lakes of the present study. Because the bottom fauna was of direct importance as food for the trout, increases in the standing crop of the bottom fauna are considered to be an indication of an increase in trout production capacity.

However, the relationships of the standing crops of bottom fauna and of fish to the annual production of each group is one that must be understood. Brujewica (1939) pointed out that the ratio of the standing crop of the bottom fauna to the standing crop of fish is 2.5 : 1 while the annual production of bottom fauna to fish production is

48 : 1 because of the much more rapid rate of turn over of the bottom fauna.

The sampling methods for bottom fauna collections have been described under Methods and Equipment.

Sampling of the bottom fauna began in June of 1948. A single station was established on each lake and samples were collected at regular intervals from shore to a depth of 30 feet. Exploratory sampling had established that the area beyond 30 feet contributed very little to the total populations of bottom fauna organisms. In Hemlock Lake no organisms were taken in samples beyond a depth of ten feet. However, in order to maintain uniform sampling, samples were collected out to the 30 foot depth.

The data from three summers sampling are presented on the following pages (Tables 10, 11, 12, 13, 14, and 15). The number of samples, area sampled, total number and volume of organisms present, number and volume of organisms per square foot and percent of the samples empty are indicated at the beginning of each table. The number, volume and percent of total numbers and volumes are indicated for each group present. The invertebrates are grouped under headings selected as the most meaningful. The sub-family Ceratopogoninae is included in the group Chironomidae. Midges, most important volumetrically, were medium to large ranging from 12-30 millimeters in length. These midges were not identified to species but were of the plumosis group and

TABLE 10

INVERTEBRATE FAUNA COLLECTED BY BOTTOM SAMPLING
SOUTH TWIN LAKE 1948, 1949 AND 1950
(FERTILIZED 1946-1947)

	1948	1949	1950
Collection dates	1948	1949	1950
Number of samples	40	42	53
Percent of samples empty	20	4.8	11.3
Area of samples (sq. ft.)	10	10.5	13.2
Total number of organisms	612	988	1378
Number per sq. ft.	61	94	104
Total volume of organisms (cc.)	24.11	39.26	43.75
Volume per sq. ft.	2.41	3.74	3.31

		1948		1949		1950	
Chironomidae*	A	393	64.2	227	23.0	968	70.3
	B	3.16	13.1	1.10	2.8	4.08	9.4
Anisoptera	A	10	1.7	38	3.8	23	2.5
	B	1.45	1.8	10.65	27.2	5.63	12.7
Clams	A	40	6.5	56	5.7	47	3.4
	B	18.05	74.9	17.80	45.3	22.05	50.4
Snails	A	28	4.6	413	41.8	3	.2
	B	.58	2.4	6.00	15.3	.01	....
Chaoborus	A	94	15.4	2	.2	1	.1
	B	.37	1.6	T	....	T	....
Hyallela	A	....	....	116	11.7	28	15.8
	B	....	....	.62	1.6	1.15	2.6
Ephemerida	A	27	4.4	18	1.8	29	2.1
	B	.14	.6	.11	.3	.16	.4
Crayfish	A	....	....	1	.1	15	1.1
	B	....	....	1.60	4.1	8.90	20.3
Zygoptera	A	3	.5	31	3.1	22	1.6
	B	.02	.1	.10	.2	.50	1.1
Tricoptera	A	6	1.0	56	5.6	38	2.8
	B	.28	1.1	.88	2.3	.81	1.8
Annelida	A	....	....	5	.5	5	.4
	B	....	....	.02	.1	.02	....
Coleoptera	A	7	1.2	16	1.6	....	....
	B	.02	.1	.21	.5	....	....
All others**	A	4	.7	9	.9	9	.6
	B	.05	.2	.18	.4	.51	1.2

* - Chironomidae includes the sub-family Ceratopogoninae.
** - All others includes Leeches, Lepidoptera, Stratomyiidae and Tabanidae.
A - Number and percent of total number.
B - Volume (cc.) and percent of total volume.

TABLE 11

INVERTEBRATE FAUNA COLLECTED BY BOTTOM SAMPLING
SECTION-FOUR LAKE 1948, 1949 AND 1950
(FERTILIZED 1949-1950)

Collection dates		1948		1949		1950	
Number of samples		32		53		51	
Percent of samples empty		28.1		7.6		3.9	
Area of samples (sq. ft.)		8		13.2		12.8	
Total number of organisms		63		454		1978	
Number per sq. ft.		7.9		34.4		154.5	
Total volume of organisms (cc.)		.29		18.26		18.41	
Volume per sq. ft.		.04		1.38		1.44	
Chironomidae*	A	47	74.6	232	51.1	1934	97.8
	B	.08	26.8	.89	4.8	9.42	51.1
Anisoptera	A	3	4.8	9	2.0	7	.3
	B	.16	56.4	1.56	8.5	3.05	16.6
Ephemerida	A	3	4.8	65	14.3	11	.5
	B	.02	5.2	.34	1.9	.08	.5
Hyallela	A	1	1.6	33	7.3	14	.7
	B	.01	1.7	.18	1.0	.07	.4
Crayfish	A	....	....	3	.7	4	.2
	B	....	....	13.40	73.4	5.76	31.3
Chaoborus	A	. 1	1.6	5	1.1	....	....
	B	.01	2.1	.02	.1	....	....
Tricoptera	A	....	....	6	1.3	....	....
	B	....	....	.02	.2	....	....
Zygoptera	A	2	3.2	....	....	....	....
	B	.01	2.7	....	....	....	....
Clams	A	....	....	21	4.6	5	.3
	B	....	....	.76	4.2	.01	.1
Snails	A	....	....	63	13.9	....	....
	B	....	....	.56	3.0	....	....
Annelida	A	3	4.8	8	1.8	3	.2
	B	.01	3.4	.32	1.8	T	....
All others**	A	3	2.8	9	1.9	1	1
	B	.01	1.7	.21	1.2	.01	....

* - Chironomidae includes the sub-family Ceratopogoninae.
** - All others includes Corixidae, Hydracarnia, Coleoptera and Tabanidae.
A - Number and percent of total number.
B - Volume (cc.) and percent of total volume.

TABLE 12

INVERTEBRATE FAUNA COLLECTED BY BOTTOM SAMPLING
LOST LAKE 1948, 1949 AND 1950
(FERTILIZED 1949-1950)

Collection dates		1948		1949		1950	
Number of samples		45		44		39	
Percent of samples empty		44.4		0.0		7.7	
Area of samples (sq. ft.)		11.2		11		9.8	
Total number of organisms		48		709		466	
Number per sq. ft.		4.29		64.40		47.6	
Total volume of organisms (cc.)		.82		5.31		2.78	
Volume per sq. ft.		.07		.48		.29	
Chironomidae*	A	28	58.3	667	94.1	435	93.4
	B	.11	12.9	2.90	54.6	2.49	89.4
Ephemerida	A	17	35.4	22	3.1	16	3.4
	B	.32	38.5	.28	5.3	.24	9.2
Anisoptera	A	1	2.1	2	.3	1	.2
	B	.40	48.6	.01	.1	.01	.2
Crayfish	A	....	....	1	.1	....	....
	B	....	....	2.10	39.5	....	....
Annelida	A	1	2.1	7	1.0	12	2.6
	B	T	....	.01	.3	.02	.9
All others**	A	1	2.1	11	1.5	2	.4
	B	T	....	.01	.2	.01	.4

* - Chironomidae includes the sub-family Ceratopogoninae.
** - All others includes Daphnia, Coleoptera, Tricoptera, Hyallela and Snails.
A - Number and percent of total number.
B - Volume (cc.) and percent of total volume.

TABLE 13

INVERTEBRATE FAUNA COLLECTED BY BOTTOM SAMPLING
HEMLOCK LAKE 1948, 1949 AND 1950
(FERTILIZED 1949-1950)

Collection dates		1948		1949		1950	
Number of samples		40		57		40	
Percent of samples empty		60		19.3		45	
Area of samples (sq. ft.)		10		14.2		10	
Total number of organisms		46		450		183	
Number per sq. ft.		4.6		31.7		18.3	
Total volume of organisms (cc.)		.82		15.01		2.67	
Volume per sq. ft.		.08		1.05		.27	
Chironomidae*	A	18	39.1	321	71.3	69	37.7
	B	.04	4.5	2.14	14.2	.47	17.2
Anisoptera	A	6	13.0	11	2.4	5	2.7
	B	.71	86.1	3.41	22.7	.37	13.8
Ephemerida	A	14	30.5	91	20.2	72	39.3
	B	.07	8.5	.46	3.1	.53	20.1
Tricoptera	A	8	17.4	14	3.1	19	10.3
	B	.01	.8	5.46	36.4	.62	23.1
Crayfish	A	....	....	3	.7	3	1.6
	B	....	....	1.90	12.7	.59	22.0
Hyallela	A	....	....	6	1.3	11	6.0
	B	....	....	.03	.2	.06	2.2
All others**	A	....	....	4	.8	4	2.0
	B	....	....	1.61	10.7	.05	2.2

* - Chironomidae includes the sub-family Ceratopogoninae.
** - All others includes Chaoborus, Leeches, Annelida and a Tadpole.
A - Number and percent of total number.
B - Volume (cc.) and percent of total volume.

TABLE 14

INVERTEBRATE FAUNA COLLECTED BY BOTTOM SAMPLING
WEST LOST LAKE 1948, 1949 AND 1950
(FERTILIZED 1949-1950)

		1948		1949		1950	
Collection dates		1948		1949		1950	
Number of samples		42		60		50	
Percent of samples empty		23.8		1.7		10	
Area of samples (sq. ft.)		10.5		15		12.5	
Total number of organisms		117		227		481	
Number per sq. ft.		11.1		15.1		38.4	
Total volume of organisms (cc.)		.63		2.90		5.93	
Volume per sq. ft.		.06		.19		.47	
Chironomidae*	A	64	53.9	88	38.8	328	68.2
	B	.40	63.5	1.45	39.5	3.63	61.3
Anisoptera	A	1	.9	7	3.1	3	.6
	B	.01	1.3	.88	30.5	1.54	26.0
Chaoborus	A	45	38.5	85	37.4	88	18.3
	B	.20	31.3	.38	13.3	.40	6.8
Ephemerida	A	2	1.7	12	5.2	41	8.5
	B	.01	1.6	.06	2.1	.22	3.7
Hyallela	A	2	1.7	14	6.2	12	2.5
	B	.01	1.0	.07	2.6	.06	1.1
Crayfish	A	....	....	1	.4	1	.2
	B	....	....	.20	6.9	.02	.3
All others**	A	3	2.7	20	9.0	8	1.6
	B	.01	1.4	.15	5.0	.05	.8

* - Chironomidae includes the sub-family Ceratopogoninae.
** - All others includes Sialis, Corixidae, Annelida, Zygoptera and Tricoptera.
A - Number and percent of total number.
B - Volume (cc.) and percent of total volume.

TABLE 15

INVERTEBRATE FAUNA COLLECTED BY BOTTOM SAMPLING
NORTH TWIN LAKE 1948, 1949 AND 1950
(UNFERTILIZED)

	1948	1949	1950
Collection dates	1948	1949	1950
Number of samples	41	41	52
Percent of samples empty	34.2	34.2	32.7
Area of samples (sq. ft.)	10.2	10.2	13.0
Total number of organisms	180	132	244
Number per sq. ft.	17.6	12.9	18.8
Total volume of organisms (cc.)	3.06	2.06	2.18
Volume per sq. ft.	.30	.20	.17

		1948		1949		1950	
Chironomidae*	A	127	70.6	99	75.0	122	50.0
	B	.56	18.2	.11	5.3	.19	8.6
Ephemerida	A	19	10.5	8	6.1	60	24.6
	B	.10	3.1	.04	1.9	.32	14.7
Anisoptera	A	7	4.4	9	6.8	15	6.1
	B	.88	29.7	1.42	68.7	.70	31.9
Clams	A	19	10.6	4	3.0	5	2.0
	B	1.41	46.1	.01	.5	.09	4.3
Hyallela	A	1	.5	5	3.8	16	6.6
	B	.01	.2	.03	1.3	.08	3.9
Tabanidae	A	2	1.1	1	.8	....	....
	B	.10	3.3	.24	11.6	....	....
Crayfish	A	....	....	....	....	1	.4
	B	....	....	....	....	.70	32.0
Hemiptera	A	....	....	3	2.3	7	2.9
	B	....	....	.21	10.2	T	....
All others**	A	5	2.7	2	1.5	17	6.9
	B	.01	.3	T	....	.09	2.5

* - Chironomidae includes the sub-family Ceratopogoninae.
** - All others includes Snails, Chaoborus, Tricoptera, Zygoptera and Coleoptera.
A - Number and percent of total number.
B - Volume (cc.) and percent of total volume.

probably were chiefly Chironomus plumosis and C. decorus (Curry, personal communication). The mayfly genera grouped under the heading Ephemerida consisted chiefly of the genus Caenis. The genus Stenonema was present in all the lakes but by habit remained on the under side of logs and was seldom taken in the bottom sampling. In Lost Lake Ephemeria was present in moderate numbers. The Limnophilidae were the most numerous of the caddis but numbers of the genus Molanna were taken in North and South Twin and Hemlock Lakes. Large numbers of micro-caddis (family Hydroptilidae) were sometimes present on the algal mats in South Twin Lake. In all the lakes members of the genus Gomphus were by far the most numerous of the dragonflies. Dragonflies of the family Libellulidae, the sub-family Aeschininae, were collected in varying numbers from each of the lakes and the genus Cordulegaster was common in North Twin Lake. The genus Musculium was the only clam present. Most of the snails collected were of the genera Physa.

The classification of the insect groups is that of Comstock (1947) and for the other invertebrates the text of Ward and Whipple (1918) was followed.

The percent of the total volume contributed by each group has been graphed (Figures 18, 19, 20, 21, 22, and 23). North and South Twin Lakes had much higher volumes of bottom fauna organisms in the Twin lakes but were not important in the other four lakes. Much of the increase in the

Figure 13. South Twin Lake (Fertilized 1946 - 1947)

Composition of bottom fauna from sampling by percent of total volume.

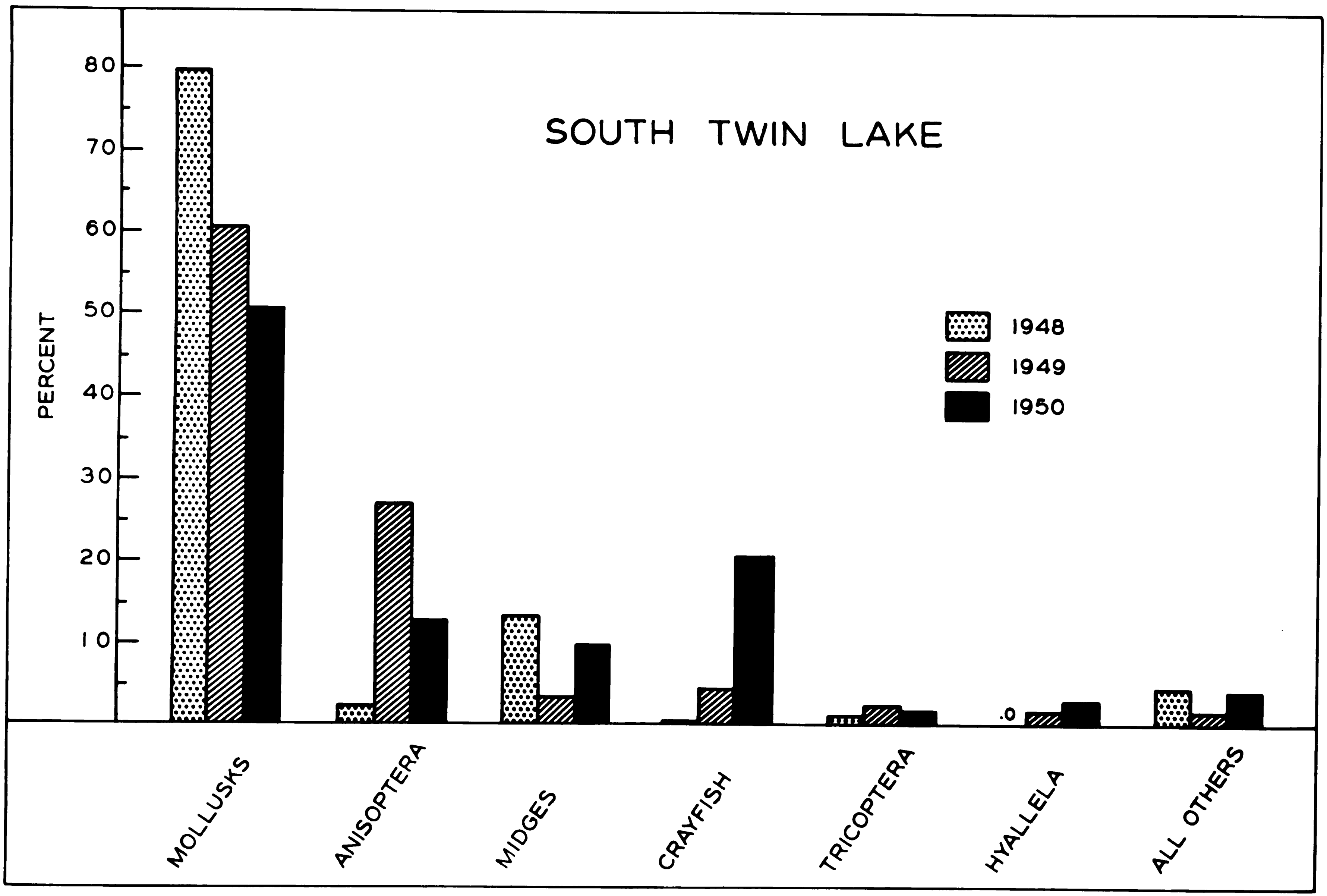

SOUTH TWIN LAKE
PERCENT
80
70
60
50
40
30
20
10
1948
1949
1950
.0
MOLLUSKS
ANISOPTERA
MIDGES
CRAYFISH
TRICOPTERA
HYALLELA
ALL OTHERS

Figure 19. Section-Four Lake (Fertilized 1949 - 1950)

Composition of bottom fauna from sampling by percent of total volume.

