T. Page.

Tawas Point, shore line changes 135
Taylor, Frank B., cited on glacial lakes 97, 123, 141
Tecumseh, road gravels 109
Terminal moraine 102
Thunder Bay, ice retreat 140
Till plain 102
soils 113
Toleston Beach 132, 133
Tilting, Great Lake basin 135
Toronto, marine clays 120
Traverse Bay, drumlins 102
Trent outlet 132, 133
Tunnels, surface geology 98

U.

Ubly outlet 130
U. S. Department of Agriculture, Bureau of Soils 97
Upham, W., glacial lakes 140, 141
Upper Fox river, outlet Lake Jean Nicolet 140
Upper Peninsula Experiment Station, notes on soils 97
Ice Age 136

V.

Valparaiso moraines 122, 123
Van Wert stage, Maumee beach 126, 136
Volusia series, soils 113
Vriesland, lake beach 123

W.

Walled Lakes 104
Water supply, surface geology 98
Wheal Kate, kame 141
Whitney, Milton, soil surveys 97
Winchell, N. H., Green Bay lobe 138
Winchells, surface geology 97, 101
Wisconsin glacial epoch 120, 122
Wisconsin river, Lake Jean Nicolet 140
Woodward, R. S., on compression of the earth 100

Y.

Yarmouth interglacial interval 120
Ypsilanti, Defiance moraine 127
Illinoian drift 121
Maumee beach 127

A BIOLOGICAL SURVEY

OF

Walnut Lake, Michigan.

BY

THOMAS L. HANKINSON.

WITH CHAPTERS ON THE PHYSIOGRAPHY, GEOLOGY AND FLORA OF THE REGION BY CHARLES A. DAVIS; AND A PAPER ON THE AQUATIC INSECTS OF THE LAKE BY JAMES G. NEEDHAM.

A REPORT OF THE BIOLOGICAL SURVEY OF THE STATE OF MICHIGAN, PUBLISHED BY THE STATE BOARD OF GEOLOGICAL SURVEY AS A PART OF THE REPORT FOR 1907.

LANSING, MICHIGAN
WYNKOOP HALLENBECK CRAWFORD CO., STATE PRINTERS
1908

LETTER OF TRANSMITTAL.

OFFICE OF THE STATE GEOLOGIST,
LANSING, MICHIGAN.

To the Honorable, the Board of Geological Survey of the State of Michigan.

Hon. Fred M. Warner, President.
Hon. D. M. Ferry, Jr.
Hon. L. L. Wright, Secretary.

Gentlemen:—I have the honor to transmit herewith, received from Chief Field Naturalist, A. G. Ruthven, for publication as a part of the Annual Report for 1907, a report on the results of a biological survey of Walnut Lake, Michigan, by Thomas L. Hankinson and associates. This report is a contribution from the Biological Survey of the State of Michigan, which the Legislature authorized you to supervise and execute by Act No. 250 of the session of 1905. It consists of a report on the fauna (particularly the fish) of Walnut Lake, and contains much of a practical nature on the economic relations, habits and distribution of the several species, special attention being given to the occurrence of the whitefish in this lake.

This report was undertaken very largely at the suggestion of Captain Clark of Northville, with the hopes of obtaining a practical result in connection with the pure scientific treatment. We hoped to find out why whitefish flourished in this lake, what it was in the surroundings that made them thrive, so that we might know where whitefish might be successfully planted and raised.

The answer seems to be that it depends on the presence of oxygen in the deep "abyssal" part of the lake, both for the whitefish and their food, the larvæ of certain midges.

Very respectfully,

ALFRED C. LANE,
State Geologist.

LETTER OF TRANSMITTAL.

Sir:—I hand you herewith a report on the results of a biological survey of Walnut Lake, Oakland county, Michigan, by Thomas L. Hankinson and others. The principal object of the investigations upon which this report is based was the determination of the reasons why the whitefish can live in Walnut Lake, so that a basis might be had to determine in what other lakes the species could be propagated.

The zoological part of the report consists of six sections, as follows:

(1) A description of the different fish habitats in the lake, with a list of the fish found in each;

(2) A list of the fish of the lake, with notes on the preferred habitats, food and breeding habits, and economic importance of the species;

(3) A list of the animals of the lake, which have an influence upon the fish fauna;

(4) A summary of the data applying to the occurrence of the whitefish in the lake;

(5) An appendix describing the apparatus used in the aquatic work;

(6) A list of the aquatic insects of the lake, with notes on their economic importance by James G. Needham.

It will thus be seen that aside from the discovery of the environmental conditions frequented by the whitefish in Walnut Lake, the report forms an important contribution to our knowledge of the fish fauna of this lake, and of the habits of the species found there.

ALEXANDER G. RUTHVEN,
Chief Field Naturalist, Biological Survey of Michigan.

ALFRED C. LANE,
State Geologist.

CONTENTS.

	Page.
Letter of transmittal	155
Introduction	161
Acknowledgments	162
Equipment and methods of work	162
Nomenclature and measurements	163
Physiography and Geology, by C. A. Davis	164
Location and description of Walnut Lake	164
The bed-rock	165
Glacial Geology of the region	166
Post-glacial history of the region	169
Marl	170
Peat	171
Human agencies	171
Soils and drainage basin of Walnut Lake	172
Physiographic features of the lake shores	172
Field stations	173
Barren shoal type	175
Bulrush-covered shoal type	182
Swamp loosestrife-fringed type	185
Marsh bay type	187
Bulrush shoal type	190
Swampy shore type	191
Deep water type	192
Fish of Walnut Lake	198
Condition of fish	199
Species, relative numbers and economic importance of the fish	199
Methods of fishing	200
Annotated list of the fish in Walnut Lake	200
The Flora, by C. A. Davis	217
Relations of plants to animals	217
Requirements of plants	217
Adaptation of plants	217
Law governing plant distribution	218
Types of water plants and their association	218
Factors controlling plant distribution in a given lake	218
The lake a desert	219
Reason for zonal arrangement of plants	219
Invariable order of zones	219
Limits of the different zones	219
Zones above the water level	219
Ideal classification of the plant zones of the region about Walnut Lake	220
Reasons for variations from the zonal arrangement	220
The plant zones of a lake affected by the soils of the bottom	220
Application of principles to the flora of Walnut Lake	221
Relations of soils to zonal distribution	221
Marl	221
Stony or gravelly soils	222
Black mud or impure peat	222
Effects of aquatic and marsh plant associations on their habitat	222
The plant zones represented in a lake	223
The sedge zone	223