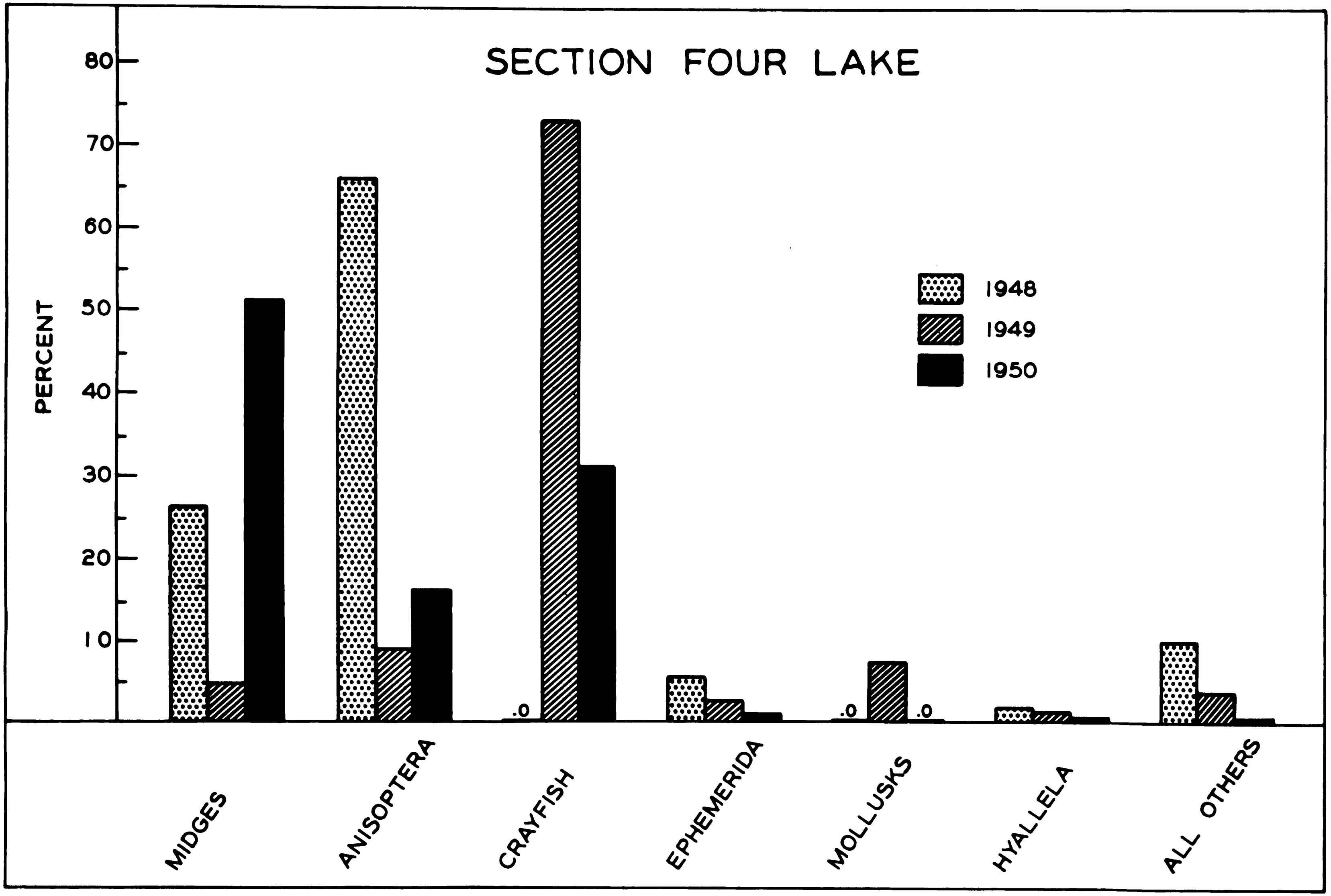
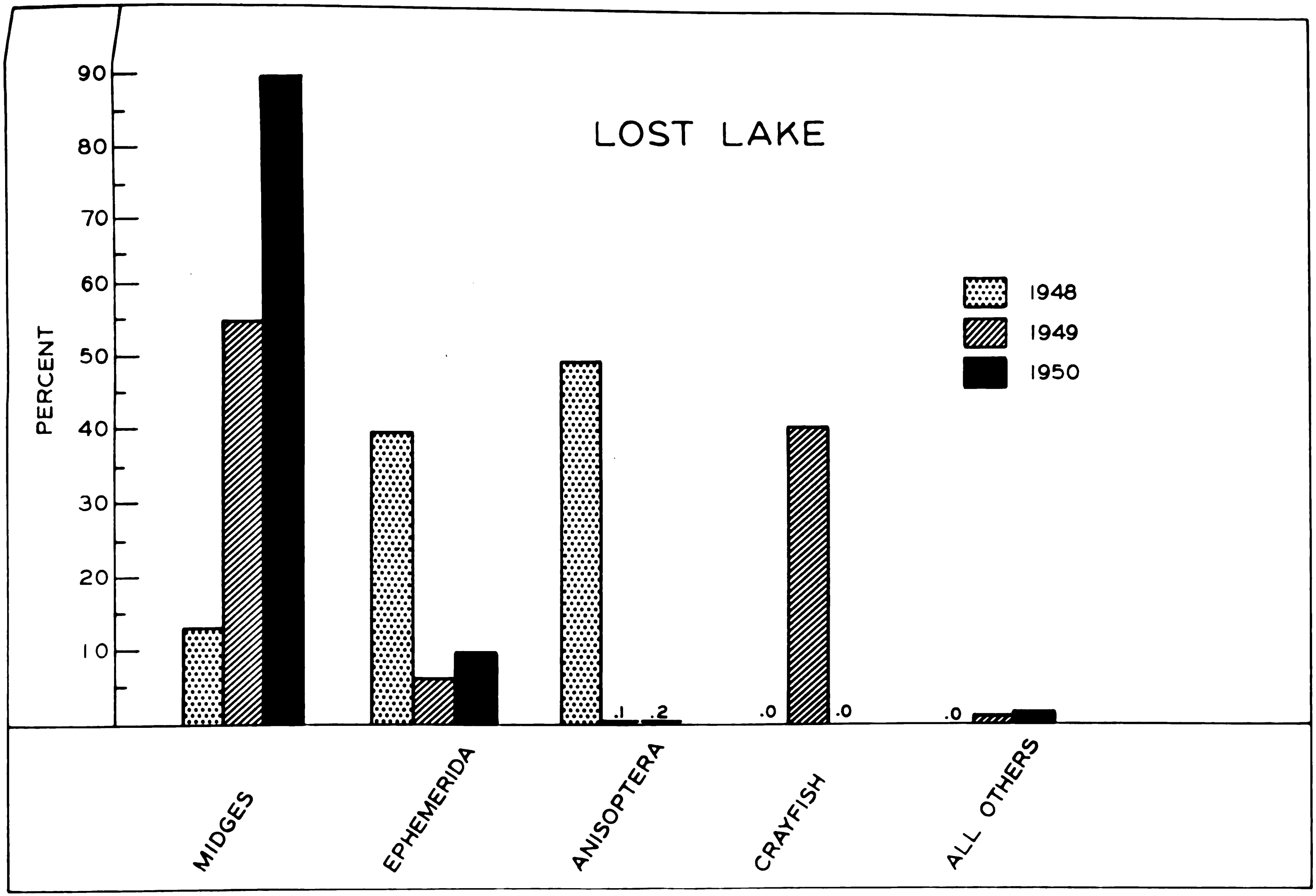

SECTION FOUR LAKE
PERCENT
80
70
60
50
40
30
20
10
1948
1949
1950
.0
.0
.0
MIDGES
ANISOPTERA
CRAYFISH
EPHEMERIDA
MOLLUSKS
HYALLELA
ALL OTHERS

Figure 20. Lost Lake (Fertilized 1949 - 1950)

Composition of bottom fauna from sampling by percent of total volume.



LOST LAKE
PERCENT
90
80
70
60
50
40
30
20
10
1948
1949
1950
.1
.2
.0
.0
.0
MIDGES
EPHEMERIDA
ANISOPTERA
CRAYFISH
ALL OTHERS

Figure 21. Hemlock Lake (Fertilized 1949 - 1950)

Composition of bottom fauna from sampling by percent of total volume.

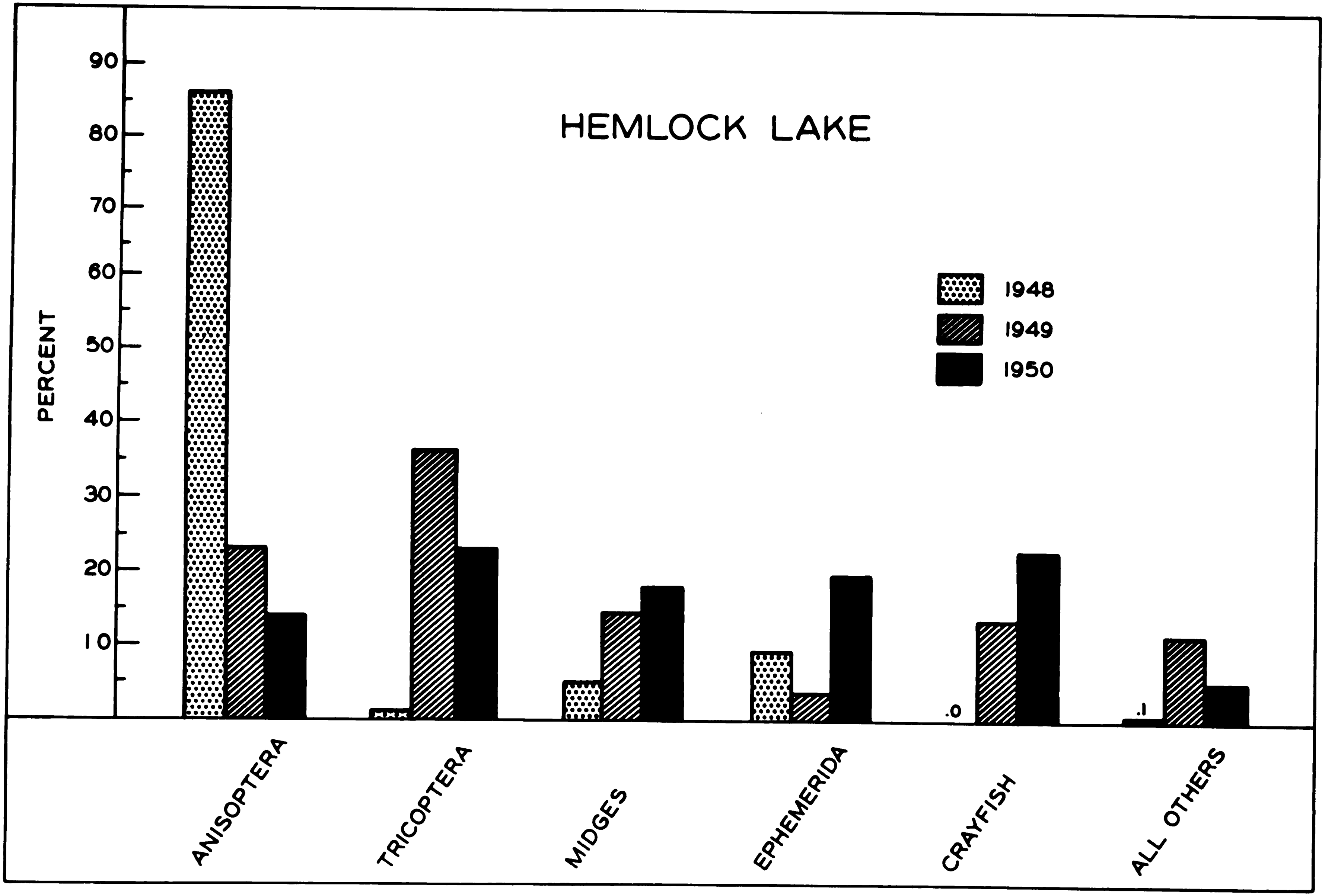

HEMLOCK LAKE
PERCENT
90
80
70
60
50
40
30
20
10
1948
1949
1950
.0
.1
ANISOPTERA
TRICOPTERA
MIDGES
EPHEMERIDA
CRAYFISH
ALL OTHERS

Figure 22. West Lost Lake (Fertilized 1949 - 1950)

Composition of bottom fauna from sampling by percent of total volume.

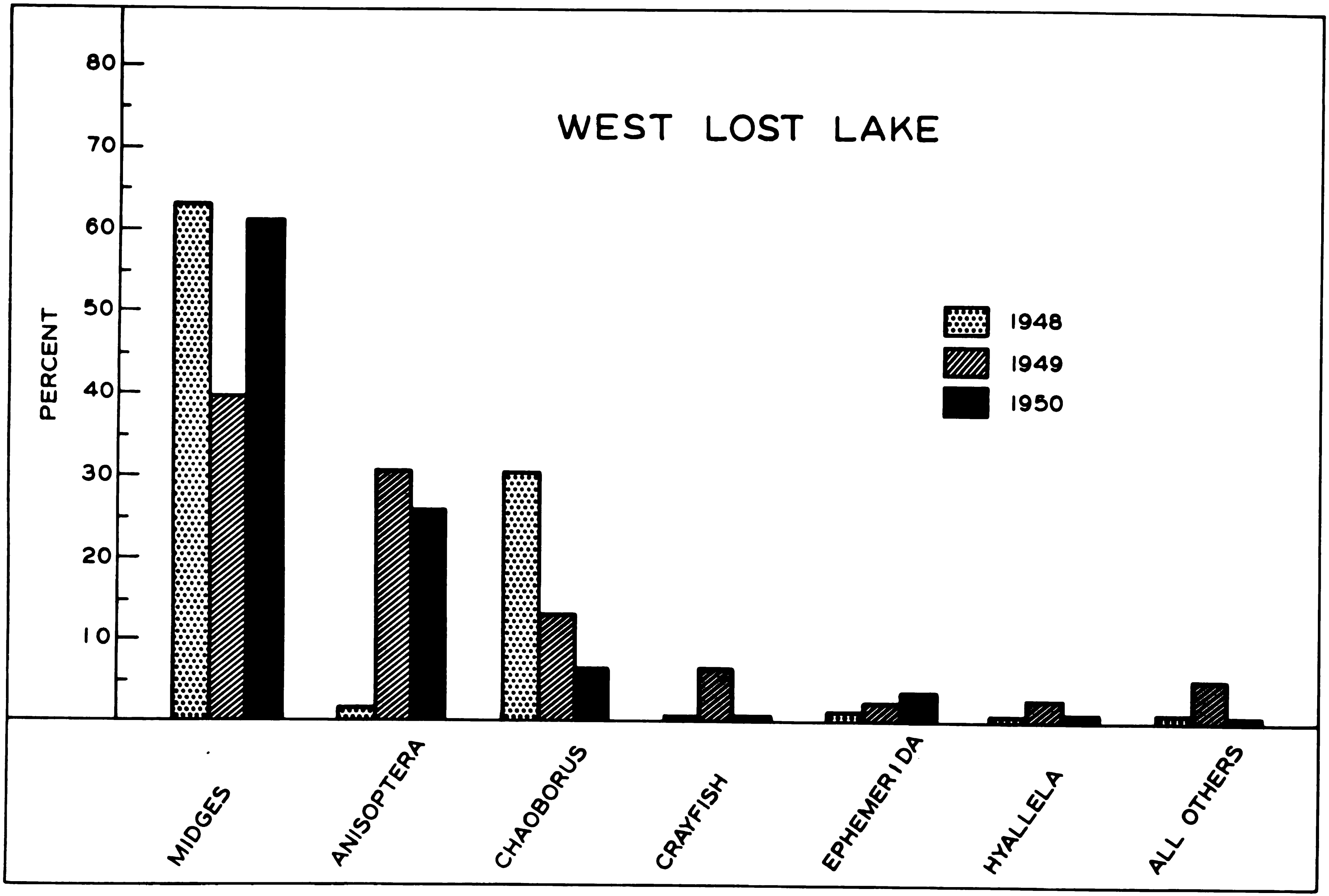
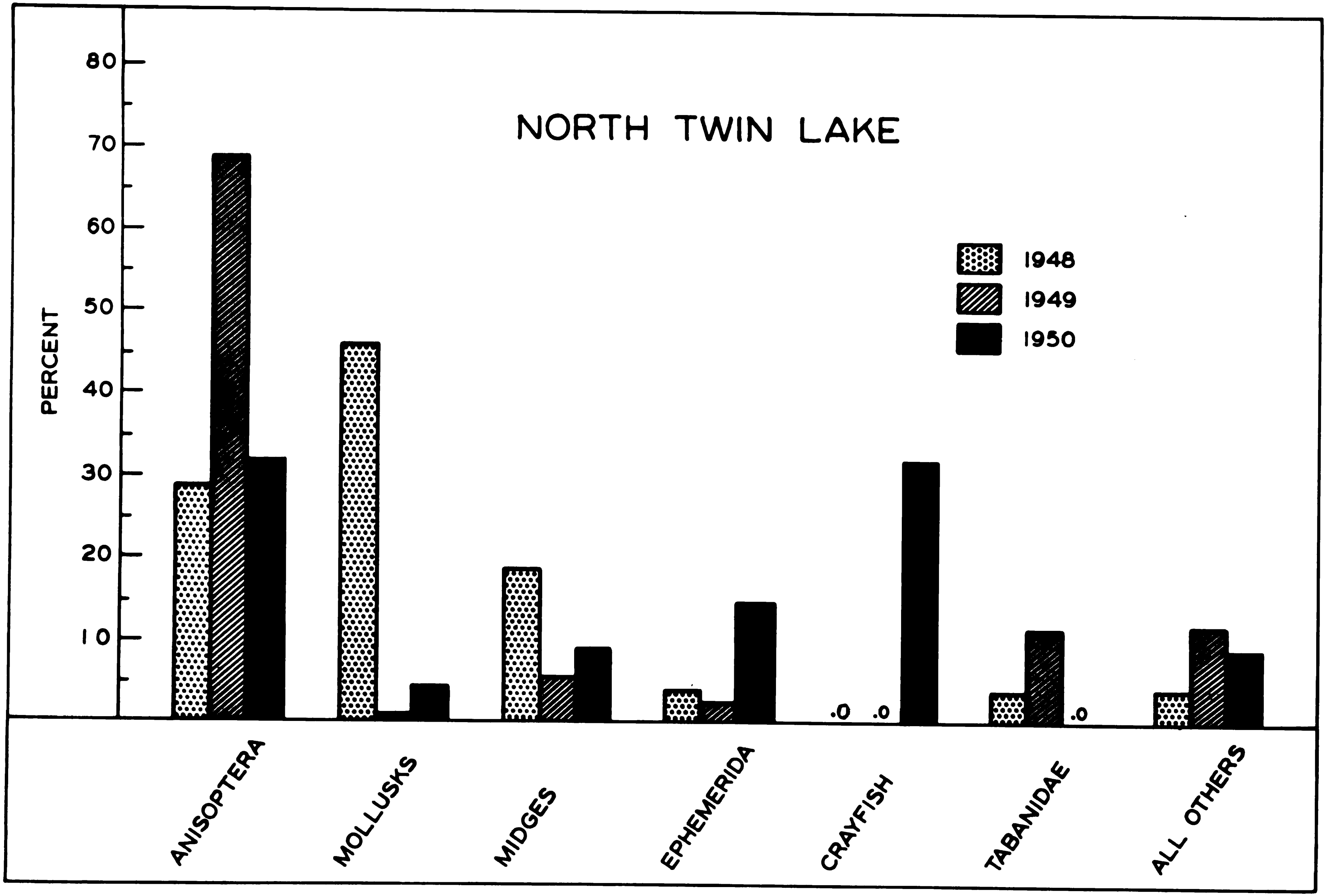

WEST LOST LAKE
PERCENT
80
70
60
50
40
30
20
10
1948
1949
1950
MIDGES
ANISOPTERA
CHAOBORUS
CRAYFISH
EPHEMERIDA
HYALLELA
ALL OTHERS

Figure 23. North Twin Lake (Unfertilized)

Composition of bottom fauna from sampling by percent of total volume.



NORTH TWIN LAKE
PERCENT
80
70
60
50
40
30
20
10
1948
1949
1950
.0
.0
.0
ANISOPTERA
MOLLUSKS
MIDGES
EPHEMERIDA
CRAYFISH
TABANIDAE
ALL OTHERS

volume of the bottom fauna was made up of midges. The feeding habits of the midges as "ooze browsers" made them one of the first groups to reflect the increase in amount of food present in the form of dead plankton. In July of 1949 midge egg masses covered every object from the lake surface to a depth of 18 inches (Figure 23a) and is indicative of the large increase in midges.

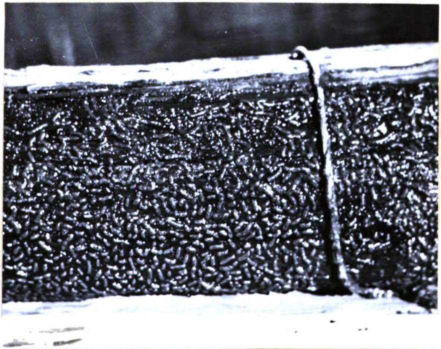
During the determinations of the volume of the individual organisms it was necessary to calculate the average volume of some of the smaller invertebrates. Presented below (Table 16) are the average volumes of several sizes of midges and of the small scud *Hyallela* and the small mayfly *Caenis*.

TABLE 16

CALCULATED AVERAGE VOLUMES OF SMALL INVERTEBRATES

Millimeters		Volume in cc.	Number of organisms
Midges	0 - 4	.0005	200
	5 - 6	.0014	150
	7 - 8	.0032	200
	9 - 10	.0046	200
	11 - 12	.0070	100
	13 - 14	.0120	50
	15 - 16	.0178	45
Hyallela		.0053	250
Caenis		.0050	140

Figure 25a   Midge egg masses on under surface of buoy (Section-Four Lake, July, 1949).



In South Twin Lake there were extensive beds of potomogetons and Chara in the littoral zone. In contrast, the other five lakes had very little rooted aquatic vegetation. There were, then, important differences in the availability to the fish of the food organisms between lakes. The factors of availability could not be measured and make difficult the evaluation of differences in potential fish production between lakes on the basis of amounts of fish food present.

In comparing the food levels of these lakes with the results of others (Ball, 1948; Eggleton, 1931; Adamstone and Harkness, 1923; Deevey, 1941) the extreme paucity of trout food organisms is indicated. In earlier studies Eschmeyer (1937) indicated that these lakes provided interesting trout fishing prior to the establishment of perch populations in the lakes. Others have shown that an increase in the levels of bottom fauna populations can be expected following removal of all or part of warm water fish populations present (Ball and Hayne, 1952; Wilkins, 1952). Thus, care must be taken in attributing increases in the bottom fauna during the present study entirely to the effects of fertilization. The study was designed so that the sampling of control lakes and the two lakes not poisoned would provide a means of determining the increases in fish food organisms due to fertilization and that which was a result of the removal of the predation by the fish populations present prior to poisoning.