	Page.
The bulrush zone	224
The pondweed zone	225
The water-lily zone	227
Water crowfoot	227
Other zones	227
Flora of the highlands	228
List of plants collected at Walnut Lake	228
The Fauna of Walnut Lake	232
Summary and conclusions	238
Appendix I, Description of apparatus and methods of recording observations	240
Collecting apparatus	240
Equipment for making observations	242
Equipment for making records	243
Appendix II, Data on stomach contents of fish taken in Walnut Lake	244
Appendix III, Notes on the aquatic insects of Walnut Lake, with special reference to a few species of considerable importance as fish food, by James G. Needham	252

LIST OF ILLUSTRATIONS.

Plate.		End.
XIII.	Map of Walnut Lake and surrounding region	End.
XIV.	Map of Walnut Lake showing bottom topography	"
XV.	Outline map of Lake, showing location of stations	"
XVI.	Portion of Station 23, showing effect of ice on trees	"
XVII.	Beach of Station 23, showing encroaching vegetation from the sedge zone	"
XVIII.	Station 32 in April	"
XIX.	Station 32, looking east	"
XX.	Portion of Station 32, showing zone of plant life in August	"
XXI.	Station 49, looking north	"
XXII.	Station 46, looking south	"
XXIII.	Station 3, looking south	"
XXIV.	Midges on spear house at Station 3	"
XXV.	Similar to last, but nearer view	"
XXVI.	Beach at Station 16, showing wave-sorted shell fragments	"
XXVII.	Marshy shore of Station 16 in April	"
XXVIII.	Station 6, looking south toward lake	"
XXIX.	Station 15, looking south	"
XXX.	Station 15, looking west	"
XXXI.	Station 4, with No. 1 in foreground	"
XXXII.	Station 31, in April	"
XXXIII.	Station 31, in June	"
XXXIV.	Station 31, showing loosestrife plants and part of lily zone	"
XXXV.	Station 26, looking east	"
XXXVI.	Station 26, looking north, in April	"
XXXVII.	Station 26, looking north, in June	"
XXXVIII.	Station 26, looking south toward lake	"
XXXIX.	Station 26, in August, showing mass of detached crowfoot plants washed against loosestrife	"
XL.	Station 26, showing water crowfoot blossoms	"
XLI.	Station 7, looking southwest from lake	"
XLII.	Station 7, looking east out into lake	"
XLIII.	Station 41, looking south, in April	"
XLIV.	Station 41, looking south, in summer	"
XLV.	Station 41, looking north	"
XLVI.	Station 41, looking southeast	"
XLVII.	Station 54, looking northeast	"
XLVIII.	Surface vegetation in Station 54	"
XLIX.	Margin of pool in Station 54	"
L.	Portion of Station 54 where black bass were found nesting	"
LI.	Station 40, in August	"
LII.	Station 40, in April	"
LIII.	Station 40, plant zones near center of station	"
LIV.	Station 40, showing plant zones	"
LV.	Station 40, interior of swamp zone	"
LVI.	Portion of bottom on gravelly shoal of Station 23, where fish nest	"
LVII.	Another portion of the same bottom shown in 56	"
LVIII.	Eggs of blunt-nosed minnow	"
LIX.	Eggs of the tadpole stone cat	"
LX.	Eggs of the blue-spotted sunfish	"
LXI.	*Lepomis euryorus*, living specimen	"
LXII.	Nesting place of the long-eared sunfish, Station 4	"

Plate.
LXIII. Long-eared sunfish about nest..... End.
LXIV. Long-eared sunfish over nest, another view of same fish..... "
LXV. Swamp loosestrife, showing drooping branches..... "
LXVI. Swamp loosestrife, showing roots on drooping branches..... "
LXVII. Eggs of musk turtle..... "
LXVIII. Rafts of rushes, possibly made by muskrats..... "
LXIX. Rushes cut off near water surface..... "
LXX. Fyke net on land..... "
LXXI. Fyke net set in shallow water..... "
LXXII. Trammel net set at Station 54..... "
LXXIII. A haul with plant hooks..... "
LXXIV. Aquaria..... "
LXXV. Chironomus cases x 3..... "

LIST OF FIGURES.

Figure 18.—Diagram showing results of gas analysis..... 197
Figure 19.—Chironomus albistria Walker: m, the epipharyngeal comb; n, the labial border; both x 55..... 256
Figure 20.—Unknown Chironomus larva from stomach of whitefish: p, epipharyngeal comb, x 310; q, labial border, x 55..... 257
Figure 21.—Semidiagrammatic figure of the buccal apparatus of the larva of Chironomus viridicollis V. d. W., viewed from below, the mandibles and x, and maxillæ, y, spread out laterally, and the top of the mouth moved a little anteriorly so as to show all of the epipharyngeal armature (based on drawing by Mr. H. R. Stewart.) The line i i represents the labral margin of the mouth; the parts before it are on the front of the head, outside of the mouth; the parts behind it are in the roof of the mouth. The ill-defined fringe of fine bristles along this margin has sometimes been designated as the anterior comb. f, the pendunculate palps (only their penducles are shown in Miall & Hammond's The Harlequin Fly, Fig. 16), g, frontal sensory hairs; h, h, labral or external rakers; i, i, lateral papillæ; k, epipharyngeal (or posterior) comb; l, l, epipharyngeal or internal rakers; m, m, lateral arms; n, n, anterior cross bar; o, o, U-bar; p, maxillary palpus; q, lacinia of the maxilla; r, hypopharynx; z, the labial border, heavily chitinized (in situ, the mandibles swing obliquely down against this border)..... 258
Figure 22.—Gall-bearing petioles of Nymphæa advena, a, external views of the gall; the dotted circle marks the epidermal window, through which the adult emerges; b, the gall cut open, showing the larva of Hydromyza confluens within. 270
Figure 23.—The larva of Hydromyza confluens. a, side view of the whole larva; b, the caudal peritreme spine, greatly enlarged; c, posterior view of the respiratory apertures; d, the prothoracic spiracular apparatus, removed and enlarged (the mark close behind the mouth in the upper figure shows the location of this)..... 271

BIOLOGICAL SURVEY OF WALNUT LAKE, MICHIGAN.