The volumes of the trout food organisms (Table 17)

TABLE 17

AVERAGE VOLUME OF TROUT FOOD ORGANISMS PRESENT DURING SUMMERS OF 1948, 1949, AND 1950

	Average volume in cc. per sq. foot			Record of poisonings & fertilizations	
Lakes	1948	1949	1950		
North Twin	.16	.15	.16	Poisoned*	Unfertilized
South Twin	.49	1.47	1.54	Poisoned*	Fertilized 1946-1947
Section-Four	.03	1.10	1.54	Poisoned*	Fertilized 1949-1950
Lost	.07	.57	.29	Not poisoned**	Fertilized 1949-1950
Hemlock	.04	.71	.24	Not poisoned**	Fertilized 1949-1950
West Lost	.07	.19	.44	Poisoned*	Fertilized 1949-1950

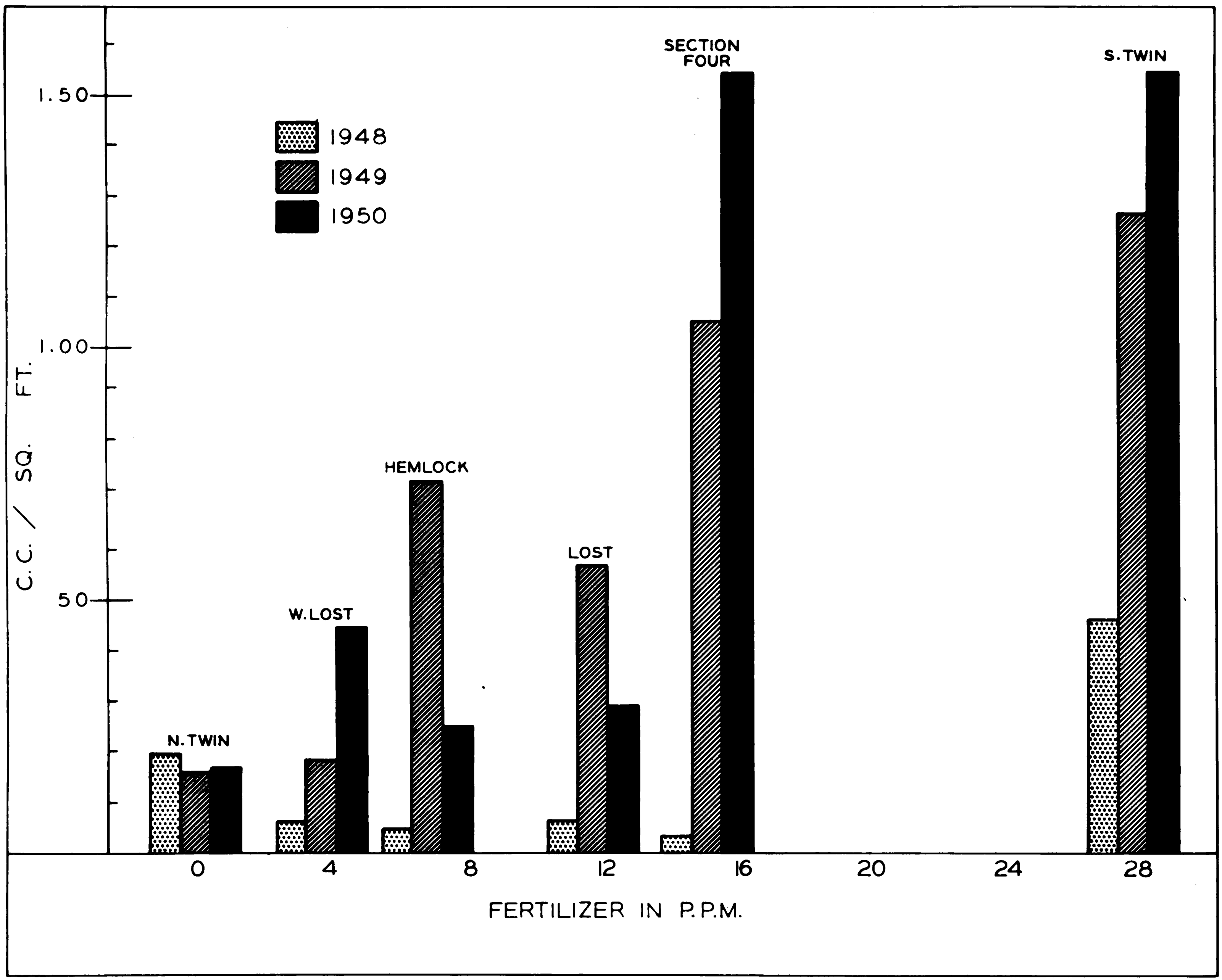
* - August 1 and 2, 1948 complete kill achieved.
** - Minnow populations present throughout period of the study included fatheads, bluntnose, northern redbellied dace and golden shiners.

together with the record of the poisonings and applications of fertilizer are shown for each of the lakes. From these data the apparent increase of trout food organisms in five of the lakes and the effect of the competition of minnow populations in trout lakes may be evaluated. Four of the lakes, West Lost, Hemlock, Lost, and Section-Four, were fertilized during 1949 and 1950. During the first year of fertilization, the increase in the volumes of food organisms present was correlated very closely with the amount of fertilizer added (Figure 24). During the second year of fertilization, 1950, the food organisms of the two lakes in which trout alone were present, Section-Four and West Lost, continued to increase, however, the amounts of food organisms present in the two lakes in which populations of minnows were present decreased sharply. The interpretation applied to these data is that the bottom fauna organisms were able to utilize larger food supplies to achieve important increases in one season. However, the larger supplies of food organisms available increased the survival of the minnows spawned in the spring of 1950 and the increased predation of the minnows depressed the population of fish food organisms. Additional evidence that this interpretation is correct may be found in Figures 27 and 28 showing the depth distribution of the fish food organisms for the two lakes with minnow populations, Lost and Hemlock. The 1950 decrease in amount of food organisms occurred chiefly in the depth zone of from 0 to 5 feet, where the minnow populations were concentrated.

If the above interpretation of the data is correct, then it is apparent that minnows in trout lakes are undesirable. While small numbers of minnows were utilized by the trout for food, the decrease in the efficiency in the transfer of energy when another trophic link is added has been pointed out by Lindeman (1942) and Clarke (1946). Supporting evidence that the presence of minnows in Lost

Figure 24. The volume of trout food organisms per square foot present in each lake (1948, 1949 and 1950).

Total amounts of fertilizer added are indicated.



1948
1949
1950
N. TWIN
W. LOST
HEMLOCK
LOST
SECTION FOUR
S. TWIN
1.50
1.00
50
C.C. / SQ. FT.
0
4
8
12
16
20
24
28
FERTILIZER IN P.P.M.

and Hemlock Lakes was undesirable may be seen in the section of fish production. The fish from Lost and Hemlock Lakes caught by fishermen were smaller than the fish caught in the other lakes (Figure 31). The production of pounds of trout per acre for Lost and Hemlock Lakes was lower than for any of the other lakes.

In comparing the standing crop of the bottom fauna for each of the lakes during the three years of the study, first consideration is given to the volume of trout food organisms present. The volume of the trout food organisms present in the bottom fauna for each lake for the years 1948, 1949, and 1950 have been correlated with the amounts of fertilizer added in p.p.m. (Figure 24). During 1948, the summer prior to the present fertilization program, South Twin Lake had the largest standing crop of trout food organisms by volume and was followed by North Twin Lake with the other four lakes of the group supporting lower populations of food organisms. South Twin Lake had been fertilized during the summers of 1946 and 1947 and the greater volume of trout food organisms present there is thought to be largely the result of the added nutrients. The 1948 sampling indicated that the volume of trout food organisms in North and South Twin Lakes, .19 and .45 ccs. per square foot respectively, was considerably in excess of the amounts present in the other four lakes of the group, all of which had less than .07 cc. per square foot.

The volume of food organisms present increased during the period of fertilization in the fertilized lakes and did not increase in North Twin Lake where no fertilizer was added. In South Twin Lake, fertilized in 1946 and 1947, important increases also occurred.

The effect on the bottom fauna of the removal of predation from warm water fishes may be observed in North and South Twin Lakes from which slow growing populations of perch were removed but which were not fertilized during the present study. There was no change in the volume of trout food organisms in North Twin Lake following the removal of the perch while in South Twin Lake the volume of the trout food organisms was approximately trebled following the removal of the perch population (Table 17 and Figure 24). The explanation for this seemingly contradictory evidence is believed due to the presence of extensive beds of submergent aquatic plants in South Twin Lake. Beds of potomogetons and Chara were present around the entire perimeter of the lake from near shore to a depth of 15 feet and beyond. It was in the bottom areas occupied by these plant beds that the increases of food organisms occurred. It is concluded that the predation of trout on the food organisms of the bottom fauna groups was efficient enough to replace to a large degree the former predation of the perch in North Twin, Section-Four, and West Lost Lakes but was ineffective in South Twin Lake because of the presence of dense beds of submerged aquatics. If this assumption is correct, the increase in the food organisms in the fertilized lakes was largely due to the applications of fertilizer.

Two important food items of the brown trout in North Twin Lake were backswimmers (*Notonecta undulata*) and water boatmen (*Arctocorixia alternata*) were not collected by the Ekman sampler at a rate commensurate with their obvious abundance. The analysis of the stomach content of the brown trout from North Twin Lake (Table 24) also revealed that zooplankton (mostly *Daphnia*) was an important source of food for the trout. The trout in North Twin Lake grew at a faster rate than fish from any of the other lakes and the production of trout in pounds per acre was second only to South Twin Lake. These facts suggest that sampling the bottom fauna did not provide a true picture of the amount of trout food present in North Twin Lake and partially explains how the production and growth rate of the trout present could be so high while the volume of food organisms indicated by the bottom sampling program remained low (Figure 24).

Changes in the vertical distribution of the bottom fauna (mollusks omitted) were recorded during the three years of the study (Tables 18, 19, 20, 21, 22, and 23 and Figures 25, 26, 27, 28, 29 and 30). Certain patterns of distribution are present in each lake and the effect of fertilization on these is indicative of the general increase in the productivity of the lake.

TABLE 18

SOUTH TWIN LAKE
DEPTH DISTRIBUTION OF TROUT FOOD ORGANISMS BY VOLUME

	1948		1949		1950	
Depth (feet)	Av. volume per sample	No.*	Av. volume per sample	No.	Av. volume per sample	No.
0 - 5	.34	7	1.16	8	.94	9
6 - 10	.07	6	.37	10	.88	11
11 - 15	.10	6	.18	9	.28	8
16 - 20	.22	9	.04	8	.14	8
21 - 25	.01	6	.09	7	.05	9
26 - 30	T	6	....	..	.03	8

* - Number of samples

TABLE 19

SECTION-FOUR LAKE
DEPTH DISTRIBUTION OF TROUT FOOD ORGANISMS BY VOLUME

	1948		1949		1950	
Depth (feet)	Av. volume per sample	No.*	Av. volume per sample	No.	Av. volume per sample	No.
0 - 5	T	6	.53	9	.72	8
6 - 10	.01	6	.63	10	.25	11
11 - 15	.03	5	.33	13	.27	8
16 - 20	.01	6	.10	9	.48	8
21 - 25	T	5	.04	6	.44	8
26 - 30	T	4	.01	6	.15	8

* - Number of samples

TABLE 20

LOST LAKE
DEPTH DISTRIBUTION OF TROUT FOOD ORGANISMS BY VOLUME

	1948		1949		1950	
Depth (feet)	Av. volume per sample	No.*	Av. volume per sample	No.	Av. volume per sample	No.
0 - 5	T	7	.39	7	.05	8
6 - 10	.06	9	.02	9	.03	9
11 - 15	.02	7	.09	8	.11	7
16 - 20	.01	8	.08	12	.16	6
21 - 25	T	7	.13	7	.07	5
26 - 30	T	7	.15	1	.02	4

* - Number of samples.

TABLE 21

HEMLOCK LAKE
DEPTH DISTRIBUTION OF TROUT FOOD ORGANISMS BY VOLUME

	1948		1949		1950	
Depth (feet)	Av. volume per sample	No.*	Av. volume per sample	No.	Av. volume per sample	No.
0 - 5	.02	12	.89	11	.28	7
6 - 10	.05	11	.09	18	.04	8
11 - 15	.00	7	.08	15	.04	6
16 - 20	.00	4	.01	6	.00	6
21 - 25	.00	2	.00	5	T	6
26 - 30	.00	4	.00	1	T	7

* - Number of samples.

TABLE 22

WEST LOST LAKE
DEPTH DISTRIBUTION OF TROUT FOOD ORGANISMS BY VOLUME

	1948		1949		1950	
Depth (feet)	Av. volume per sample	No.*	Av. volume per sample	No.	Av. volume per sample	No.
0 - 5	T	9	.13	8	.20	8
6 - 10	.01	8	.03	11	.08	10
11 - 15	T	7	.01	9	.09	8
16 - 20	.01	6	.05	14	.23	8
21 - 25	T	6	.06	8	.06	8
26 - 30	T	6	T	10	.02	8

* - Number of samples.

TABLE 23

NORTH TWIN LAKE
DEPTH DISTRIBUTION OF TROUT FOOD ORGANISMS BY VOLUME

	1948		1949		1950	
Depth (feet)	Av. volume per sample	No.*	Av. volume per sample	No.	Av. volume per sample	No.
0 - 5	.15	7	.16	8	.07	9
6 - 10	.07	6	.06	11	.12	11
11 - 15	.05	7	T	10	.02	8
16 - 20	.01	6	T	10	T	7
21 - 25	.01	10	.00	2	T	8
26 - 30	.00	5	.00	1	.02	9

* - Number of samples.

Figure 25 South Twin Lake

(Fertilized 1946 - 1947)

Depth distribution of trout food organisms by volume during the summers of 1948, 1949 and 1950.

Figure 26 Section-Four Lake

(Fertilized 1949 - 1950)

Depth distribution of trout food organisms by volume during the summers of 1948, 1949 and 1950.

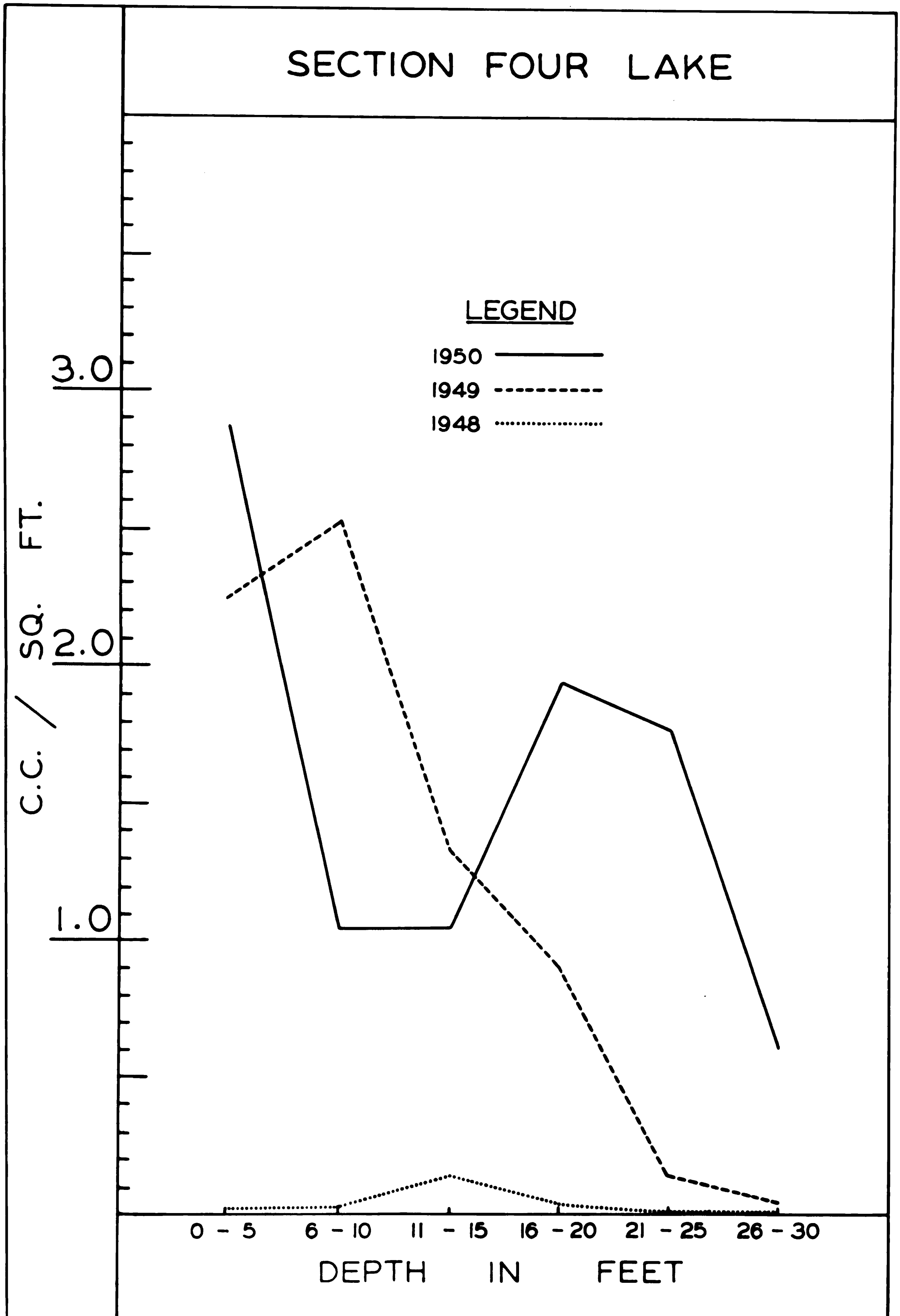
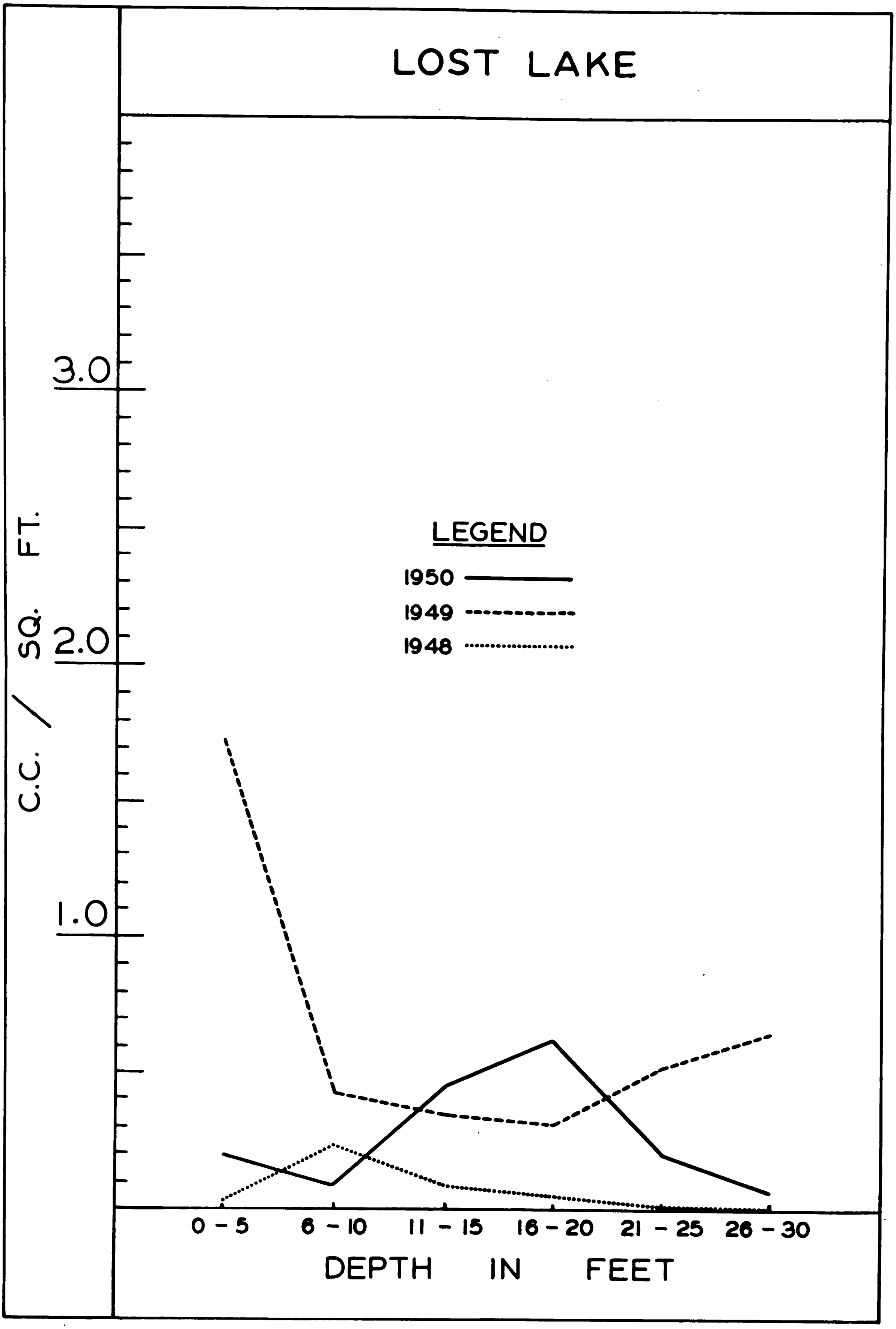

SECTION FOUR LAKE
LEGEND
1950
1949
1948
3.0
2.0
1.0
C.C. / SQ. FT.
0 - 5
6 - 10
11 - 15
16 - 20
21 - 25
26 - 30
DEPTH IN FEET

Figure 27 Lost Lake

(Fertilized 1949 - 1950)

Depth distribution of trout food organisms by volume during the summers of 1948, 1949 and 1950.