BY THOMAS L. HANKINSON.

INTRODUCTION.

The present paper is the result of a biological survey of Walnut Lake, Oakland county, Michigan, carried on during the spring and summer of 1906, from April 3rd. to August 30th. The chief purpose of the work was to obtain facts concerning the fish life, not only to find out what kinds of fish lived in the lake, but more particularly to learn as much as possible about the feeding habits, breeding habits, habitat and environic (biological and physical) relations of the species. The work while thus ecological, was also economic in nature, for if successful it should reveal some of the laws governing the occurrence and local distribution of the species studied, and thus furnish evidence of the kinds of lakes in which these forms may be planted most successfully. The investigation was made at Walnut Lake, primarily, because it was known that whitefish live and thrive there. These fish have been planted in a number of apparently similar lakes in the State by the Michigan Fish Commission, but for unknown reasons, have been unable to maintain themselves, except in a few instances. It was, therefore, hoped that a study of this lake might lead to a knowledge of the conditions which enable the whitefish to live there, and that this information would be such that it could be used in the future work of stocking inland lakes of the State with this fish.

Staff and collaborators.—The investigation was in official charge of the State Geologist, Dr. Alfred C. Lane. Professor Jacob Reighard, one of the Zoological Advisors of the Michigan Board of Geological Survey, with Charles C. Adams, at the time Curator of the Museum of the University of Michigan, outlined the general plan of the work. Professor Reighard also gave much personal oversight to the investigations while they were being carried on. The field party was in direct charge of the writer, who devoted his time to the study of the fish life of the lake. In this he was aided for a part of the season by Messrs. Ellis Michael of La Porte, Indiana, and Elmer McDonald of Lerna, Illinois, as scientific assistants, and by Joseph Peters of Detroit, as fisherman. Mr. McDonald also acted as botanical collector during his stay. The party was augmented from time to time by the following specialists, who spent limited periods working on special aspects of the problem:

Prof. James G. Needham, Lake Forest University, Insects.
Mr. Bryant Walker, Detroit, Michigan, Mollusks.
Mr. A. Franklin Shull, University of Michigan, Insects.
Prof. N. H. Harvey, State Normal College, Fresh-water Sponges.
Dr. Charles A. Davis, Ann Arbor, Michigan, Plants.
Dr. John Eastwood, State Hygienic Laboratory, Water Analyses.

Acknowledgments.—I wish to express my thanks to the following persons who most generously assisted us in the work, by actual field work, by advice, or by identifying specimens. Those who helped in the last named way have the names of the kind of specimens determined for us following their names.

Jacob Reighard, University of Michigan, Ann Arbor, Mich.
A. C. Lane, State Geologist of Michigan.
C. C. Adams, University of Chicago, Chicago, Illinois.
W. B. Barrows, Michigan Agricultural College, Lansing, Michigan.
O. W. Caldwell, Normal School, Charleston, Illinois.
T. H. Briggs, Normal School, Charleston, Illinois.
F. S. Collins, Malden, Massachusetts, Algæ.
Ellen Bach, Ann Arbor, Michigan, Characeæ.
C. A. Davis, Ann Arbor, Michigan, Seed plants.
G. N. Calkins, Columbia University, New York City, Protozoa.
J. P. Moore, Philadelphia, Pennsylvania, Leeches.
Ada Weckel, Portage, Wisconsin, Amphipods.
A. E. Ortmann, Carnegie Museum, Pittsburg, Pennsylvania, Crayfish.
E. A. Birge, Madison, Wisconsin, Daphnia.
J. G. Needham, Lake Forest, Illinois, Aquatic insects.
O. A. Johannsen, Ithaca, New York, Aquatic diptera.
Nathan Banks, Washington, D. C., Spiders.
Bryant Walker, Detroit, Michigan, Mollusks.
Alexander G. Ruthven, University Museum, Ann Arbor, Michigan, Amphibians and reptiles.
R. E. Richardson, Urbana, Illinois. A few sunfish and minnows.

I would mention especially the financial assistance given the party by Dr. A. C. Lane and Mr. Bryant Walker, for which we are duly grateful, and the kind assistance of many of the residents near and about the lake.

Equipment and methods of work.—Full equipment was furnished the party by purchase, and by loan from various institutions, and a small laboratory for indoor work was fitted up in a room in the farm house where the party secured lodgings. After the preliminary study of the lake and its surroundings, it was divided into a series of stations, or regions having peculiar sets of environmental conditions for fish. These stations were visited as frequently as possible thereafter, and each was examined to determine its peculiar biological conditions, inhabitants, and other significant features. The routine work in the field consisted principally of the study of the conditions at the different stations, but no attempt was made to give all stations equal attention, the visits to particular stations being made when weather conditions were most favorable for observation, or when some particular specimens or facts were wanted. On account of the large size of the lake it was impossible to devote a large amount of time to each station, but this difficulty was in part avoided, for as the season advanced it was noted that the established stations could be grouped under several major types, and study was focussed on type stations.

Besides the field work, much indoor work was necessary, and specimens were taken to the temporary laboratory for study, identification and preservation. All specimens which could not be identified with certainty by members of the party were sent to various specialists for identification, after being properly prepared. In the indoor work the fish were, of course, given particular attention. When the collections from the different stations were brought in, the specimens were sorted, those of each species measured

and the larger ones weighed. Specimens of each species in the collection were then opened, the sex organs noted, parasites removed and preserved, and any food in the alimentary canal removed, examined, and saved for more detailed study. The study of the food removed from the fish furnished us with many clews to the habits of the various fish, their habitats, their relation to other organisms, and economic importance. In the time available not much could be done toward making exact determinations of every substance found in the alimentary canal of every specimen, even if this had been desirable in a general ecological survey of the fish life of the lake, such as was undertaken. The stomach contents were preserved, however, and have been deposited with the Walnut Lake Collection in the Museum of the University of Michigan, where they can be more carefully studied. In many cases negative data concerning food were obtained, but these are usually not significant, especially where collecting was done with the fyke-net or gill-net, since it is possible that digestive processes were active for many hours after the fish were caught. Allowance must also be made when examining the stomach content records of fish taken at a particular station, for the possibility of the individual having obtained the material at some station other than the one where it was caught.

Maps.—The lake was carefully surveyed during the winter preceding the field work, by A. A. Adams, under the direction of Professor Gardner Williams of the University of Michigan, and the excellent map, (Pl. 14), was based on this survey. A large number of soundings were made through the ice, and the bottom and shape of the basin of the lake was thus obtained. This carefully prepared map was the basis for much field work, and saved a great amount of time in the location of stations. A topographic map of the region around Walnut Lake was published by the U. S. Geological Survey, cooperating with the Michigan Geological Survey* just after the field work for the season was completed. A portion of this map is used as the base for the map of the surface geology (Pl. 13).

The soil map of the Pontiac area† was also of considerable service in the reconnaissance of the country in the vicinity of the lake at the outset of the work, and was used in compiling soil and vegetation data.

Nomenclature and measurements.—For the benefit of the general reader, and to aid the publishers, common names have been used in the body of this report instead of scientific ones, except (1) in the case of species for which no common name could be found, and (2) in the lists of the flora and fauna. In the latter, both common and scientific names are used, and the reader is referred to these sections when in doubt as to the scientific name of any species.

In all records of the length of fish, the measurements were from the tip of the snout to the tip of the caudal fin. All measurements and weights are in American units, and temperature readings are in centigrade units.

*The Pontiac Quadrangle. U. S. Geological Survey, Washington, D. C., 1907.
†Soil Survey of the Pontiac Area, Michigan. Bureau of Soils, U. S. Dept. Agriculture, Washington, D. C., 1904.

PHYSIOGRAPHY AND GEOLOGY.

BY C. A. DAVIS.

Location and description of Walnut Lake.—Walnut Lake lies in the southern part of Oakland County, Michigan, four and one-half miles south-southwest of Pontiac, which is the nearest large town. It is a little more than a mile east of the line of the Detroit and Orchard Lake Electric Railway, which gives direct connection between the lake and Detroit, either by way of Pontiac, or more quickly by way of Farmington Junction. More exactly, it is situated in the south half of Sec. 24, and the north half of Sec. 25, West Bloomfield Township (T. 2 N., R. 9 E.). It is rather more irregular in outline than is usual in lakes of its class, and has a shore line about three and one-half miles long. The longer axis lies east and west, and is nearly a mile (in round numbers, 5000 feet) in length, and its extreme width from north to south is a little more than three-fourths of a mile (more exactly, 4350 feet). Its area is approximately 232 acres, or about one-third of a square mile, and the greatest depth found by the surveyors was 101.3 feet. Its surface lies at an elevation of 881 feet above sea level, as determined by the U. S. Geological Survey, and is 306 feet higher than the Detroit river.

The lake is beautifully situated in a district where the surface is gently undulating and mostly cleared for farming purposes, but there are sufficient remnants of the forest which formerly covered the entire region, in the form of woodlots and uncleared swamps, to give variety to the landscape, and to add to its attractiveness. The region to the north of the lake is higher and rougher than that immediately adjacent, and abounds in basins and depressions some of which are of considerable size and contain lakes, swamps and bogs in various stages of development. It may be said, in passing that Walnut Lake lies near the southern border of one of the most picturesque regions to be found in Southern Michigan, and, when its beauty is fully appreciated, is destined to become the summer home of a much larger number of people than now seek it. To the south of the lake the country slopes gently, and a few miles south becomes a nearly flat plain, the geological significance of which is pointed out below.

The hydrographic basin of the lake is relatively small. There are only three small streams flowing into it, but one of which is permanent, and that becomes very insignificant in August. These three streams all enter the lake on its north side, one at the extreme extension (Station 26, Pl. 15), and the others at the head of the wide bay at the northeastern end (Station 40, Pl. 15).

Originally the lake had no surface outlet, but about 1896 an artificial channel was dug at the western end (Station 1, Pl. 15), through a shallow valley, to a small stream which runs southeastward to the Rouge river, thus lowering the surface level several feet. It was reported by farmers of the vicinity that there was no outlet from the lake whatever until this ditch was dug; it is possible that the water found its way out from the basin by percolation through porous sub-strata, as is the case with many lakes without outlets, but there is no known evidence of this.

At present, of the entire length of about three and one-half miles of shoreline, but a half-mile along the west shore, and about a quarter of a mile on

the east side, are low and marshy. These marshes vary in width from a few feet to about three hundred, the widest part lying just southwest of the outlet, covering a broad platform of marl. There are two areas of firm marl shore, each about a fifth of a mile long, one on the south side and the other along the straight part of the shore. The rest of the shore is gravelly and more or less covered by bulrushes, sedges, and similar grass-like plants, which flourish in wet places, while in a few places the sod-forming grasses of the surrounding cultivated and pasture lands come down to the water's edge, a condition which probably prevailed on a much larger part of the shore before the water level was lowered by cutting the outlet.