LOST LAKE
LEGEND
1950
1949
1948
3.0
2.0
1.0
C.C. / SQ. FT.
0 - 5
6 - 10
11 - 15
16 - 20
21 - 25
26 - 30
DEPTH IN FEET

Figure 23 Hemlock Lake

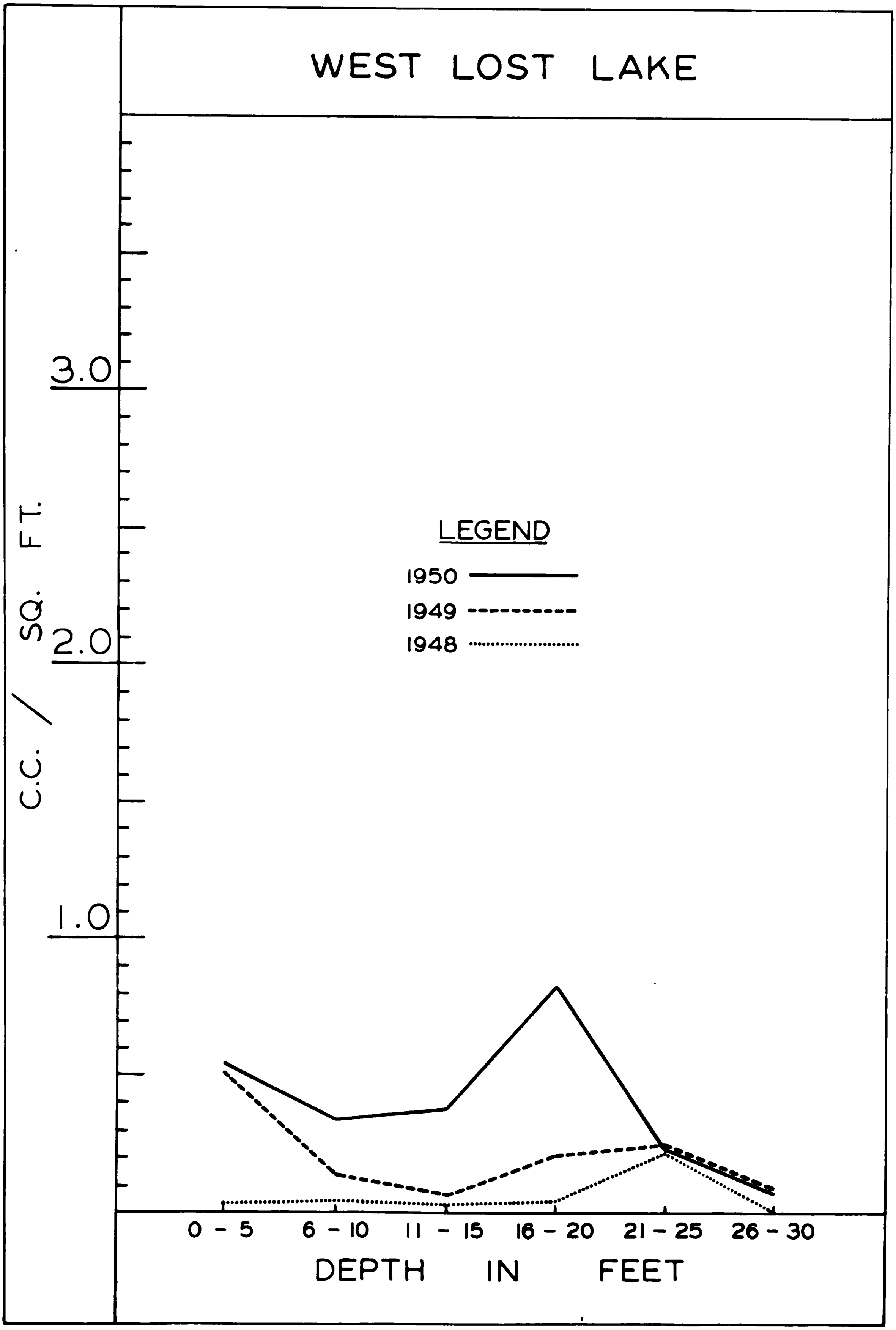
(Fertilized 1949 - 1950)

Depth distribution of trout food organisms by volume during the summers of 1948, 1949 and 1950.

Figure 29 West Lost Lake

(Fertilized 1949 - 1950)

Depth distribution of trout food organisms by volume during the summers of 1948, 1949 and 1950.

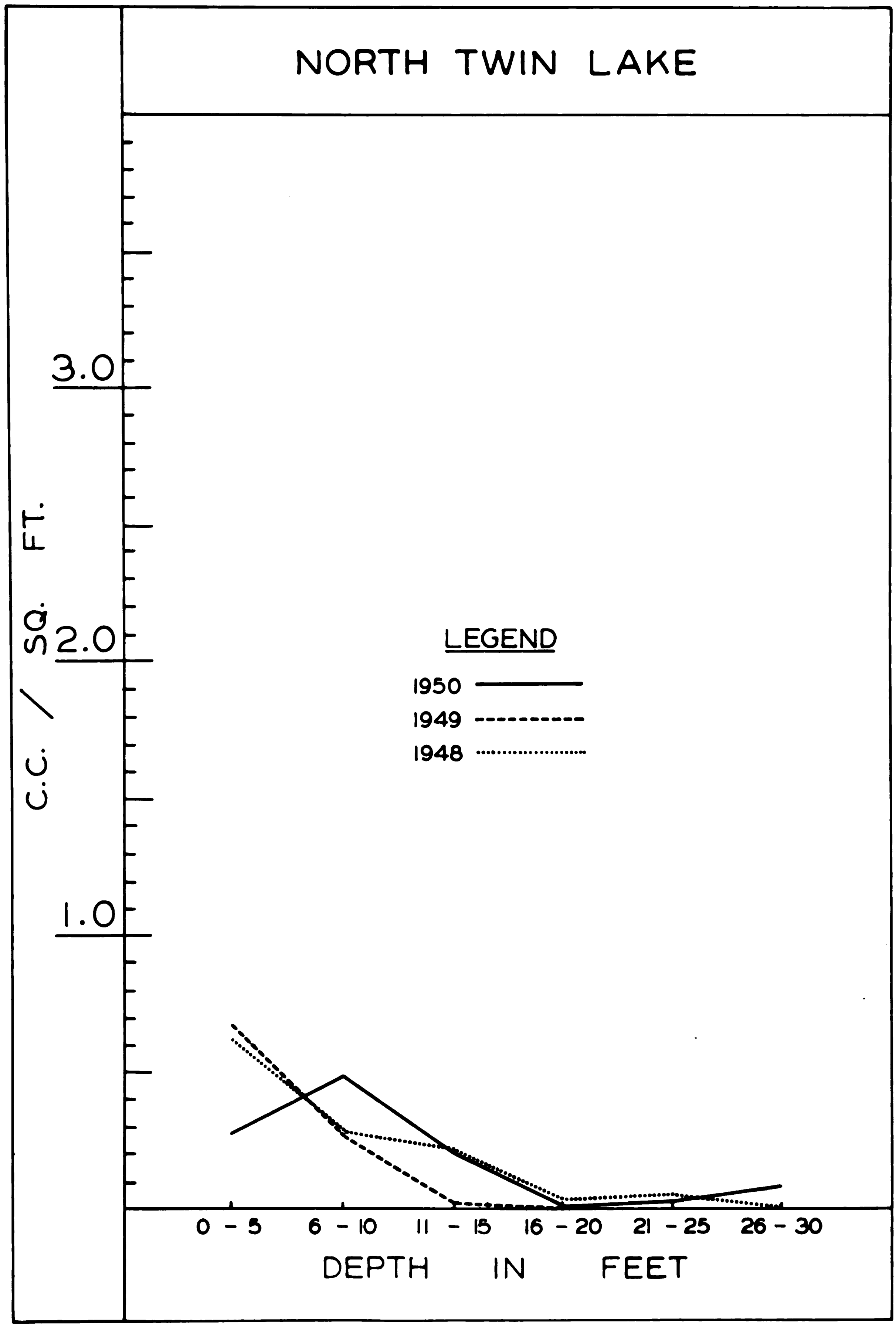


WEST LOST LAKE
3.0
2.0
1.0
C.C. / SQ. FT.
LEGEND
1950
1949
1948
0 - 5
6 - 10
11 - 15
16 - 20
21 - 25
26 - 30
DEPTH IN FEET

Figure 30 North Twin Lake

(Unfertilized)

Depth distribution of trout food organisms by volume during the summers of 1948, 1949 and 1950.



NORTH TWIN LAKE
C.C. / SQ. FT.
3.0
2.0
1.0
LEGEND
1950
1949
1948
0 - 5
6 - 10
11 - 15
16 - 20
21 - 25
26 - 30
DEPTH IN FEET

Distribution of food organisms in all six lakes in 1948, with the exception of South Twin Lake, was similar to one of the distribution curves described by Deevey (1941). This curve is characterized by having the highest level of bottom fauna populations in the shallow area and a steady rate of decrease in the numbers present as the depth increases. Deevey states that this distribution is characteristic in general of several unproductive Connecticut lakes and points out that European investigators have found the same pattern in unproductive lakes in Europe. The pattern of distribution in South Twin Lake in 1948 differed from the general pattern of the other five lakes in the group. In South Twin Lake the distribution of the bottom fauna (Figure 25) indicated the greatest population of bottom organisms in the shallow water with a general decline as the depth increased until the region of the sub-littoral zone was reached, there the populations increased and a second decrease followed as the depth increased. This type of distribution is somewhat intermediate to distributions indicated by Deevey as characteristic of a more productive type of lake which he termed "mesotrophic Chironomus" lakes. Borutsky (1939) calculated the heavy mortality which occurs in midges at the different stages of metamorphosis. The larval midge mortality in depths beyond the littoral zone is nearly complete in unproductive lakes because of the paucity of food. The increased volume of the bottom fauna in the sub-littoral zone was largely from species of "plumosis type" Chironomus. The increase in these midges indicated better survival and was a direct result of greater amounts of food present in the form of dead plankton from the blooms which followed fertilization (Curry, personal communication). It may be concluded that South Twin Lake, fertilized during the summers of 1946 and 1947, had a pattern of distribution for the bottom fauna as a result of fertilization which was characteristic of an eutrophic type of lake.

In June and July of 1949 and 1950, West Lost, Hemlock, Lost, and Section-Four Lakes received applications of fertilizer. The distribution pattern of the bottom fauna in these four lakes changed from the pattern characteristic of unproductive lakes to a pattern similar to that of South Twin Lake in 1948 and to that of more productive types of lakes indicated by Deevey (1941) during fertilization (Figures 26, 27, 28, and 29). The increase in the volume and food organisms in the sub-littoral zone was again due to increased numbers of midges of the plumosis type. The exception was Hemlock Lake which had a distribution pattern very similar to that described by Deevey as typical of certain lakes with sub-marginal productivity.

During 1949 and 1950 the distribution of bottom fauna in South Twin Lake changed from a pattern similar to Deevey's mesotrophic Chironomus to the pattern characteristic of less productive lakes. It was concluded that this change was due to the subsiding of the effects of fertilizer added in 1946 and 1947.

North Twin Lake, the unfertilized control lake, continued to display the distribution pattern of an unproductive oligotrophic lake during the three years of the study.

The conclusion may be drawn that the application of fertilizer brought about a change in the depth distribution pattern of the bottom fauna from a pattern typical of unproductive oligotrophic lakes to a pattern indicated by others to be typical of lakes with a higher level of productivity. The data from South Twin Lake indicated that the pattern induced by fertilization remained for the first summer following fertilization but disappeared during the second and third summers after fertilization and the pattern typical of less productive lakes replaced it.

Stomach Analyses

Certain information is provided by the food analyses of brown trout stomachs collected during the summer of 1950. Collections were made at the time of poisoning and during the opening week of trout season.

The data presented (Table 24) include numbers of stomachs examined, total volume of food present, and average volume of food in each stomach. The percent of the trout stomachs in which each food group appeared and the percent of the total volume contributed by each group were calculated.

TABLE 24

RELATIVE IMPORTANCE OF INVERTEBRATES AS FOOD OF BROWN TROUT INDICATED BY STOMACH ANALYSES (1950)

Lakes		North Twin	South Twin	West Lost	Section-Four	Lost	Hemlock
Number of stomachs		25	44	33	26	23	21
Total volume (cc.)		21.0	30.4	41.2	27.3	2.1	3.70
Average vol. per stomach		.60	.69	1.25	1.05	.09	.17
Chironomidae (pupa)	A	100	74	71	39	87	95
	B	44	8	7	5	34	51
Hyallela	A	...	5	...	58	24	...
	B	...	2	...	19	4	...
Crayfish	A	...	57	28	8	9	4
	B	...	82	22	15	71	7
Notonectidae	A	72	...	52	...	...	...
	B	26	...	51	...	...	...
Odonata	A	8	13	5	27	4	24
	B	6	1	1	22	5	21
Cladocerans	A	60	9	...	...	...	...
	B	13	T	...	...	...	...
Ephemerida	A	8	4	...	19	...	...
	B	T	T	...	2	...	...
Corixidae	A	...	...	...	4	53	32
	B	...	...	...	T	11	13
Terrestrial insects*	A	40	...	42	...	...	19
	B	6	...	5	...	...	2

* - Winged ants.
A - Percent of stomachs with organisms present.
B - Percent of total volume.

Bottom fauna provided much of the food for the brown trout. There was, however, considerable variation in importance of the food organisms between lakes. Midge pupae were the most frequent article of food but were not volumetrically the most important. While midge pupae were present in nearly all the brown trout stomachs no midge larvae were found. Midges were apparently eaten only during the time of emergence. Crayfish formed the bulk of the food volume in South Twin and Lost Lakes. Notonectidae were important as food in West Lost and North Twin Lakes and corixids were present in many of the trout stomachs from Hemlock and Lost Lakes. Scuds were a common food only in Section-Four Lake and daphnia were present in over half of the fish from North Twin Lake. When the fish had been feeding on daphnia they were the only food present, indicating that the trout actively sought this food. North Twin Lake was the only one of the group where large numbers of daphnia were present consistently. They were present in the lower thermocline and were apparently readily available to the trout. With the exception of midges, the major food items of the trout in North Twin Lake were not adequately represented in the bottom fauna samples. The effectiveness of an Ekman dredge in capturing crayfish is also open to question because of their avoiding action.

The average total volume of food present in the stomachs of fish taken from Lost and Hemlock Lakes was much less than for the other four lakes. Both lakes were fertilized but contained populations of minnows. The growth rate for the trout from these lakes and production in pounds per acre were also lower. Minnows were never an important food item.

Foods of brown and brook trout from South Twin Lake were compared. Midge larvae and snails, common foods of the brook trout, were not present in the brown trout stomachs. Terrestrial insects were found more frequently in the brown trout. Brook trout fed on bottom food organisms not selected by the brown trout, which fed more from the surface.

While much information can be drawn from the limited stomach sampling program, conclusions drawn should not be weighed too heavily without additional data.

Angling Yield

During the fishing seasons of 1949 and 1950 four of the lakes were fertilized and in this period the yield of trout to the anglers greatly increased. Trash fish were removed from four of the lakes in 1948 and in September of the same year heavy concentrations (500 per acre) of yearling brown trout were planted in all of the lakes.

The limited records indicate that, prior to fertilization, poisoning, and plantings of brown trout, only Hemlock and Lost Lakes provided trout fishing. Total take was estimated as 50 brook trout from Lost Lake and 25 brook trout from Hemlock Lake in 1948. The average length of these fish was less than eight inches. Very little fishing effort was expended on the lakes after the opening week end.

During the winter of 1948-49 The Institute for Fisheries Research, under a special act of the Michigan legislature, was given control of the six lakes utilized for the present study and five miles of the Pigeon River. The area was designated as the Pigeon River Trout Research Area and is dedicated to trout research. Since its organization, the research station has been headed by Dr. Edwin Cooper. During the 1949 and 1950 trout seasons, fishing was by free permit only. A limit of five, seven-inch fish per day was placed in effect on all lakes. Length and weight of all fish removed by fishermen from the lakes as well as complete information on the numbers of hours fished, baits used, and time of day fished were recorded. The collection of these data and the cooperation of the staff at the Pigeon River station was of the utmost value to the writer.

During the 1949 season there was an increase in the number of fishermen utilizing the area. The increased use of the area reflected the publicity given the area as a trout research station. The use and fish yield from the lakes increased during the 1949 fishing season (Table 25).

The total of 823 hours of fishing represents considerable use of the lakes. The major portion of effort was

TABLE 25

FISHING EFFORT AND SUCCESS BY LAKES
(1949)

Lakes	No. of fishing trips	Per cent success-ful	No. of hours fished	Fish caught	Catch per hour
South Twin	142	45.0	410.5	200	.487
Lost	85	30.6	224.5	76	.348
Hemlock	30	43.3	104.0	39	.375
Section-Four	19	47.4	51.0	28	.548
West Lost	9	0.0	27.5	--	.000
North Twin	4	0.0	5.5	--	.000
Totals	289	38.3*	823.0	345	.419*

* - Average.

still early season fishing. The lowered rate of success after mid-May is indicated when the fishing success and effort is compared by months (Table 26). Nearly all of the fishing in August and September was confined to South Twin Lake. A decided improvement in catch per hour occurred after the July low and the best fishing of the season in terms of catch per hour was in September.

A comparison between the 1948 and 1949 fish populations of these lakes indicates the progress made toward their re-habilitation. The removal of the trash fish population in four of the lakes and a measurable increase in the food organisms of the five fertilized lakes provided a situation basically favorable for the brown trout which were introduced. Growth and survival was best in South Twin Lake and Section-Four Lake and corresponded to the highest rates of fertilization. West Lost and North Twin Lakes showed poor survival and moderate growth rates. Hemlock Lake seemed to have moderate survival and growth. Lost Lake returns indicated reasonably good survival but very poor growth.

TABLE 26

DISTRIBUTION OF FISHING EFFORT AND SUCCESS BY MONTHS (1949)

Month	Hours of effort	Fish caught	Catch per hour
April*	80.5	50	.621
May	458.5	205	.446
June	90.0	34	.377
July	71.5	4	.056
August	51.5	14	.270
September**	59.5	38	.638
Total	821.5		

* - Season opened on last day of April.
** - Season closed on September 11.

The six lakes of the present study achieved widespread popularity during the 1950 season. The lakes were visited by fishermen from nine states and 48 Michigan counties. Excellent trout fishing was provided by most of the six lakes. Limit catches (5 fish) were the rule during the fore part of the season and a high quality of fishing was to be had on one or more of the six lakes throughout the season. Valuable information was drawn from the creel census records concerning the food habits of the trout in the lakes, the effectiveness of hook and line fishing in removing brown trout to the angler in comparison to the other species of trout. The data establishes the amount of use made of the lakes in 1950 and the fishing success (Table 27).