Between the shore and the deep part of the lake, as is shown by the contour map, Pl. 14, there is an irregular belt of shallow water less than 5 feet deep. This is 700 or 800 feet broad along the east side, but in some places along the southwestern and southern margins it is only a few feet wide. The bottom of these shallows is almost entirely marl, which thus forms a platform almost around the lake, and, in the case of the marsh at the west end, has actually filled a bay of considerable size. This marl bottom has an admixture of sand in places, but is generally quite pure, and makes a firm, clean bottom. From the outer edge of this shelf the sides of the lake basin are quite steep down to depths of from 30 to 60 feet, where the slope becomes more gradual to 75 feet, and in a number of smaller areas to 95 or even more than 100 feet. The location, relative size and shape of these deeper holes are accurately shown in Pl. 14.

The bed rock.—As determined by the records of deep wells in the adjacent territory, the bed-rock in the vicinity of Walnut Lake is rather uniformly about 300 feet, or a little more, below the surface, rising from about 500 feet above sea level near Detroit to 750 feet just north of Pontiac, while the land surface rises from about 600 feet to over 1000 in about the same distance. It has already been noted that the present surface rises much more abruptly after Oakland county is reached than in the regions to the southeast, and the same is true in a lesser degree of the rock surface, which forms a low, broad ridge, 200 feet or more high, the axis of which runs northeast and southwest; this ridge had a marked influence in determining the trend and location of the surface deposits.

The rock lying nearest the surface over most of Oakland county is the Coldwater shale, a thick deposit of generally dark-colored gray, blue, red, or green, fine-grained, thin-bedded, soft rock, often called slates by well drillers. In most places where it has been penetrated, it is found to be dry, or yields small quantities of salt water. Below this is the dark-colored, often bituminous Antrim shale, which is the bed-rock nearest the surface in southeastern Oakland county, and, immediately above it, is a light-colored, often coarse-grained, water-bearing sandstone—the Marshall sandstone—which is the rock nearest the surface in the extreme northwestern corner of the county. Full accounts of these formations will be found in the various publications of the Michigan Geological Survey.

Below the Antrim shale, and forming the upper stratum of bed rock farther to the south, are the limestones of Devonian and Silurian ages, with sandstones among those of the earlier periods. The chief interest in the bed-rock lies in the fact that from it a large amount of the material which constitutes the present surface deposits has been derived. These deposits are glacial drift, and, as it is estimated that from 50 to 90% of such drift was gathered by the ice from within a few miles of the places where it was laid down, it will readily be seen that there is an intimate relationship be-

tween the bed rock in the region passed over by the ice and the soils of the region of deposition. Moreover, a comparative study of the mineral constituents of the soil, especially of the larger rock fragments, and the rock formations of the adjacent regions, gives an accurate means of finding out the direction of ice-flow. Thus, if the ice moved across sandstone areas, it would be expected that unmodified drift of the regions of deposition would be sandy, and the soils formed from it rather poor in plant food and coarse in texture, while the larger rock fragments would be of sandstone; if shales and limestones were the chief rocks in the path of the ice, the resulting drift would be fine-grained and the soils clayey, while the boulders and pebbles would be chiefly limestones and shales, or because of the soft character of these rocks, wanting, or of more resistant materials brought from a greater distance. If the Antrim shale and Monroe limestone, both easily recognized, occur in quantity in the drift of the region north of their out-cropping over the Coldwater shale or Marshall sandstone, it is good evidence that the ice which deposited them came into the locality where they were left, from the south. Such evidence is always to be taken as incomplete, however, unless very definite, since the same rocks may occur in other directions in regions more remote, from which the ice may have brought them.

Glacial geology of the region.—The last geological epoch before the present was the Glacial, during which great ice-sheets pushed out from centers of ice accumulation in the polar regions and covered parts of what are now the temperate zones. In eastern North America, an ice sheet pushed out from the highlands of Labrador, and, at the period of its greatest development, extended across the basin of the Great Lakes as far southwest as the Mississippi river, covering the intervening regions, including Michigan. From this farthest limit, the ice sheet slowly melted back, as climatic conditions ameliorated, and finally disappeared entirely, but the retreat occupied a very long time, and was accompanied by many halts and small readvances, only the last of which left legible records. If the following facts are borne in mind, the theory of glacial erosion and deposition will be more easily comprehended. The movement of glacial ice is, in effect, a kind of slow flowage, as if the ice were a very stiff liquid, and as with other liquids the rate of movement is swifter where the slope is steep and the mass deepest. Where the rate of flow is greater than that of melting the ice advances, where less it retreats, and when the two are equal, the ice margin is stationary. The ice in its passage over the land surface removed, from the underlying rocks, the soil-covering resulting from the action of the agencies of rock-disintegration through previous ages of geological time, broke away, rounded, and pulverized fragments of these, and generally planed and polished the surface of the parts left. A large part of this eroded material, including fragments of all sizes, was picked up by the ice, incorporated in it and transported for greater or less distances, and then dropped wherever the ice melted. Much of the included material was carried to the margins of the ice, since these were the chief areas of melting, and there piled up as accumulations which generally took the form of lines of low, rounded hills, known as terminal and marginal moraines, or of flat sheets, with more or less undulating surfaces, called ground moraines or till plains. In these moraines all kinds of material from the entire region traversed by the ice are likely to be present, and, because of the transporting power of the ice, it has taken the form of a mixture of fragments of all sizes, from the finest clay to huge boulders, but with the finer material predominating. This material is

technically called till, while the whole deposit, sorted and unsorted, left by the ice, is called glacial drift.

In moraines of marginal types, and less frequently in the ground moraines, were frequently included detached masses of ice, sometimes of large size, which, becoming buried in mineral debris, persisted for a longer or shorter time after the main mass had melted away, and, finally disappearing, left more or less steep-sided depressions, which, later, became lakes. The water from the melting ice, flowing both within and without the glacier, carried with it suspended mineral matter, which was deposited in places where there was slackening of the current, to form more or less extensive areas of gravel, sand, or even finer material, along the channels which the water followed. These deposits were most frequent and extensive on the morainal slopes away from the ice front, and along the valleys in which the water from the melting ice ran, and are known as glacio-fluvial deposits, and, since they were formed outside the ice, or near its borders, are important aids in showing the direction of the movement and retreat of the glacial ice sheet and its lobes.