TABLE 27

DISTRIBUTION OF FISHING EFFORT AND SUCCESS BY LAKES (1950 SEASON)

Lakes	No. of fishing trips	Percent successful	No. of hours fished	Fish caught	Catch per hour
South Twin	390	47.4	1,063	548	.52
Section-Four	367	58.9	1,000	688	.69
Lost	221	53.4	592.5	470	.79
Hemlock	113	53.1	306.5	231	.75
West Lost	167	61.7	396	381	.96
North Twin	237	35.9	569.5	222	.39
Totals	1,495	51.3*	3,927.5	2,540	.63*

* - Average

In 1,495 fishing trips to the lakes during which a total of 3,953.5 hours of effort was expended on the lakes, 51.3 percent of the trips were successfull and 2,540 trout were caught at the rate of .63 fish per hour. The catch-per-hour figure is excellent by Michigan standards.

The creel census records of 1949 and 1950 compared to the small use made of the lakes in 1948 illustrate the large increase in the recreational value of the lakes. Not only was the increased effort spent on the lakes more profitable in terms of fish per hour of effort but also the effort and success was more equally distributed throughout the fishing season (Table 28).

TABLE 28

DISTRIBUTION OF FISHING EFFORT AND SUCCESS BY MONTHS (1950)

Month	Hours of effort	Fish caught	Catch per hour
April*	210.5	251	1.021
May	1,712.5	1,296	.757
June	262.5	117	.446
July	481.0	180	.374
August	851.5	524	.615
September**	416.0	229	.550
Total	3,932.0		

* - Season included only last two days of April.
** - Season ended September 11.

The average size of the trout taken by angling from each lake during the 1950 season was compared using the statistical procedure of covariance (Snedecor, 1946). Since the times of capture varied between lakes (Table 29), it was desired to eliminate the variation in average length of the trout due to differences in time of capture. Covariance in this instance allows the worker to evaluate the effect of time and compare the variation due to differences between lakes after the effect of time has been subtracted.

TABLE 29

THE DISTRIBUTION OF PERCENT OF TOTAL CATCH BY MONTHS

Lakes	May*	June	July	August	September**
Hemlock	95.5	4.0	.5	0.0	0.0
Lost	87.7	12.1	0.0	.2	0.0
Section-Four	65.6	6.7	23.1	3.1	1.5
South Twin	53.4	4.9	1.3	34.4	6.0
North Twin	32.8	0.0	2.4	32.4	32.4
West Lost	10.3	0.0	.5	60.6	28.6

* - Includes last two days of April.
** - Season ended September 11, 1950.

After applying covariance (Appendix p. C), in order to determine the adjusted mean length of the trout from each lake (Table 30), the method of graphic presentation (Dice and Leraas, 1936) for the mean with plus and minus twice the standard error indicated was used (Figure 31).

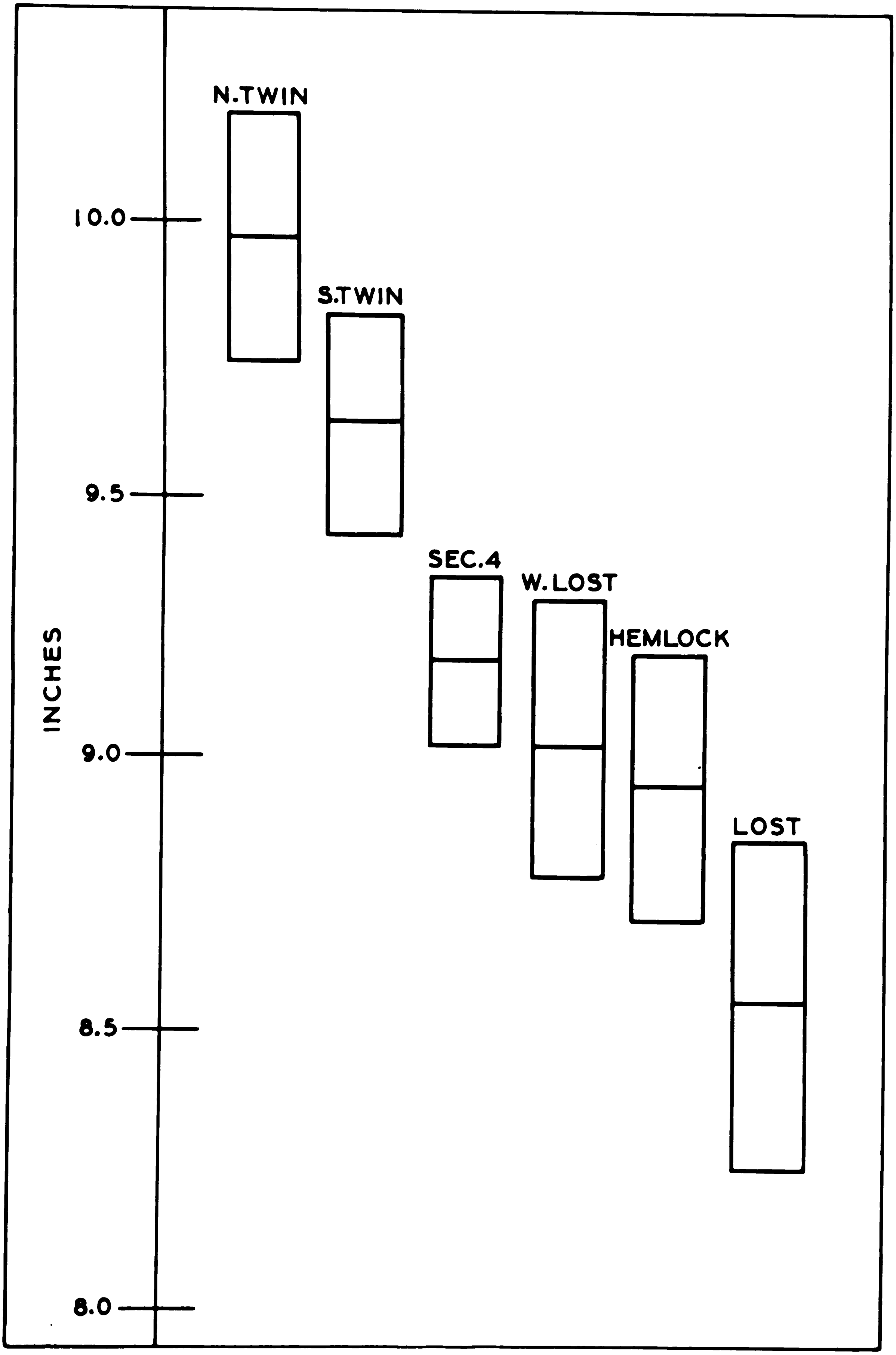
From these comparisons it was determined that the trout from North and South Twin had a greater average length than trout from any of the other lakes. There was no real difference in the size of the trout between the Twin lakes. The fish from Section-Four Lake were smaller than those from North and South Twin, larger than the fish from Lost Lake and were not different in length from the fish from West Lost and Hemlock Lakes. No difference could be shown between average length of the fish from West Lost, Hemlock, and Lost Lakes.

TABLE 30

AVERAGE LENGTH IN INCHES OF THE BROWN TROUT REMOVED BY ANGLING BEFORE AND AFTER ADJUSTMENT FOR TIME OF REMOVAL

Lakes	Unadjusted	Adjusted
South Twin	9.66	9.65
Section-Four	9.22	9.18
Lost	8.26	8.59
Hemlock	8.59	8.95
West Lost	9.41	9.01
North Twin	10.13	9.96

Figure 31 The corrected average length of brown trout caught from each lake during 1950.


N.TWIN
S.TWIN
SEC.4
W.LOST
HEMLOCK
LOST
10.0
9.5
9.0
8.5
8.0
INCHES

The value of the lakes in terms of fishing hours and the fish in the angler's creel underwent a striking increase during the period of the present program. In 1948 two to three hundred hours of early season fishing produced approximately 75 brook trout averaging less than eight inches. In 1949 some 823 hours of effort produced 345 trout averaging about eight and one-half inches and in 1950 nearly 4,000 hours of fishing were spent on the lakes and 2,540 brown trout averaging 9.4 inches were creeled. The effort was no longer concentrated in the first month of the season but was spread throughout the entire season with much of the very best fishing occurring in August and September.

Considerable information has been gained concerning the catchability of brown trout in lakes. Fishing quality remained high throughout the summer. The heavy fishing pressure took a high proportion of the fish present but did not remove nearly all the fish present as so frequently occurs when brook trout lakes are subjected to comparable pressure. Because more trout avoided capture for longer periods, the fishing public had the opportunity of catching fish of larger average size. Further, the brown trout fed on or near the surface and could be taken on a dry fly throughout the season, thus, offering sport superior to the taking of fish from deep water which is the only method of taking brook trout after the early season fishing.

It has been suggested that the 1950 season was an exceptionally cool one and the presence of brown trout in the upper waters throughout the season was an exception. Further trials should provide the answer. It is suggested, however, that brown trout comfortably occupy warmer water than brook trout and will therefore spend a greater proportion of any season in the surface waters than will brook trout.

The credit for these changes in recreational value must be attributed to three factors. Trash fish were removed from four of the lakes; the planting schedule was changed from 500 fingerling brook trout per acre to the same number of yearling brown trout; and fertilizer was applied to four of the lakes (a fifth, South Twin, was fertilized in 1946 and 1947). All three changes undoubtedly contributed to increasing the yield of fish. These were important factors in total production as well as in yield to the angler and further discussion is withheld until the discussion of trout production.

In the preparation of the data from the creel census program certain interesting observations concerning the nature of the data from this source developed and have been evaluated.

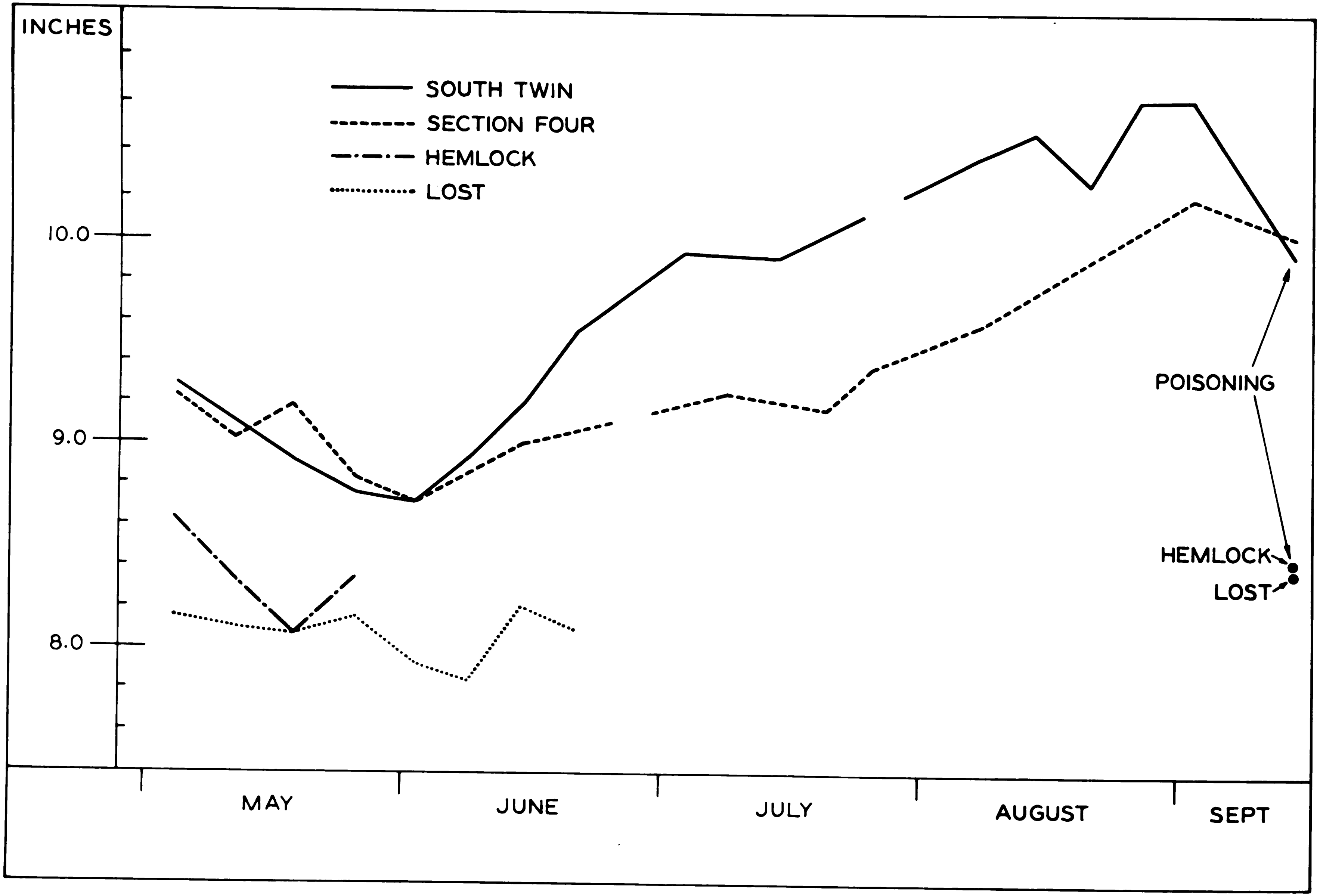
The average length of the trout caught each week was calculated. During the first five or six weeks of the 1950 season the average length of the trout captured decreased. This fact was observed on the four lakes (Figure 32) where weekly catches were sufficiently large (15 to 253 fish).

In seeking an explanation of the decrease in the average length of the fish, selective action of fishing was investigated. It was suspected that, because of the ease in which the five fish limit could be taken on some lakes of the group during this period, that the fishermen were returning the smaller legal fish to the water and retaining only the larger. Continuing this line of reasoning, as the fish became more difficult to take a decrease in average length resulted. To determine if this was actually what was happening, the limit catches were compared to the catches of only one or two fish, reasoning that the man taking five fish would be more selective. There was no difference in the average of the two catch groups and both showed the decrease noted in the general averages.

It was decided that the selection of the larger fish on the part of the fishermen was inherent in hook and line fishing. That the larger, faster growing portion of fish population is more vulnerable to fishing has been one explanation of Lee's phenomena (Hile, 1936). Cooper (Ms.), working on the Pigeon River in the same area as the present study, recently found that the fishermen in the stream selected the faster growing fish present. It is necessary to explain why the factor of selectivity should produce this type of curve of the average lengths (Figure 32). The correct explanation is thought to be that little growth oc-

Figure 32. Average lengths (each week) of brown trout removed by angling throughout the 1950 season.

Average lengths of brown trout recovered after poisoning (September 25, 26, 1950) are also indicated.


INCHES
10.0
9.0
8.0
SOUTH TWIN
SECTION FOUR
HEMLOCK
LOST
POISONING
HEMLOCK
LOST
MAY
JUNE
JULY
AUGUST
SEPT

curred from the opening of the trout season to the last of May. The action of the fishing in selecting the larger, more rapid growing fish during this time depressed the average size of fish present in the lake. Examination of the "K" factor or factor of condition of the brown trout during this period indicated that the condition of the fish improved rapidly and that the condition factor of the trout at the point where rapid increases in the average length began stood at .86 to .88 for the fish of each of the four lakes. It is therefore reasoned that this condition must be reached before rapid growth can begin. The average length of the fish taken by poison at the end of September was smaller than the averages indicated by the anglers' catch during the last week of the season for South Twin and Section-Four Lakes. This provided additional evidence that fishing tends to select the more rapidly growing fish.

It has been shown from the data that the faster growing fish and larger fish present in trout lakes are more vulnerable to fishing. There is indication that the trout did not begin to grow in these lakes until after reaching a condition factor of .86 to .88. The combination of selectivity of fishing and a delayed beginning of growing apparently were the cause of the peculiar curve formed when the average lengths of the fish were plotted.

It was noted during the examination of the creel census data that changes in fishing effort seemed to be correlated closely with the quality of the fishing. There was considerable fluctuation in the quality of the fishing. A lake producing good catches might suddenly cease to provide good fishing and another lake where no trout were being caught might suddenly provide excellent results.

The degree of this correlation between past success and present effort has been determined in the following manner. From the total hours of effort on all lakes the percent of fishing provided by each lake for the season (Table 31) and the expected effort for each week has been calculated and the differences between expected effort and actual effort calculated (Appendix p. D).

TABLE 31

HOURS OF FISHING EFFORT AND PERCENT OF TOTAL HOURS (1950)

Lakes	Hours of effort	Percent of total
South Twin	1,063.0	.271
Section-Four	1,000.0	.255
Lost	592.5	.151
North Twin	569.5	.145
West Lost	396.5	.101
Hemlock	306.5	.078
Totals	3,928.0	.996

The lakes were ranked by fishing quality for each week of the season (Table 32). The variability due to regression ("r") was calculated from the rank of the lake in fishing quality and the difference from the expected in fishing effort. The formula for "r" (Walker, 1943) is presented:

$$r = \frac{S\ xy}{\sqrt{S\ x^2 \cdot S\ y^2}}$$

If fishing effort is high following the period when a lake ranks high in success and vice versa then the value for "r" approaches closer -1. The nearer the value to -1 the greater the correlation. From the above computations, the degree of correlation was to be found highly significant for five of the six lakes (Table 33). The more outstanding the fishing quality the greater degree of correlation was found. For example, in West Lost Lake where the ranking of the lake in quality changed from a consistent fifth or sixth place to first place the degree of correlation was high.

In other lakes where the fishing quality was neither very good nor very bad but was consistently mediocre, the degree of correlation was lower. For South Twin Lake the fishing effort was not found to be influenced to a significant degree by the preceding fishing quality. The lake was usually near the mid-rank according to success and correlation was actually reversed. The poorer the past fishing the more effort expended.

TABLE 32

CATCH PER HOUR FOR EACH WEEK AND RANK OF LAKE BY FISHING SUCCESS
(1950 SEASON)

Weeks	South Twin		North Twin		West Lost		Lost		Section-Four		Hemlock	
1*	.50	4	.00	5.5	.00	5.5	1.60	2	1.51	3	2.23	1
2	.37	3	.60	5	.90	2	.86	4	.59	6	2.68	1
3	.89	3	.81	4	....	6	1.24	2	.57	5	1.06	1
4	.42	3	.28	5	.40	4	.10	6	.68	2	.73	1
5	.34	3	.07	5	.00	6	.44	2	.65	1	.14	4
6	.64	2	...	5	....	5	.66	1	.35	3	....	5
7	.51	2	.00	5	....	6	.75	1	.25	4	.42	3
8	.33	2	...	5	....	5	.33	2	.33	2	....	5
9	.05	2	...	5	....	5	.00	3	2.50	1	....	5
10	.20	2	...	6	.00	5	.09	3	.67	1	.03	4
11	.40	1	...	4.5	....	4.5	....	4.5	.18	2	....	4.5
12	.18	2	.00	4.5	....	6	.00	4.5	.53	1	.06	3
13	.00	3.5	.27	2	....	5.5	.00	3.5	.57	1	....	5.5
14	...	5.5	.16	3	2.66	1	.00	4	.60	2	....	5.5
15	.29	2	.17	3	1.49	1	.05	4.5	.05	4.5	.00	5
16	.77	2	.47	3	.85	1	.04	5	.08	4	.00	6
17	.65	3	.74	1	.72	2	.00	5	.47	4	....	6
18	.33	3	.50	2	.53	1	....	5.5	.00	4	....	5.5
19	.38	4	.39	3	.79	1	.00	5.5	.42	2	.00	5.5
20**	.35	3	.53	2	.98	1	....	5.5	.22	4	....	5.5

* - Opening date April 29.
** - Closing date September 11.

TABLE 33

VARIATION DUE TO REGRESSION ("r") OF RANK OF LAKES BY QUALITY OF CATCH TO DIFFERENCE IN EFFORT FROM THE EXPECTED

Lakes	D.F.	Value of "r"	Significance
West Lost	390	- .963	**[1]
Lost	390	- .331	**
North Twin	390	- .308	**
Section-Four[2]	344	- .503	**
Hemlock	390	- .416	**
South Twin[3]	390	+ .233	**

1 - Highly significant.
2 - Quality of preceding week gives greater correlation.
3 - Opposite correlation (the poorer the fishing quality the more effort expended).

The fishing quality and fishing effort changes are a continuous process from day to day and the ranking of lakes according to degree of success by weeks is artificial. For this reason a comparison of each week's success rank to percent of effort or the preceding week's success rank to percent of effort, whichever provides the best fit, is felt to be justifiable.

Correlation was highest on five of the lakes when the comparison between quality and effort was made on the basis of the same week. For Section-Four Lake the use of the quality of the fishing for the preceding week gave slightly greater correlation although both comparisons gave a highly significant degree of correlation.

It is concluded that the effort devoted to fishing the lakes very closely followed shifts of previous fishing success. So accurate were these shifts and so lacking were other means of dispensing the information that it is believed that a large amount of the direction originated at the creel census checking station. Because of the direction given to the fishing effort the fishing quality was increased. This represents an increase in the return of hatchery fish which is very desirable. That the creel census program does affect the quality of the fishing, at least in the case of the Pigeon River trout lakes, should be recognized. Conservation departments elsewhere (Eschmeyer, 1950) have a policy of dispensing to the public whatever information is available in order to increase the take of fish and it is suggested that an increase in return of hatchery fish from lakes could be achieved by a similar policy in this state.

Fish Production

Evaluation of the effects of fertilizer on trout production and growth is one of the important objectives of the present study. Comparisons between the fertilized lakes and the control lakes are difficult to interpret because of basic differences present in each lake aside from the effects of fertilization. A review of the history of fishing and management of the lakes has therefore been included for comparisons of fish production before and following fertilization.

The lakes were mapped and inventoried by crews from The Institute for Fisheries Research in 1931 and 1932 (Eschmeyer, 1938). The inventories reported large brook trout in Hemlock and Lost Lakes. These trout were planted by individuals and provided excellent fishing in 1931. Fingerling brook trout were planted in 1933 by the Conservation Department and other plantings followed. Adult rainbow trout were planted in South Twin and Section-Four Lakes in 1935. Eschmeyer indicated that the trout grew well in Hemlock, Lost, and West Lost Lakes where only forage species were present. Survival and growth were poor in North and South Twin and Section-Four Lakes where perch populations were present.

A complete creel census was made of the fishing on three of the lakes during 1935 and 1936 (Table 34).

TABLE 34

RECORD OF FISHING YIELDS AND ESTIMATES OF STANDING FISH CROPS PRIOR TO FERTILIZATION OF 1949 AND 1950

Standing crops	Yield
South Twin	
1934 ... 29 lbs. perch 1948 ... 230 lbs. perch[1]	....
North Twin	
1948 ... 118 lbs. perch golden shiners[2]	....
West Lost	
1948 ... 67 lbs. perch	1935 ... 24 lbs. trout 1936 ... 22 lbs. trout[3]
Lost	
....	1935 ... 30 lbs. trout 1936 ... 12 lbs. trout 1948 ... 5 lbs. trout[4]
Section-Four	
1934 ... 23 lbs. perch 1948 ... 97 lbs. perch[5]	....
Hemlock	
....	1935 ... 8 lbs. trout 1936 ... 4 lbs. trout 1948 ... 1 lb. trout

1 - South Twin Lake fertilized in 1946 and 1947.
2 - Estimates of standing crop in 1948 were based on marking and recovery technique.
3 - Creel census in 1935 and 1936 complete.
4 - Estimate from incomplete creel census on Lost and Hemlock Lakes.
5 - Considered to be an overestimation (see text).

The planted trout in Lost and Hemlock Lakes in the early 1930s apparently did well for a few years and then declined rapidly following the pattern pointed out by Rawson (1947) for fish introduced into waters in numbers greater than the food chain will support.

Stocking of fingerling brook trout continued each year with occasional plantings of brown or rainbor trout. Trout fishing remained poor where perch were present. Hemlock and Lost Lakes were free from competitive warm water fish and some good brook trout fishing was to be had during the early days of each season (Crowe, personal communication).

In 1946 fertilization experiments were begun by Dr. R. C. Ball, then of The Institute for Fisheries Research (Ball, 1948). North and South Twin Lakes were utilized, South Twin receiving applications of fertilizer and North Twin kept as a control. The winterkill which occurred in South Twin Lake following the second summer of fertilization eliminated the few small trout present and killed many perch.

From the data it is possible to compare the standing crop of perch present in 1934 with the standing crop of perch present in 1948 after applications of fertilizer during the summers of 1946 and 1947. Eschmeyer (1937 and 1938) estimated about 29 pounds of perch to the acre in South Twin Lake in 1934. In 1948 Ball estimated 230 pounds per acre. This wide difference may be partially the result of a low estimate by Eschmeyer (he reported only fish recovered "plus a few pounds") but the increase must mainly be the result of fertilization since an error in estimating could have accounted for but little of the ten-fold increase indicated.

The recovery from Section-Four Lake after the 1934 poisoning (a complete kill) was 23 pounds of perch per acre (Table 34). This number is believed to be much closer to the true standing crop than the 97 pounds per acre estimated from the 1948 poisoning. In 1946, when the population estimate was made on the basis of recovery of marked brook trout, the toxicant was applied late in the day and the fish did not die until nightfall. Most recoveries were of bloated fish coming to the surface in the next 72 hours. Under these conditions perch tend to be recovered at a higher rate than trout and would account for overestimating the weight of the perch.

Creel census during the 1948 season indicated fishermen caught one trout from North Twin Lake, approximately 50 small brook trout from Lost Lake and about 25 from Hemlock Lake.

During the summer of 1948 the four lakes in which competing warm-water fishes were present were poisoned and, on the basis of rate of recovery of marked fish, population estimates were made of the trash fish (Table 34). The population estimates from the poisoning in 1948 provided a comparison of the productivity of four of the lakes. The estimates indicated that South Twin and North Twin were supporting larger populations of warm-water fishes than Section-Four and West Lost Lakes.

Estimates of the standing crop and yield from previous records have been reviewed to establish as accurately as possible the levels of fish production for each of the lakes prior to fertilization (Table 34).

The standing crops of trout food organisms and plankton (previously discussed) provide additional information by which to evaluate the relative potential fish production of each lake of the group.

On the basis of all the available evidence, the ranking of the six lakes in potential fish production per unit area prior to the fertilization of 1949 and 1950 is believed to have been: South Twin, North Twin, West Lost, Lost, Hemlock, and Section-Four Lake. The high fish production in South Twin Lake was largely due to fertilization during 1946 and 1947.

During the period of fertilization a complete record of the weight of trout planted and the weight of trout removed was maintained. The pounds of trout remaining at the end of the program were estimated. From these data the fish yields and standing crops of fish during fertilization have been determined.

The weight of the trout removed by netting and angling in 1949 was small. The net yield per acre (weight of fish removed less their weight when planted) has been calculated

(Table 35). The fish removed from the lakes by angling in 1949 were largely from South Twin Lake. The trout from this lake (fertilized 1946 and 1947) averaged an inch longer than the fish removed by anglers from other lakes of the group.

TABLE 35

THE NET* YIELD IN POUNDS PER ACRE OF BROWN TROUT DURING 1949

Lakes	Angling	Gill nets	Total	Pounds per acre
South Twin**	23.7	13.8	37.5	9.6
Section-Four	1.8	8.0	9.1	3.5
Lost	1.9	2.4	3.3	.9
Hemlock	1.1	4.3	5.4	.9
West Lost	0.0	2.8	2.8	.8
North Twin	0.0	1.4	1.4	.3

* - Weight at capture less planting weight.
** - Fertilized 1946 and 1947.

Few sub-legal trout were caught in South Twin Lake while, during most of the 1949 fishing season, the majority of the fish from the other lakes were sub-legal. In Section-Four Lake, the lake fertilized the heaviest during 1949, the trout netted in September averaged 9.7 inches in total length (Figure 33), much larger than the angling catch from any of the other lakes. Apparently, while growth between the time

Figure 33 Brown trout (average length 9.71 inches) netted in Section-Four Lake one year after planting. (Average length 5.6 inches at time of planting.)


6
7
8
9
10

of planting in September of 1948 until after fertilization in June of 1949 was slow, *Daphnia* were present soon after fertilization in heavy concentrations (previously discussed) and provided a ready source of food. During this period the growth of brown trout in Section-Four Lake was excellent. The better growth of the trout in South Twin and Section-Four Lakes is indicative of more food as a result of fertilization.

Only small numbers of fish were taken from Hemlock, North Twin, West Lost and Lost Lakes. The netting of these lakes indicated that growth was rather poor. Survival was also poor except in Lost Lake. The survival was particularly poor in North Twin Lake and only eight trout were taken in three days of netting.

Yearling brown trout with left pectoral clipped were planted in all six lakes in September of 1949 at the rate of 250 to the acre. The fin clip distinguished these fish from those planted in 1948.

The 1950 catch far exceeded the 1949 catch. Where only 345 fish were removed by anglers during 1949 from all the lakes, 272 were taken from Lost Lake on the opening week end of 1950. Anglers removed a total of 64 pounds of trout per acre from Section-Four Lake and South Twin Lake provided 45.5 pounds per acre. The net pounds of trout per acre have been calculated and represent the truest picture of the weight of the trout produced in the lakes (Table 36).

TABLE 36

WEIGHT AND COMPOSITION OF THE ANGLERS CATCH (1950)

Lakes	Acres	Fish	1948* percent	1949* percent	Total pounds	Total weight per acre	Weight at planting	Net weight per acre**
South Twin	3.9	548	.51	.49	177.5	45.5	69.0	27.8
Section-Four	2.6	688	.40	.60	166.4	64.0	80.1	33.2
Lost	3.5	470	.21	.79	74.8	21.4	52.0	6.5
Hemlock	5.9	231	.15	.85	46.5	7.9	34.7	2.0
West Lost	3.7	331	.30	.70	106.5	28.8	35.8	19.1
North Twin	4.7	222	.05	.95	85.1	18.1	27.3	12.3

* - Proportion of catch originating from 1948 and 1949 plantings.
** - Weight at time of removal less planting weight.

The survival of the 1948 plantings is indicated in the proportion of the catch contributed by the two plantings (Table 36). The 1948 plant was most important to the 1950 catch in South Twin Lake and Section-Four Lake indicating the best survival in these two lakes which had received the most fertilizer. The poor net yield from Lost and Hemlock Lakes is an indication of the very poor growth in these lakes.

Following the 1950 fishing season the lakes were poisoned. An estimate of the trout population was based on the rate of recovery of 100 marked brown trout, planted just prior to the application of the toxicant, of the same age and size of those already in the lakes (Ball, Ms.). While the differences in the rate of recovery between lakes is large the estimates of the fish population present are believed to be accurate. Differences between lakes in physical features, the amounts of turbidity, and the amounts of rooted aquatic vegetation offer explanations of why the fish were recovered at quite different rates. In North Twin Lake where the water was clearest, the slope one of the least precipitous and little aquatic vegetation present, the recovery rate was 81 percent of the marked fish (Table 37). The large portion of deep water and steep sloping shoal areas in Section-Four and Lost Lakes are believed to have been factors reducing the rate of recovery (21 and 39 percent respectively). In South Twin Lake the heavy beds of

TABLE 37

ESTIMATED NUMBERS AND WEIGHTS OF FISH PRESENT AT THE TIME OF THE 1950 POISONING (WEIGHTS IN POUNDS)

Lakes	Percent marked recovered	Weight of unmarked rec.	Estimated weight	Estimated weight per acre	Weight of fish planted	Net weight per acre
South Twin	.41	132	346	88.7	24.0	64.7
Section-Four	.21	14	67	25.7	9.4	16.3
Lost	.39	49	168	48.0	28.9	19.1
Hemlock	.41	27	68	11.5	7.1	4.4
West Lost	.67	92	124	33.5	13.9	19.6
North Twin	.81	353	406	86.4	22.5	63.9

potomogetons undoubtedly accounted for the disappearance of many trout. West Lost, similar to North Twin Lake, had only a slightly lower rate of recovery.

Fish samples taken at the time of poisoning have been used to calculate the difference in size and weight of the trout in each lake (Table 38). The small size of the trout from Lost and Hemlock Lakes are again indicated. It will be noted that in Lost Lake the 1948 fish which were an inch less in average length at the time of planting than the average length of trout planted in 1949 grew so little that they remained smaller even though a year older.

TABLE 38

WEIGHT AND LENGTH OF BROWN TROUT FROM 1950 POISONING

	Fish from 1949 planting		Fish from 1948 planting	
Lakes	Average total length (inches)	Average weight (grams)	Average total length (inches)	Average weight (grams)
South Twin	9.67 - 54	160.4 - 54	10.44 - 51	201.7 - 51
Sec.-Four	9.89 - 17	149.6 - 17	10.28 - 18	183.6 - 18
Lost	8.35 - 36	94.1 - 36	8.23 - 34	90.3 - 34
Hemlock	8.23 - 34	89.0 - 34	9.41 - 22	162.1 - 22
West Lost	9.56 - 54	135.0 - 54	9.95 - 14	163.4 - 14
North Twin	10.80 - 60	213.0 - 60	11.20 - 12	235.0 - 12

The net weight of the trout removed from each lake by angling, netting, and the 1950 poisoning have been added together (Table 39). Net production of trout per acre has been related to the amount of fertilizer added (Figure 34).

TABLE 39

NET WEIGHT OF FISH REMOVED BY ALL METHODS
(1949 and 1950)

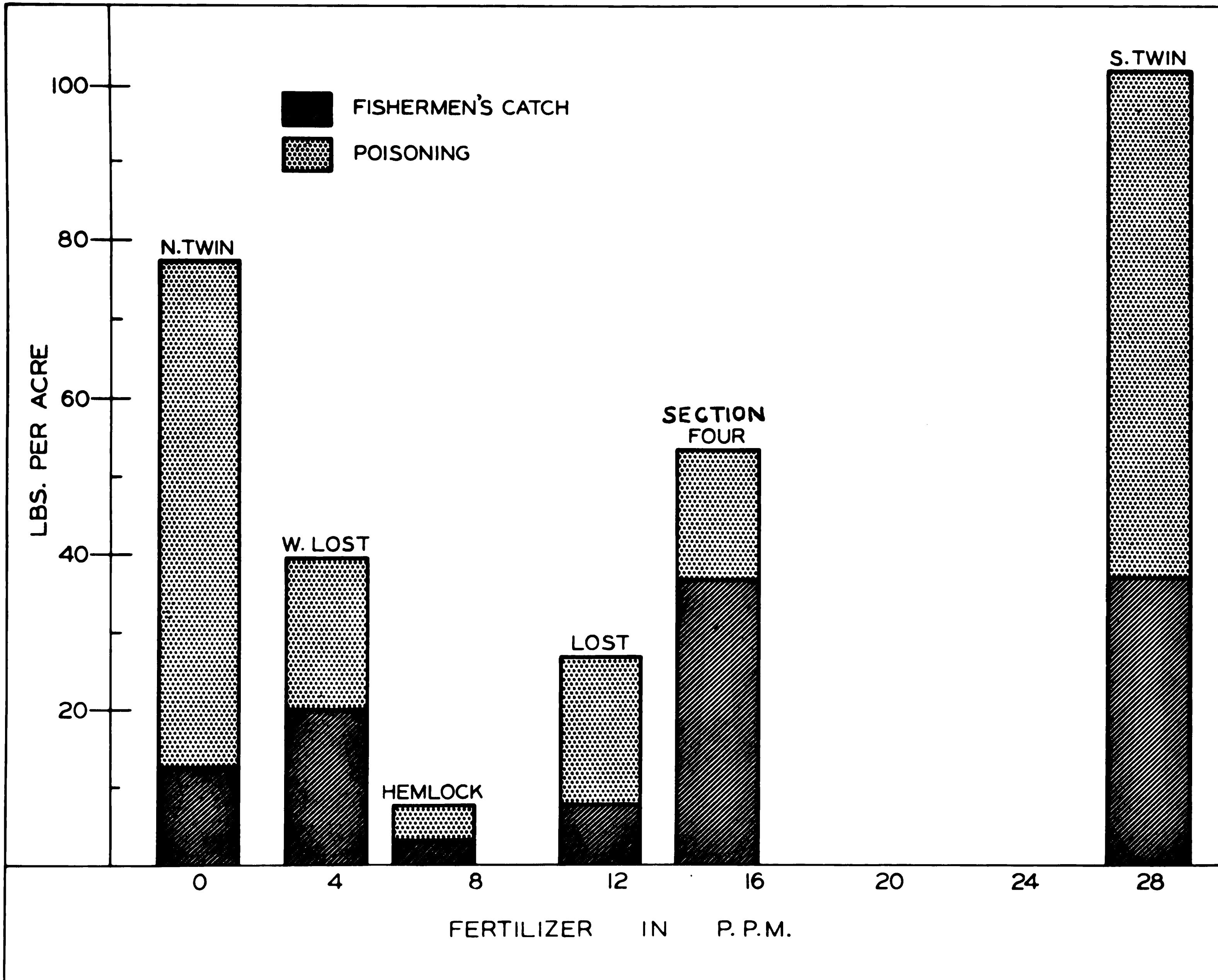
Lakes	Net weight per acre, 1949 angling, netting	Net weight per acre, 1950, angling	Net weight per acre, 1950 poisoning	Total net weight per acre
South Twin*	9.6	27.8	64.7	102.1
Section-Four	3.5	33.2	16.3	53.0
Lost	.9	6.5	19.1	26.5
Hemlock	.9	2.0	4.4	7.3
West Lost	.8	19.1	19.6	39.5
North Twin**	.3	12.3	63.9	76.5

* - Fertilized 1946 and 1947.
** - Unfertilized.

The effect of fertilization on the production of trout is the most important consideration of the present study. Trout production is, however, the end result of complex processes of energy transfer and is affected by many factors. The interpretation of the effect of these factors on production is difficult. To facilitate understanding of the

Figure 34. Production of brown trout per acre (net weight) related to amounts of fertilizer added.

The weight of trout removed by angling and the weight estimated as present at time of poisoning (September 25, 26, 1950).



FISHERMEN'S CATCH
POISONING
LBS. PER ACRE
100
80
60
40
20
N. TWIN
W. LOST
HEMLOCK
LOST
SECTION FOUR
S. TWIN
0
4
8
12
16
20
24
28
FERTILIZER IN P.P.M.

effects of fertilization, each lake will be discussed separately.

South Twin Lake was estimated to have had a standing crop of approximately 29 pounds of perch to the acre in 1934 (Table 34). A total of 28 p.p.m. of fertilizer was added during the summers of 1946 and 1947. A winterkill occurred during the winter of 1947-48. In August of 1948 the lake was poisoned and the standing crop of perch present was estimated at 230 pounds to the acre on the basis of marking and recovery. The increase is interpreted as largely due to the effects of fertilization although the estimate of Eschmeyer may have been slightly low. Trout planted in 1948 grew well, better than any of the trout in the other lakes prior to applications of fertilizer in 1949. During the 1950 season, fishermen removed 548 fish from the lake or 28 pounds per acre of net yield. The net weight of the fish removed and the net weight of the fish population present in September 1950 total 102.1 pounds of fish to the acre.

The bottom fauna studies indicated that the volume of the trout food organisms per square foot in South Twin Lake was greater than in any of the other lakes (Figure 24).

Fertilization is concluded to have resulted in a tenfold increase in the standing crop of perch. Dense beds of potomogetons appeared following fertilization and probably were a direct result of it. The high production levels of this lake in comparison with the others of the group are believed to have been partially the effect of fertilization but both South Twin and North Twin Lakes must be considered to have been basically more productive than the other four.

Section-Four Lake had a standing crop of 23 pounds of perch to the acre in 1934 (Table 34). The estimate of 97 pounds of perch per acre in 1948 is almost certainly too high. During 1949 and 1950, 15 p.p.m. of fertilizer was applied, the largest applications of the present program. Fishermen removed 638 trout weighing 166 pounds during the 1950 season. The total surface area of Section-Four Lake is only 2.6 acres.

Prior to fertilization the necessary basic elements of the food pyramid were almost completely lacking. Section-Four Lake could have supported only very small numbers of trout and yield would have necessarily remained very low. Following fertilization the volume of the trout food organisms per square foot increased forty-fold (Figure 24) making possible the excellent trout production observed. The population estimate at the end of the 1950 season indicated that fishermen were able to harvest most of the trout present at the beginning of the season. Had larger numbers survived until the final poisoning their additional growth increment might have raised the production figure to a still higher figure.