Since the ice moved more rapidly in the deeper parts these became the axes of movement, and pushed out farther from the centers of distribution than the thinner areas; thus the ice sheet had a scalloped margin, and, in later stages, was divided into lobes or tongues, the marginal moraines of which were roughly concentric, forming a series of belts, one inside the other back to the last strongholds of the ice. It seems probable that the ice was always thinner on the highlands than in the adjacent valleys, hence disappeared first from the former, while the latter still remained local centers of movement.*

The valleys now occupied by the Great Lakes were such centers of movement, and each of them has a series of moraines more or less parallel with the margins of the present basins, extending in constantly widening lines as they are crossed from the newer to the older ones over the region adjacent to them, until they meet in confluent masses known as interlobate moraines, i. e., moraines formed by the margins of two lobes when they were close together, or in contact. Thus the ice which covered the region which lies about Walnut Lake, in the latter part of the glacial period at least, since this is the part which left the clearest record, had its primary center of movement in the Labrador highland, but came into this immediate locality from the southern part of the basin in which Lake Huron now lies, and eventually melted back into it. At the same time the country beyond Pontiac, a few miles to the north, was covered by ice, also from the Labrador center, but coming immediately from the northern end of the Lake Huron basin, pushing out to the southwest through Saginaw Bay.

The topography about Walnut Lake, with its irregular lines of low, rounded hills, numerous, undrained or poorly drained hollows and swampy valleys is typical morainal topography of a rather simple kind. The region to the northwest, covered by great masses of sand and gravel and containing numerous lakes, is a well-marked and characteristic line of glacial drainage, along which the waters of the melting ice of the two closely opposed lobes of the ice sheet found an outlet to the southwest, thence to the Mississippi valley and the sea. The sands and gravels of the area are glacio-fluvial deposits left by this drainage, as the force of the streams and their carrying power decreased. The lakes and swamps of this drainage area are located chiefly in basins left by the melting masses of ice which had become de-

*See report on Surface Geology, preceding this paper in this Annual Report for 1907.

tached from the main bodies for some reason, and persisted for a sufficient time to become partly buried by the materials which the outpouring streams from the main ice masses piled around them. Several miles to the north and northwest of this drainage region is a broken tract of country which was apparently the place where the margins of the two lobes came together more closely still, and the records of each have been partly obliterated by the outwash (as the debris-laden waters are termed) from both. This complex region is succeeded still farther north and northwest by the bold and prominent moraines of the ice lobe from Saginaw Bay.

A mile to the south of Walnut Lake is another but much less extensive line of glacial drainage marked by a flat belt of sandy soil, about a mile wide, extending northeast and southwest on the south side of the morainal tract in which the lake lies. On the south side of this is a narrow morainal tract which marks the halt of the ice front, while the sandy area was the line of outlet for the water discharged from it. This drainage valley is less complicated in structure and relations than the one to the north, since it received the water from but one ice margin, but otherwise it exhibits the same characteristics and, because of its simplicity, is less difficult to study. Its course is also marked by fewer and smaller depressions, of which Wing and Gilbert lakes are the most extensive.

A short distance southwest of Walnut Lake is a nearly flat, clayey district of less than ten square miles in area, which has the chief characteristics of a till plain. This forms a recess in the moraine with which it is connected and is an area in which the glacial debris was deposited in a nearly flat sheet, possibly from thick or resistant ice which persisted longer than that on either side of it.

About three and one-half miles south of the lake, after crossing the drainage valley and attendant moraine, the characteristic forms of glacial deposition abruptly disappear, and the country becomes monotonously flat, with only occasional low, symmetrical ridges of sand and gravel running for long distances across it. The highest of these ridges lies just south of, and extends along the border of, the hilly country, and others, which are more prominent, run more or less parallel with it, as the slope towards Lake Erie is traversed.

These ridges are the shore lines or beaches of a series of lakes which existed towards the end of the Glacial period, between the front of the retreating ice and the highland which had recently been abandoned by it, the water from the melting ice rising to such a height as was necessary to find an outlet to the sea, either around the edge of the ice or across some gap in the moraines. The ice sheet persisted somewhat longer in the east, in southern Ontario and in the St. Lawrence valley, than it did in its thinner western extension, and hence the early outlets of the lakes mentioned above were to the southwest, ultimately through the Mississippi valley. The level of their outlets, or spillways, as they are sometimes called, fixed the height to which the waters of the lakes rose, and the length of time for which they served to keep the water at a given level, if other things were equal, determined the strength or prominence of the resulting beaches. Thus it is fair to assume that well-marked beaches are the result of a much longer period of action than low and faint ones.

These old shore lines of the glacial lakes may be recognized by their close resemblance to shores of the present lakes, and consist both of cut shores, where waves and currents washed away the materials against which they struck, and of built shores, those on which the waves piled sand and gravel into long, low, usually smooth-topped ridges, very narrow in proportion to

their length. The highest glacial lake is known as Lake Maumee, and three fragmental shore lines from about 800 feet down to 760 feet above sea level are attributed to this lake. The next stage below this was Lake Whittlesey, with a nearly continuous beach about 740 feet, and the lowest one within the limits of the area mapped was Lake Arkona, which formed a definite shore line about 40 feet below the last. The position of these important ancient shore lines in the Walnut Lake region is shown on the map, Plate 13, together with the names by which they are known.