Lost Lake produced a few large brook trout in 1931 which had been planted in 1927. Regular planting began in

1933 and a complete creel census in 1935 and 1936 indicated that fishermen harvested 30 pounds of brook trout per acre in 1935 and 12 pounds in 1936 (Table 34). These are total weights. The net weights as calculated in the present study are not known. In 1948 the yield was 5 pounds of brook trout per acre, all taken in early season fishing. A total of 11.4 p.p.m. of fertilizer was applied during 1949 and 1950. Important increases occurred in the volume of trout food organisms present. Net yield to fishermen during 1950 was only 6.5 pounds per acre. At the time of the poisoning the trout population was estimated as 19.1 pounds per acre. Growth of the trout in Lost Lake was the poorest of any of the lakes (Table 38).

The increase in amount of food present after fertilization was not reflected in increased production or rapid growth. It is believed that the populations of several species of forage fish present competed for the food and were not in turn food items of the trout. Because of the error in the old map of the lake (Table 4) Lost Lake was stocked heaviest. The increase in crowding and resulting greater need of food for maintaining body weight is an additional reason for the poor growth of the trout in this lake.

Hemlock Lake was planted in 1927 with a few brook trout and from this early planting six trout taken in gill nets in 1931 had a total weight of 20 pounds which is very exceptional for Michigan. However, the yield in terms of pounds per acre was never high. The creel census of 1935 and 1936 indicated a harvest of 8 and 4 pounds per acre respectively. A total of 6.4 p.p.m. of fertilizer was applied to Hemlock Lake during 1949 and 1950. The increase noted in the amounts of trout food present did not result in a high production of trout per acre. The net weight of fish harvested by anglers and the weight estimated as present at the time of poisoning totaled only 7.3 pounds. The trout in Hemlock Lake ranked fifth in growth rate with Lost Lake sixth. Contributing factors to the low productivity of Hemlock Lake are believed to be the competition of the minnows, the small littoral zone, and the large and biologically unproductive hypolimnion. The pelagic area in Hemlock (largest lake of the group) was also unproductive.

West Lost Lake had, in 1948, a standing crop of perch and sunfish estimated as 67 pounds per acre (Table 34). The yield of trout to the anglers during 1935 and 1936 was indicated by the general creel census to have been 22 and 21 pounds of trout to the acre. These data, together with the estimated trout food available, establish that, prior to fertilization, West Lost Lake ranked behind North and South Twin and ahead of the other three lakes of the group in potential fish production. West Lost Lake was fertilized very lightly (total of 3.9 p.p.m.) during 1949 and 1950. The removal of the warm-water fish from this relatively productive lake accounted for some of the increase in food organisms and contributed to the production of 39.5 pounds of trout to the acre. However, the added nutrients provided considerable stimulus to the lower levels of the food pyramid. The increase in the amount of plankton present following fertilization is indicated by the record of secchi disk readings (Figure 16). That increased amounts of organic matter were produced during the period of fertilization is indicated by the increased rate of oxygen depletion in the hypolimnion.

North Twin Lake served as a control lake in the present study. The net weight of trout produced was second only to South Twin Lake and the rate of growth exceeded that of all other lakes in the group (Figure 34 and Table 38). The poisoning of 1948 indicated the standing crop of perch and golden shiners of 118 pounds per acre, second by weight to South Twin Lake (Table 34). The production of bottom fauna before fertilization was higher than all lakes except South Twin. Barrett (1952) determined that the amounts of phosphorus present in North Twin Lake (without artificial enrichment) usually equalled or exceeded the amounts present in the waters and bottom muds of the rest of the lakes in the group. These data establish that the natural productivity of North Twin Lake was high in relation to other lakes in the group without added nutrient material. Perhaps the most important single factor in the excellent production and growth of the trout in North Twin Lake was the unexplained poor survival of the 1948 trout planting. The original planting rate of 500 yearling brown trout per acre in each lake was considered excessive but was used intentionally to insure the use of any increase in fish production capacity following fertilization. Crowding the lakes with trout placed a burden on the supplies of available food merely to maintain the weight of the fish planted. Because of the poor survival of this planting in North Twin Lake the food supplies were not taxed as heavily. The planting of trout in 1949 at the rate of 250 per acre meant that North Twin was understocked while most of the other lakes, with the exception of West Lost Lake where survival of the first plant was also low, were overstocked. For these reasons the growth of the trout in North Twin Lake was greater than for any of the other lakes and the production of pounds per acre was exceeded by only South Twin Lake.

The production of trout in each lake and the effects of fertilizer in the production have been reviewed. The conclusion has been reached that the effects of fertilizer on trout production can be more accurately determined by comparisons on a before and after basis than by comparing fertilized and unfertilized areas. The differences in factors which affect the potential production capacity of the lakes are so large even in a group as homogeneous in character as the group utilized in the present study that evaluation of the effects of fertilization are difficult to determine by comparisons between lakes.

North Twin, South Twin, and West Lost Lakes were basically far more productive of fish than Hemlock, Lost, and Section-Four Lakes. The more productive lakes occupied shallower basins and were less alkaline than the three deep marl or partially marl lakes of the group. Veatch (1932) points out that in proceding from the time of formation through the process of aging and to extinction lakes in Michigan generally proceed from very alkaline condition to a less alkaline condition. From this it would also be concluded that the North and South Twin and West Lost Lakes were closer to an eutrophic and more productive condition than the remaining three lakes.

The excellent production of trout from North Twin Lake (unfertilized) has served to demonstrate that it and South Twin and West Lost Lakes as well, should provide excellent trout growth and a high yield of brown trout without fertilization. Lost Lake, Hemlock Lake, and Section-Four Lakes are so low in basic biotic potential that trout yield will remain low without artificial enrichment. The small number of trout the lakes are capable of supporting will not provide interesting fishing in the face of the concentration of fishing effort that the trout waters in this state receive.

The question of the ethics of artificial enrichment of natural lakes is now pertinent. Hasler (1947), in outlining the objections to fertilization of natural lakes, stresses that enrichment from any source will hasten the eutrophication and extinction of the lakes. Since the basic concept of conservation is the use of natural resources, water included, so that the most benefit will go to the most people. Any action of the present generation which hastens the extinction of lakes is not good conservation. However, in the situation which exists in the lake type represented by the three unproductive marl lakes where the capacity to provide interesting fishing is lacking or nearly so, the use of fertilizers in effect provides a new source of fishing and is, therefore, ethical and does not violate the concepts of conservation. The situation is similar to the treatment of bog lakes by Hasler (1951) with lime to increase fish production.

That fertilization will make productive this type of marl lake is demonstrated by the large increases in volume of fish food organisms present and the resulting high yield of brown trout to the fishermen from Section-Four Lake during the period of fertilization.

DISCUSSION

The objective of the present study has been to evaluate the effects of the addition of inorganic fertilizer to a group of Michigan trout lakes. Previous studies have indicated that fertilizing natural lakes to increase fish production may be limited by undesirable changes in the environment or by economic considerations. The investigation has been undertaken to determine if reduced rates of fertilization can avoid or reduce the undesirable effects.

Creel census studies have indicated a low harvest of warm-water species and strongly suggest that the expense of fertilizing to increase a crop not adequately harvested cannot be justified. The high rate of harvest from trout lakes has suggested that fertilization there might be economically justified if undesirable effects could be avoided by modified techniques. For these reasons trout lakes appear to be the only type of water justifying the expense of fertilization.

The winterkills which followed heavy application of fertilizer to lakes in the same part of the state (Ball, 1948 and Ball and Tanner, 1951) are the most serious results of fertilization to be avoided. The effect of the reduced rates of application on the winter and summer oxygen supplies were carefully measured. Winterkill conditions were not produced by the low rates of application but some oxygen reduction occurred and was related directly to the amount of fertilizer added. The highest rate of application very nearly resulted in winterkill conditions during the winter following the second summer of fertilization. The effects of fertilization are definitely accumulative from year to year and applications should not be repeated until the effects of the first application can no longer be detected. Jduging from the one lake in the group which had been fertilized during 1946 and 1947 the duration of the increased biological activity and reduction of oxygen may be three or more years. Summer oxygen reduction occurred in the four fertilized lakes. By the end of the second summer little oxygenated water remained below the thermocline in the fertilized lakes. The oxygen reduction was not severe in the thermocline and it is doubtful if oxygen was a limiting factor during the summer stagnation period.

The repositioning of the thermocline in a shallower position as a direct result of fertilization combined with the removal of oxygen from the hypolimnion reduced the amount of water available to the trout during the mid-summer period.

The decrease in total hardness which apparently occurred as a result of the increased amounts of plankton present may be a possible solution to the management of some of the excessively hard waters of the state.

Increased amounts of plankton following application of fertilizer preceded general increases in biological activity.

Important increases in the bottom fauna occurred. The midges showed the greatest increase. The feeding habits of these "ooze browsers" made them quick to respond to increased amounts of plankton. The changes in the depth distribution of trout food organisms resulted from greater amounts of plankton. The organisms dwelling in the sublittoral zone are dependent on the dead plankton from above for food. Prior to fertilization food from this source was limited.

The least amount of fertilizer used resulted in important gains in the amount of trout food available but ine increase in food organisms was directly correlated with the amount of fertilizer added.

Aside from the effects of fertilization, interesting facts were gained concerning the brown trout in lakes. Contrary to general opinion, the fishermen were able to capture a large percentage of brown trout present. Brown trout were not as vulnerable to fishing as brook trout but were taken more consistantly throughout the season. Brook trout, after the first month of the season, are usually taken only in deep water. During the 1950 season brown trout were present in the surface waters and were the source of much fine fishing throughout the season. It may have been that 1950 was an exceptionally cool season and further experiments should determine the answer. Because the brown trout attained a larger size than brook trout in the face of heavy fishing pressure, they provided greater sport for the fishermen. It was apparent that the creel census station served to direct the fishermen to the better fishing and the possibility of increasing the return of hatchery fish should be considered. Further investigation of the use of brown trout for stocking lakes should include the use of fingerling fish instead of yearlings.

Fish production was stimulated by the increase in food available following fertilization. Several factors, the removal of trash fish, the presence of minnows in two of the lakes, differences in availability of food organisms, and differences in potential productivity of the lakes, made it difficult to state with accuracy how much of the increase was due to fertilization. The presence of minnows in two of the lakes was shown to reduce the production of trout and to restrict trout growth.

South Twin Lake which was fertilized in 1946 and 1947 was observed throughout the study in order to evaluate the residual effects of fertilization. It was apparent that the high fish production for this lake during the second and third years following fertilization must be attributed to the effects of the fertilizer. The levels of the bottom fauna remained high but the plankton levels showed definite signs of decreasing and the rates of summer and winter oxygen depletion were nearly back to the prefertilization condition by 1950. The large beds of potomogetons which developed after the application of fertilizer showed no signs of decline as late as the summer of 1951. It must be concluded that, while other workers have indicated that the nutrient materials disappear from the economy of the lake by the year following fertilization (Einsele, 1938; Barrett, 1952) the biological effects do not subside as rapidly. It appears that the extent of the eutrophication occurring as a result of fertilization is considerable. Because of the eutrophying effect and hastening of the extinction of the lake, fertilization cannot be justified in most instances. However, it has been pointed out that there are lakes in this state that are suited for trout except that the amount of trout food present will not support enough fish to provide interesting fishing when the lake is fished heavily. In these instances where fertilization creates a new source of fishing it should be considered as a practical and ethical approach to management of these unproductive lakes. Two lakes, Section-Four and Lost, in the present study are lakes in this classification. The excellent fishing and high production in Section-Four Lake is proof that fertilization can create fishing in lakes of very low productivity.

The excellent production of trout from the unfertilized control lake indicated quite clearly that removal of competing warm-water species and adequate stocking will provide excellent fishing from the three more productive lakes of the group.

The lakes of the present study were lakes of unusual appearance and formation but the conditions effecting the production of fish are not unique and the results of the present study will apply on generally similar lakes.

From the information now available from this and preceding investigations, it appears that the only situation in Michigan where the use of fertilizer would be practical would be on small landlocked trout lakes subject to heavy fishing and with an extremely low fish production. If a lake is low in fish and fish food production and so typically oligotrophic as to have oxygen present throughout most of the volume of the hypolimnion during the mid-summer stagnation period then it would probably justify fertilization. Fertilizer should be applied at not more than a total of 10 p.p.m. per year and should not be repeated until the stimulus of the added nutrients has dissipated.

SUMMARY

1. Inorganic fertilizer was applied to four of a group of six trout lakes and a fifth lake retained as a control. The sixth lake had been fertilized during the two summers preceding the present investigation and observations were continued to evaluate the residual effects. Low rates of application of fertilizer were used and the lake with the greatest total hardness received the most (a total of 15 p.p.m. during two summers) and the softer water lakes received lesser amounts. The lowest rate of application was 3.9 p.p.m. total for the two summers.

2. The thermocline in three of the fertilized lakes of the group shifted to a shallower position during the summers of 1949 and 1950. This change in the position of the thermocline did not occur in the two lakes remaining unfertilized during the present study nor in the lake fertilized at the lowest rate.

3. Three of the fertilized lakes decreased in total hardness at a greater rate than did the two lakes which were not fertilized during 1949 and 1950.

4. Fertilization resulted in the oxygen being depleted from the hypolimnion and limited reduction of oxygen in the

thermocline occurred. In the one lake of the group fertilized for two summers prior to the present investigation the oxygen was depleted from the hypolimnion during the first summer following fertilization but not during the next two summers. The volume of oxygenated water remaining under the ice during the critical period of late winter was reduced in the fertilized lakes. The lake fertilized at the highest rate very nearly approached winterkill conditions. The lakes treated at lower rates had some oxygen reduction but winterkill was avoided by a wide margin. The reduction of oxygen both in summer stagnation periods and in late winter was more severe after the second season of fertilization. In the one lake fertilized prior to the present study the amount of oxygenated water present beneath the ice increased the third winter following fertilization.

5. Increases in plankton occurred in all the fertilized lakes and these increases were correlated with the amount of fertilizer added. Filamentous algae did not become a problem in any of the lakes. In the one lake where rooted aquatics were common the plants were largely eliminated when the turbidity of the water increased following fertilization.

6. Important increases in the bottom fauna were observed in

all the fertilized lakes. No increase was apparent in the unfertilized lake. The amount of increase was closely correlated with amounts of fertilizer added. The depth distribution of trout food organisms changed during the period of fertilization with the volume of food organisms in the sub-littoral zone becoming more important. A similar change was not noted for the unfertilized lake. In the lake which has been fertilized previously the volume of bottom fauna organisms in the sub-littoral zone became less important each year after the cessation of fertilization.

7. Stomach analysis of the brown trout showed a nearly complete dependence on the bottom fauna for food. In the two lakes of the group where forage fish were present they were not important as trout food. The volume of food in the stomachs of trout taken from the lakes with the highest production was much larger than the volume of food present in the stomachs of trout taken from the two least productive lakes.

8. The quality of the fishing and the effort expended on the lakes increased during the period of fertilization. The yield in trout per acre was high in several of the lakes. The brown trout provided fishing of excellent quality during the entire season. There was evidence that angling is selective of the larger faster growing

brown trout. Probably considerable direction was given to the fishing effort towards the highest quality fishing by the creel census checking station.

9. The greatest trout production was from the lake which had been fertilized previously at a much higher rate of application than was used on any of the four lakes fertilized during the present program. The unfertilized control lake had the next highest production of trout and the most rapid growth. The fish production capacity increased in the fertilized lakes. In the two lakes with populations of forage fish present the production was lower and the growth rates poorer than in any of the lakes with only trout present.

LITERATURE CITED

Adamstone, F. B. and W. J. K. Harkness
1923 The bottom organisms of Lake Nipigon. Univ Toronto Stud., Biol. Ser.; Pub. Ont. Fish Res. Lab. 15: 123-170

American Public Health Association
1946 Standard Methods for the Examination of Water and Sewage. Am. Pub. Health Assoc., New York. 9th. ed., 286 pp.

Ball, Robert C.
1948 Relationship between available fish food, feeding habits of fish and total fish production in a Michigan lake. Tech. Bull. 206, Michigan State College Agr. Exp. Sta.

1949 Experimental use of fertilizers in production of fish food organisms and fish. Tech. Bull. 210, Michigan State College Agr. Exp. Sta.

---- Standing crop of brown trout based on recovery of marked fish following poisonings of six trout lakes. (In preparation.)

Ball, Robert C. and Don W. Hayne
1952 Effects of the removal of the fish population on the fish food organisms of a lake. Ecol. 33 (1): 41-48.

Ball, Robert C. and Howard A. Tanner
1951 The biological effects of fertilizer on a warm-water lake. Tech. Bull. 223, Michigan State College Agr. Exp. Sta.

Barrett, P. H.
1952 Effects of alkalinity on adsorption and regeneration of phosphorus in natural lakes. Thesis, Michigan State College. Unpublished.

Baten, W. D.
1938 Elementary Mathematical Statistics. John Wiley and Sons, Inc., New York. 329 pp.

Borutsky, E. V.
1939 Dynamics of the total benthic biomass in the profundal of Lake Beloie. Proc. Kossino Limnol. Sta. Hydrometeorol. Ser. U.S.S.R. 22: 73-74.

Brujewica, S. W.
1939 Distribution and dynamics of living matter in the Caspian Sea. Comptes Rendus (Doklady) de l'Academic des Sciences de l'U.R.S.S. 1939 Vol. XXV, No. 2.

Chu, S. P.
1943 The influence of the mineral composition of the medium as the growth of planktonic algae. Part II The influence of the concentration of inorganic nitrogen and phosphate phosphorus. J. Ecol. 31: 109-148.

Clarke, George L.
1946 Dynamics of production in a marine area. Ecol. Monogr. 16: 321-335. October, 1946.

Comstock, John H.
1947 An Introduction to Entomology. Comstock Pub. Co., New York. 9th. ed., revised.

Cooper, Edwin L.
---- Growth of brook trout (Salvelinus fontinalis) and brown trout (Salmo trutta) in the Pigeon River, Otsego Co., Michigan. (In preparation.)

Deevey, Edward S., Jr.
1941 The quantity and composition of the bottom fauna of thirty-six Connecticut and New York lakes. Ecol. Monogr. 11: 413-455. October, 1941.

Dice, Lee R. and Harold J. Leraas
1936 A graphic method for comparing several sets of measurement. Contribution Lab. of Vert. Gen. Univ. of Mich. 3: 1-3, 1 fig.

Drews, Robin A.
1951 The cultivation of food fish in China and Japan: A study disclosing the contrasting national patterns for rearing fish consistant with differing cultural histories of China and Japan. Thesis. Univ. of Mich. Unpublished.

Eggleton, F. E.
1931 A limnological study of the profundal bottom fauna of certain fresh-water lakes. Ecol. Monogr. 1: 231-332.

Einsele, Wilhelm
1938 Uber chemische und killoid-chemische Vorgange in Eisen-Phosphor-Systemen unter limnochemischen und limnogeologishcen Gesichtspunkten. Arch. Hydrobiol. 33: 361-387.

1941 Die Umsetzung von zugefuhrtem, organischen Phosphat im eutrophen See und ihre Ruckwirkung auf seinen Gesamthaushalt. Zeit. f, Fischerei 39 (3): 407-488.

Eschmeyer, William R.
1937 Some characteristics of a population of stunded perch. Pap. Mich. Acad. Sci., Arts, and Letters, 22 (1936): 613-628.

1938 Experimental management of a group of small Michigan lakes. Trans. Am. Fish Soc. 67 (1937): 120-129.

1950 Fish and Fishing in TVA Impoundments. Tenn. Dept. of Cons.

Hasler, Arthur D.
1947 Eutrophication of lakes by domestic drainage. Ecol. 28 (4): 383-394.

Hasler, A. D., O. M. Brynildson and Wm. T. Helm
1951 Improving conditions for fish in brown-water bog lakes by alkalization. J. Wildl. Mgt. 15 (4): 347-352. October, 1951.

Hasler, Arthur D. and Wilhelm Einsele
1948 Fertilization for increasing the productivity of natural inland waters. Trans. 13th N. A. Wildl. Conf. 1948. pp. 527-555.

Hayes, F. R.
1951 On the theory of adding nutrients to lakes with the object of increasing trout production. Canadian Fish Culturist 10: 32-37.

Hile, Ralph
1936 Age and growth of the cisco <u>Leucichthys artedi</u> (LeSueur) in the lakes of the northeastern Highlands, Wisconsin. Bull. U. S. Bur. Fish. 19: 211-317.

Hogan, Joe
1933 Experiments with commercial fertilizers in rearing largemouth black bass fingerlings. Trans. Am. Fish. Soc. 63 (1933): 110-119.