The relationship of this phase of geological history to present day conditions and especially to the animal and plant life in Walnut Lake is plain, when it is understood that the drainage of the region at the present time is largely controlled by the ancient lines of drainage, and that the modern streams find their way to the sea through valleys formed by the glacial streams or by the outlets of the glacial lakes; these valleys and streams are known to be the lines of migration through which many species from the valley of the Mississippi have found their way into the Great Lakes and their tributary streams. In cases where the connection is not a direct one, as where two streams flowing in different directions occupy an ancient valley, as frequently happens, the divide between the two is commonly a swamp, in which, in times of flood, there is a complete water connection from one stream to the other, so that fish and other aquatic animals pass as freely over the divide as if it did not exist.

It is then important, in considering the origin of our Michigan lakes, to take into account also the past history of the region, and especially the glacial history, since this undoubtedly had much to do in establishing possible routes over which species of animals returned to the glaciated regions from the country south of the Ohio River, in which they had passed the long period of the ice invasion.

To particularize still further and apply the principles laid down above to the immediate district under consideration, the moraine in which Walnut Lake lies is known as the Fort Wayne moraine, and extends from the city in Indiana near which it was first studied, and from here has been traced around the lake Erie basin. This moraine is one of the last well-marked moraines formed by the Huron-Erie lobe of the ice sheet, before it shrank back to the low lands about the deeper part of the areas now occupied by Lake Huron and Lake Erie. The basin of Walnut Lake is a morainal depression, and while it is of rather irregular form for a morainal lake, and has the outline often seen in lakes occupying drowned valleys, it seems most probable that it is the mold of an unusally formed detached mass of ice, which was wholly or partly buried in the moraine by the mineral matter included in the glacier, so that it persisted until after deposition had ceased, and, later, slowly melted away, leaving a basin with steeply sloping sides, which immediately filled with water, since much of it was below the level of any outlet channel and the ground water table as well.

Post-glacial history of the region.—After the retreat of the ice the recently abandoned surface of the glacial deposits was subject to weathering, rainwash, cutting and erosion by streams, until such time as it was protected against such deformation by the growth of vegetation dense enough to cover the loose surface and check erosion. The surprisingly small amount of evidence of such change of the form by erosion in glacial deposits of the vicinity may be taken as an indication of either different climatic conditions from those existing now, for a time after the ice retreat, so that erosion

did not proceed on the same scale as at present, or of the rapid covering of the steep, soft slopes of the moraines by plants.

The latter seems a strong possibility, since forests of trees of large size, with a dense undergrowth of lesser plants are reported by Russell [1] as growing not only around the moraines bordering the Malaspina glacier in Alaska, but on the debris-covered margins of the ice itself. If similar conditions existed around the border of the greater ice sheet towards the close of the Glacial Period, it is not surprising that the present slopes of the moraines do not show more considerable evidences of erosion by wash and weathering, because they do not erode if well protected by forests or other types of vegetation. If some agency had not prevented erosion the slopes would have been much flattened, the valleys would show much greater cutting, and the drainage systems of the streams would be much more completely developed than now, since, if the slopes had been bare long, storm-waters would have rushed into the valleys and created torrential conditions and very rapid stream cutting. The fact that in the adjacent country there has been extensive gulleying of cleared slopes in the comparatively short time, less than a century, that the region has been under cultivation, is to some extent a confirmation of the hypothesis that these slopes were not long in being covered by vegetation after they were left by the glacial ice.

Because of the small erosion of the surrounding slopes and the lack of tributary streams, the basin of Walnut Lake was not modified by mechanically deposited material from the higher lands around it, nor was a natural outlet ever developed, either by overflow from the lake itself or by the cutting back of the valley with which the lake is now connected by a ditch, as might have been the case if the drainage of the area had been more strongly developed. The feebly developed drainage in this vicinity must have had its direct effect upon the fauna of Walnut Lake, by keeping the fish and other wholly aquatic animals in the lake land-locked, except in unusually high water, when temporary surface overflow from the lake may have found its way through the present outlet valley to the established stream system with which the lake is now artificially connected, but never for a sufficiently long time for a channel to be cut down to the usual level of the lake.

This land-locked condition of the lake has prevented free migration of fish and other aquatic types into and from it, except at what must have been rare and very brief intervals, since longer ones must have inevitably opened up a permanent outlet as the texture and composition of the drift makes it very easily cut by water-courses when once these are established, as is to be seen along the present ditch.

Since the ice block melted from it the basin of the lake has been slightly increased in superficial area by the action of waves, wind formed currents and ice-shove in winter, and the material removed by these agencies has either been spread over the sides and bottom of the basin, or, in the case of the ice action, pushed back from the shore in the form of a low ridge just above the water-line.

Marl.—On the other hand, internal agents in the form of plants and animal organisms have been engaged in filling the basin, and have decreased its surface much more than the others have increased it. The chief modifying agent is marl, which is, when pure, a yellowish-white, more or less powdery or granular substance, often appearing like white clay, and composed of nearly pure calcium carbonate. Marl, or "bog lime," as it has been termed, is precipitated from the water of the basins in which it is found

[1]Russell, I. C. Second Expedition to Mt. St. Elias in 1891, U. S. G. S. Report, XIII, 2, p. 76.

by a number of organisms, both plant and animal. Of these the plants belonging to the stoneworts (Characeæ), and the blue-green algæ (Cyanophyceæ) are by far the most important agents, while of the animals, the mollusks contribute the largest amount. The marl usually contains sufficient unbroken shells of mollusks to attract attention, so that formerly the entire formation was supposed to be made up of shells, and was called shell-marl. In no other Michigan lake known to the writer would it be more easy to attribute the formation of marl deposits wholly to mollusks than in Walnut Lake, because of the vast numbers of dead shells of certain species of snails which are heaped up on the shores of the lake (Pl. 26). The presence of extensive beds of the stonewort (Chara) in various parts of the lake, associated with other lime-secreting Algæ, and the abundance of the characteristic remains of these plants in the marl, much exceeding those of the shells, point to the real origin of the beds here, as elsewhere. The occurrence and approximate extent of the marl beds along the shores of Walnut Lake have already been indicated on another page, but it should be noted here that the size of the original basin of the lake has been decreased by just so much space as these beds occupy. A full discussion of the formation and uses of marl will be found in a former report of this Survey. [1]

The marl beds furnish shallows with a firm, clean bottom upon which but little vegetation grows, and of a texture sufficiently coarse (about that of sand) to be adapted to use as spawning beds for some species of fish; that they are used as such will be seen by reference to the descriptions of the stations on a subsequent page.