Howell, Henry H.
1942 Bottom organisms in fertilized and unfertilized fish ponds in Alabama. Trans. Am. Fish. Soc. 71 (1941): 165-179.

Hubalt, E.
1943 Les Grands Lacs subalpins de Savoi sont-ils alcalitrophes? Arch. Hydrobiol. 40 (1): 240-249.

Huber-Pestalozzi, G.
1938 Die Binnengewasser Band XVI, Das Phytoplanktor des Susswassers. Stutgart.

Ivlev, V. S.
1945 The biological productivity of waters. Uspekhi Soveremennoi Biologii (Advances in Modern Biology). 19 (1): 98-120.

Kusnetzow, S. J.
1939 Determination of the intensity of oxygen-absorption in the lake water, caused by bacterial processes (Summary). Proc. Kossine Limnol. Sta. Hydrometeorol. Serv. of U.S.S.R. 22: 73-74.

Lindeman, Raymond L.
1942 The trophic-dynamic aspect of ecology. Ecol. 23 (4): 399-418.

Meehean, O. Lloyd
1933 The role of fertilizers in pondfish culture. Trans. Am. Fish. Soc. 63 (1932): 103-109.

1936 Some factors controlling largemouth bass production. U. S. Bur. Fish., Prog. Fish-Cult., 16: 1-6.

Minder, Leo
1922 Uber biogene Enthalkung im Zurichsee. Verh. Insternat. Vereinig. Limnol. 1922: 20-32.

Mortimer, C. H.
1941 The exchange of dissolved substances between mud and water in lakes. I and II. J. Ecol. 29 (2): 280-329.

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

Patriarche, Mercer H. and Robert C. Ball
1949 An analysis of the bottom fauna production in fertilized and unfertilized ponds and its utilization by young-of-the-year fish. Tech. Bull. 207, Michigan State College Agr. Exp. Sta.

Rawson, D. S.
1947 Deterioration of recently established trout populations in lakes of the Canadian Rockies. Canadian Fish Culturist. 2. 14.

Ricker, William E.
1946 Production and utilization of fish population. Ecol. Monogr. 16: 375-391. October, 1946.

Schaperclaus, Wilhelm
1933 Textbook of Pond Culture. Book Publishing House, Paul Parey, Berlin. Translated by Frederick Hund.

Scott, I. D.
1921 Inland lakes of Michigan. Mich. Geol. and Biol. Survey, Publ. 30, Geol. Ser. 25, xxi + 383.

Smith, M. W.
1945 Preliminary observations upon the fertilization of Crecy Lake, New Brunswick. Trans. Am. Fish. Soc., 1945, 75: 165-175.

Snedecor, G. W.
1946 Statistical Methods. Iowa State College Press, Ames Iowa. xvi + 485 pp.

Surber, E. W.
1943 The effects of various fertilizers on plant growths and their probable influence on the production of smallmouth blackbass in hard water ponds. Trans. Am. Fish. Soc. 73 (1943): 377-393.

Swingle, H. S. and E. V. Smith
1939 Fertilizers for increasing the natural food for fishes in ponds. Trans. Am. Fish. Soc. 68 (1938): 126-135.

Utterback, Clinton C.
1946 The penetration and scattering of solar and sky radiation in natural water bodies of the Pacific Northwest. A Symposium on Hydrobiology. Wisc. Univ. Press. pp. 45-58.

Van Deusen, R. D.
1947 Quantitative and qualitative evaluation of plankton from fertilized and non-fertilized hatchery ponds, with an appraisal of methods used. Thesis, Michigan State College. Unpublished.

Veatch, J. O.
1932 Some relationships between water plants and water soils. Tran. Mich. Acad. of Sci., Arts and Letters. 17: 409-413.

Walker, H. M.
1943 Elementary Statistical Methods. Henry Holt and Co., New York, N. Y., 368 pp.

Ward, H. W. and G. C. Whipple
1918 Fresh-water Biology. John Wiley and Sons, Inc. New York. 1111 pp.

Wilkins, L. Price
1952 Relationships of a fish population to the invertebrate fauna in two small ponds. Thesis, Michigan State College. Unpublished.

APPENDIX

SUMMARY OF THE STATISTICAL ANALYSES OF CHANGES
IN THE POSITION OF THE THERMOCLINE
(ANALYSIS OF VARIANCE)

	Unfertilized		Fertilized			
Source	South Twin	North Twin	West Lost	Hemlock	Lost	Sec. Four
Total						
Years	-	-	-	**	-	*
1948 vs 1949 and 1950	-	-	-	**	*	*
among 1949 and 1950	-	-	-	-	-	*
Months	*	*	*	**	*	-
Error term						

* - Significant (5 per cent level).
** - Highly significant (1 per cent level).

THERMOCLINE CHANGES IN SOUTH TWIN LAKE
(ANALYSIS OF VARIANCE)

Source	D.F.	S.S.	M.S.	"F"
Total	11	441.1		
Years	2	76.1	38.05	2.13-
1948 vs 1949 and 1950	(1)			
among 1949 and 1950	(1)			
Months	3	257.9	85.97	4.82*
Error	6	107.1	17.85	

- No significance.
* Significant (5 percent level).

THERMOCLINE CHANGES IN NORTH TWIN LAKE
(ANALYSIS OF VARIANCE)

Source	D.F.	S.S.	M.S.	"F"
Total	11	717.5		
Years	2	24.4	12.2	.44-
1948 vs 1949 and 1950	(1)			
among 1949 and 1950	(1)			
Months	3	549.9	183.3	6.60*
Error	6	167.6	27.9	

- No significance.
* Significant (5 percent level).

SUMMARY OF ANALYSIS OF VARIANCE FOR SUMMER OXYGEN DEPLETION

Source	Unfertilized		Fertilized			
	South Twin	North Twin	West Lost	Hemlock	Lost	Sec. Four
Total						
Between periods (prefert. vs fertilization)	-	-	**	**	**	**
Within (error)						

\- No significance.
** Highly significant (1 percent level).

AVERAGE LENGTH OF TROUT CAUGHT BY ANGLING FROM EACH OF THE SIX LAKES (1950), ANALYSIS OF COVARIANCE

Source	D.F.	S.S.			Source	D.F.	S.S.	M.S.	"F"
		X^2	XY	Y^2					
Total	69	2,481.4	260.8	54.61					
Lakes	5	470.5	85.4	30.70	Corr. lakes	5	18.58	3.716	27.124**
Error within	64	2,010.9	175.4	23.91	Corr. error	63	8.61	.137	
Error + lakes					Corr. error + lakes	68	27.19		

** - Highly significant.

DERIVATION OF ADJUSTED MEAN LENGTH OF FISH FROM 1950 CATCH

Lake	N	$\bar{X}$	$\bar{Y}$	$\bar{X}-\bar{X}_G$	$b(\bar{X}-\bar{X}_G)$	Adjusted $\bar{Y}^{1}$*	Variance of mean	± Error
West Lost	8	14.125	9.406	+ 4.582	- .400	9.006	.0171	.131
Lost	9	5.778	8.258	- 3.765	+ .328	8.586	.0152	.123
Section-Four	19	10.111	9.225	+ .457	- .040	9.185	.0072	.085
Hemlock	8	5.500	8.593	- 4.043	+ .353	8.946	.0171	.131
South Twin	15	9.533	9.661	+ .010	- .008	9.653	.0091	.096
North Twin	11	11.454	10.132	+ 1.911	- .167	9.965	.0125	.112
Total	70							

* - The adjusted mean length for each lake plus and minus two standard errors are plotted in Figure 31.

Ledgend

N = Number of weekly observations.
$\bar{X}$ = Average time of capture (weeks 1st - 20th).
$\bar{Y}$ = Average length of trout.
$\bar{X}_G$ = General average of time of capture for all six lakes.
St. error = $\sqrt{\text{var. of the means}}$.

$b = \frac{S\ xy}{S\ x^2}$ (Note S xy and S x^2 taken from error term in the co-variance table.)

$\bar{X}^1 = b(\bar{X}-\bar{X}_G)$

Var. of mean = $\frac{\text{mean sq. of error term}}{n} = \frac{.137}{n}$

Gb

CALCULATION OF DIFFERENCE (IN PERCENT) IN FISHING EFFORT FROM EXPECTED PERCENT, SOUTH TWIN LAKE, 1950

Weeks of the season	Percent of total effort	Total effort on all lakes for week	Expected hours of effort	Actual effort	Difference in hours	Actual percent of effort	Difference in percent from expected percent
1*	.2706	474.5	128.4	133.5	+ 5.1	28.1	+ 1.0
2	.2706	437.0	118.0	151.5	+ 33.5	34.7	+ 7.6
3	.2706	220.0	59.5	69.5	+ 10.0	31.5	+ 4.4
4	.2706	231.5	62.6	33.0	- 29.6	14.3	- 12.8
5	.2706	562.0	152.1	125.5	- 26.6	22.3	- 4.8
6	.2706	80.0	21.6	19.0	- 2.6	23.8	- 3.3
7	.2706	82.0	22.2	17.5	- 4.7	21.3	- 5.8
8	.2706	45.0	12.2	21.0	+ 8.8	46.7	+ 19.6
9	.2706	53.5	14.5	37.5	+ 23.0	70.1	+ 43.0
10	.2706	201.5	54.5	20.0	- 34.5	9.9	- 17.2
11	.2706	55.0	14.9	5.0	- 9.9	9.1	- 18.0
12	.2706	160.0	43.3	17.0	- 26.3	10.6	- 16.5
13	.2706	36.5	9.9	8.0	- 1.9	21.9	- 5.2
14	.2706	52.0	14.1	0.0	- 14.1	0.0	- 27.1
15	.2706	220.5	59.7	44.0	- 15.7	20.0	- 7.1
16	.2706	273.0	73.9	85.5	+ 11.6	31.3	+ 4.2
17	.2706	120.0	32.5	50.5	+ 18.0	42.1	+ 15.0
18	.2706	246.5	66.7	120.0	+ 64.9	48.7	+ 21.6
19	.2706	273.5	74.0	79.5	+ 5.5	29.1	+ 2.0
20**	.2706	103.5	28.0	25.5	- 2.5	24.6	- 2.5

* - Opening date April 29.
** - Closing date September 11.

CALCULATION OF DIFFERENCE (IN PERCENT) IN FISHING EFFORT FROM EXPECTED PERCENT, SECTION-FOUR LAKE, 1950

Weeks of the season	Percent of total effort	Total effort on all lakes for week	Expected hours of effort	Actual effort	Difference in hours	Actual percent of effort	Difference in percent from expected percent
1*	.2546	474.5	120.8	149.5	+ 28.7	31.5	+ 6.0
2	.2546	437.0	111.2	117.5	+ 6.3	26.9	+ 1.4
3	.2546	220.0	56.0	56.0	- 0.0	25.5	- 0.0
4	.2546	231.5	58.9	57.5	- 1.4	24.8	- .7
5	.2546	562.0	143.0	145.5	+ 2.5	25.9	+ .4
6	.2546	80.0	20.3	59.5	+ 39.2	74.4	+ 49.9
7	.2546	82.0	20.8	4.0	- 16.8	4.9	- 20.6
8	.2546	45.0	11.4	9.0	- 2.4	20.0	- 5.5
9	.2546	53.5	13.6	6.0	- 7.6	11.2	- 14.3
10	.2546	201.5	51.6	119.5	+ 67.9	59.3	+ 33.8
11	.2546	55.0	14.0	50.0	+ 36.0	90.9	+ 65.4
12	.2546	160.0	40.7	102.0	+ 61.3	63.8	+ 38.3
13	.2546	36.5	9.2	7.0	- 2.2	19.2	- 6.3
14	.2546	52.0	13.2	20.0	+ 6.8	38.5	+ 12.8
15	.2546	220.5	56.1	18.5	- 37.6	8.4	- 17.1
16	.2546	273.0	69.5	12.0	- 57.5	4.4	- 21.1
17	.2546	120.0	30.5	17.0	- 13.5	14.2	- 11.3
18	.2546	246.5	62.7	10.0	- 52.7	4.1	- 21.4
19	.2546	273.5	69.6	30.5	- 39.1	11.2	- 14.3
20**	.2546	103.5	26.3	9.0	- 17.3	8.7	- 16.8

* - Opening date April 29.
** - Closing date September 11.

CALCULATION OF DIFFERENCE (IN PERCENT) IN FISHING EFFORT FROM EXPECTED PERCENT, LOST LAKE, 1950

Weeks of the season	Percent of total effort	Total effort on all lakes for week	Expected hours of effort	Actual effort	Difference in hours	Actual percent of effort	Difference in percent from expected percent
1*	.1508	474.5	71.6	170.0	+ 98.4	35.8	+ 20.8
2	.1508	437.0	65.9	35.0	- 30.9	8.0	- 7.1
3	.1508	220.0	33.2	42.0	+ 8.8	19.1	+ 4.0
4	.1508	231.5	34.9	10.0	- 24.9	4.3	- 10.8
5	.1508	562.0	84.7	158.0	+ 82.1	28.1	+ 13.0
6	.1508	80.0	12.1	1.5	- 10.6	1.9	- 13.2
7	.1508	82.0	12.4	46.5	+ 34.1	56.7	+ 41.0
8	.1508	45.0	6.8	15.0	+ 8.2	33.3	+ 18.2
9	.1508	53.5	8.1	10.0	+ 1.8	18.7	+ 3.6
10	.1508	201.5	30.4	23.0	- 7.4	11.4	- 3.7
11	.1508	55.0	8.3	0.0	- 8.3	0.0	- 15.1
12	.1508	160.0	24.1	9.0	- 15.1	5.6	- 9.5
13	.1508	36.5	5.5	3.0	- 2.5	8.2	- 6.9
14	.1508	52.0	7.8	10.5	+ 2.7	20.2	+ 5.1
15	.1508	220.5	33.2	19.5	- 13.7	8.8	- 6.3
16	.1508	273.0	41.1	24.5	- 16.6	9.0	- 6.1
17	.1508	120.0	18.1	6.0	- 12.1	5.0	- 10.1
18	.1508	246.5	37.2	0.0	- 37.2	0.0	- 15.1
19	.1508	273.5	41.2	9.0	- 32.2	3.3	- 11.8
20**	.1508	103.5	15.6	0.0	- 15.6	0.0	- 15.1

* - Opening date April 29.
** - Closing date September 11.

CALCULATION OF DIFFERENCE (IN PERCENT) IN FISHING EFFORT FROM EXPECTED PERCENT, HEMLOCK LAKE, 1950

Weeks of the season	Percent of total effort	Total effort on all lakes for week	Expected hours of effort	Actual effort	Difference in hours	Actual percent of effort	Difference in percent from expected percent
1*	.0780	474.5	37.0	7.0	- 30.0	1.5	- 6.3
2	.0780	437.0	34.1	44.0	+ 9.9	10.1	+ 2.3
3	.0780	220.0	17.2	18.0	+ .8	8.2	+ .4
4	.0780	231.5	18.1	78.5	+ 60.4	33.9	+ 26.1
5	.0780	562.0	43.8	73.0	+ 29.2	13.0	+ 5.2
6	.0780	80.0	6.2	0.0	- 6.2	0.0	- 7.8
7	.0780	82.0	6.4	12.0	+ 5.6	14.6	+ 6.8
8	.0780	45.0	3.5	0.0	- 3.5	0.0	- 7.8
9	.0780	53.5	4.2	0.0	- 4.2	0.0	- 7.8
10	.0780	201.5	15.7	34.0	+ 18.3	16.9	+ 9.1
11	.0780	55.0	4.2	0.0	- 4.2	0.0	- 7.8
12	.0780	160.0	12.5	21.0	+ 8.5	13.1	+ 5.3
13	.0780	36.5	2.8	0.0	- 2.8	0.0	- 7.8
14	.0780	52.0	4.1	0.0	- 4.1	0.0	- 7.8
15	.0780	220.5	17.2	12.0	- 5.2	5.4	- 2.4
16	.0780	273.0	21.3	3.0	- 18.3	1.1	- 6.7
17	.0780	120.0	9.4	0.0	- 9.4	0.0	- 7.8
18	.0780	246.5	19.2	0.0	- 19.2	0.0	- 7.8
19	.0780	273.5	21.3	4.0	- 17.3	1.5	- 6.3
20**	.0780	103.5	8.1	0.0	- 8.1	0.0	- 7.8

* - Opening date April 29.
** - Closing date September 11.

CALCULATION OF DIFFERENCE (IN PERCENT) IN FISHING EFFORT FROM EXPECTED PERCENT, WEST LOST LAKE, 1950

Weeks of the season	Percent of total effort	Total effort on all lakes for week	Expected hours of effort	Actual effort	Difference in hours	Actual percent of effort	Difference in percent from expected percent
1*	.1009	474.5	47.9	2.5	- 45.4	.5	- 9.6
2	.1009	437.0	44.1	37.0	- 7.1	8.5	- 1.6
3	.1009	220.0	22.1	0.0	- 22.1	0.0	- 10.1
4	.1009	231.5	23.4	2.5	- 20.9	1.1	- 9.0
5	.1009	652.0	56.7	4.0	- 52.7	.7	- 9.4
6	.1009	80.0	8.1	0.0	- 8.1	0.0	- 10.1
7	.1009	82.0	8.3	0.0	- 8.3	0.0	- 10.1
8	.1009	45.0	4.5	0.0	- 4.5	0.0	- 10.1
9	.1009	53.5	5.4	0.0	- 5.4	0.0	- 10.1
10	.1009	201.5	20.3	5.0	- 15.3	2.5	- 7.6
11	.1009	55.0	5.5	0.0	- 5.5	0.0	- 10.1
12	.1009	160.0	16.1	0.0	- 16.1	0.0	- 10.1
13	.1009	36.5	3.7	0.0	- 3.7	0.0	- 10.1
14	.1009	52.0	5.2	3.0	- 2.2	5.8	- 4.3
15	.1009	220.5	22.2	74.0	+ 51.8	33.6	+ 23.5
16	.1009	273.0	27.5	91.0	+ 63.5	33.3	+ 23.2
17	.1009	120.0	12.1	18.0	+ 5.9	15.0	+ 4.9
18	.1009	246.5	24.9	54.5	+ 29.6	22.1	+ 12.0
19	.1009	273.5	27.6	65.5	+ 37.9	23.9	+ 13.8
20**	.1009	103.5	10.4	39.0	+ 28.6	37.7	+ 27.6

* - Opening date April 29.
** - Closely date September 11.

CALCULATION OF DIFFERENCE (IN PERCENT) IN FISHING EFFORT FROM EXPECTED PERCENT, NORTH TWIN LAKE, 1950

Weeks of the season	Percent of total effort	Total effort on all lakes for week	Expected hours of effort	Actual effort	Difference in hours	Actual percent of effort	Difference in percent from expected percent
1*	.1450	474.5	68.8	12.0	- 56.8	2.5	- 12.0
2	.1450	437.0	63.4	52.0	- 11.4	11.9	- 2.6
3	.1450	220.0	31.9	34.5	+ 2.6	15.7	+ 1.2
4	.1450	231.5	33.5	50.0	+ 16.5	21.6	+ 7.1
5	.1450	562.0	81.5	56.0	- 25.5	10.0	- 4.5
6	.1450	80.0	11.6	0.0	- 11.6	0.0	- 14.5
7	.1450	82.0	11.9	2.0	- 9.9	2.4	- 12.1
8	.1450	45.0	6.5	0.0	- 6.5	0.0	- 14.5
9	.1450	53.5	7.6	0.0	- 7.6	0.0	- 14.5
10	.1450	201.5	29.2	0.0	- 29.2	0.0	- 14.5
11	.1450	55.0	7.9	0.0	- 7.9	0.0	- 14.5
12	.1450	160.0	23.2	11.0	- 12.2	6.9	- 7.6
13	.1450	36.5	5.3	18.5	+ 13.2	50.7	+ 36.2
14	.1450	52.0	7.5	18.5	+ 11.0	35.6	+ 21.1
15	.1450	220.5	32.0	52.5	+ 20.5	23.8	+ 9.3
16	.1450	273.0	39.6	57.0	+ 17.4	20.4	+ 5.9
17	.1450	120.0	17.4	28.5	+ 11.1	23.5	+ 9.0
18	.1450	246.5	35.7	62.0	+ 26.3	25.2	+ 10.7
19	.1450	273.5	39.7	85.0	+ 45.3	31.1	+ 16.6
20**	.1450	103.5	15.0	30.0	+ 15.0	28.9	+ 14.4

* - Opening date April 29.
** - Closing date September 11.