Peat.—But little filling has been done by peat at Walnut Lake, and, so far as observed, the deposits of this substance are all superficial, being confined to those parts of the lake where the marl beds have nearly reached the surface. The beginnings of peat deposits may be seen, however, in the accumulations of plant remains as black mud, noted in the descriptions of the stations. The marshy tract at the west end of the lake has considerable peat above the marl, and seems to have been formed by the growth of much the same plants, the bulrushes and other shallow water types, as are seen in the shoal water at the present time, and as are now growing upon the marsh. Peat is formed in large quantities in the lakes of Michigan, and has converted great numbers of the smaller ones into bogs and marshes, but lakes like Walnut Lake, which have considerable deposits of marl, seldom have much peat until late in the history of the transition from lake to marsh. An extended discussion of the formation of peat has recently been published in the annual report of the Michigan Board of Geological Survey. [2]

Human agencies.—In recent years the lake and the conditions about it have, in various ways, been profoundly modified by the hand of man. The clearing away of the forest from the surrounding slopes give the winds much freer access to the water surface and increases evaporation, and the action of waves and currents along the shores during the season of open water, as well as blow the finer soil particles into the lake. At the same time a much larger proportion of the water which falls upon the drainage basin finds its way immediately into the lake, bringing with it the finer parts of the material obtained by erosion of the denuded land surface, in the form of mud and silt, and this material spreads itself along the shores and over the bottom, making the water less clear and pure after a storm than when the region was forest-covered.

[1]Geological Survey of Michigan, VIII, Part 3, Lansing, 1903.
[2]Davis, C. A. The Ecology of Peat Formation in Michigan, Report Mich. Geol. Surv., 1906, p. 94.

It is evident also, that the silting up of the lake will go on more rapidly under present conditions than formerly, but on account of the small drainage area directly tributary to the lake, the porous surface deposits around it, and the small size of the streams flowing into it, this change is of slight significance. The artificial outlet, which is now a permanent feature of the lake, is of more importance, since it has materially lowered the surface of the lake, and decreased its superficial area. Moreover, this change must also affect the biological relations of the lake to whatever extent the opening of a passage for the free inward and outward movement of aquatic plants and animals will affect the balance of life which was established before the outlet was made.

Soils of the drainage basin of Walnut Lake.—The morainal deposits about Walnut Lake are chiefly made up, on the surface at least, of a gravelly or sandy loam, containing a considerable number of boulders and smaller rock masses. This upper layer with its contained organic matter makes up the soil, and the type found here has been named the Miami gravelly loam in a report of the Bureau of Soils of the U. S. Dept. of Agriculture.[1] This type of soil covers practically the whole drainage basin of the lake, except at the southwest side, where a somewhat finer type, the Miami sandy loam, and at the south, where a considerable tract of coarser material, the Marshall gravel, occur. These types entirely surround the lake and cover most, if not all, of the area which can be considered tributary to it, and are sufficiently porous so that they absorb a considerable part of the rainfall, which percolates to the ground water level and finds its way out into the lake. The finer particles of these soils and of the underlying till are, in considerable part, fragments of limestone, hence the percolating water becomes strongly impregnated with calcium salts, the carbonate predominating, and, finding its way into the lake through subsurface springs, is the chief source of the marl. The water draining directly into the lake over the surface is likely to contain much less dissolved mineral matter, since it does not remain long enough in contact with the rock particles to become mineralized.

The surface of the drainage area of Walnut Lake is, then, of such porous types of soils that little water runs away on the surface, most of it becoming part of the ground water, and hence a relatively small area serves to keep the water of the lake high, and the clearing and cultivation of the land has not affected its absorbing power as much as frequently happens in more compact and clayey types, where the soil, after clearing, permits very little water to soak into it. Little is known of the structure of the glacial drift of the locality, below the soil line, but from the conditions in other places where cuts have been made, it is probable that it is made up of slightly sorted rock debris, which may be irregularly and incompletely stratified.

Physiographic features of the lake shores.—In the present paper it is not possible to go into details regarding the building of the various types of shore formations to be seen along the shores of such a lake as Walnut Lake, but it may be mentioned that quite a variety of such formations occur on a small scale, and are chiefly the result of the action of ice during winter and spring, of the waves formed by the winds, of surface currents along the shores, and of plants and animals.

The primary surface currents at any time are in the same direction with the wind; and as they are due to the drift of the surface water before the wind, the latter tends to pile up the water on the lee side of the lake, from which it returns along the other shores by gravity, in its passage cutting

[1]Soil Survey of the Pontiac Area, Michigan. U. S. Dept. Agriculture, Washington, D. C., 1904.

off the ends of any points upon these and forming spits and bars in bays behind the points, or depositing the finer and lighter drift-material in the still waters of the bays. These facts account to some extent for the deposits of fine mud in all of the bays mentioned in the descriptions of the stations on a subsequent page, and for the sand spit at station 41, described beyond (page 189) and shown in Pl. 43, although direct surface current and wave action, as shown in plate 43 are perhaps the primary causes of the formation of this spit, and the direct action may always be considered as important in all cases. The combined effect of waves and currents upon the shores is, therefore, to straighten them by eroding the points and filling the bays, the latter process greatly hastened, in many cases, by submerged plants, which retard the moving water, thus causing suspended matter to drop near or on them, and act as direct contributors to the filling by their growth and decay.

The erosion effects mentioned may be seen on the ends of any point exposed to the action of waves and currents, in the coarseness of the material upon them, and in the evidences of removal of the end of the point, which will usually have a prolongation of considerable length, extending lakewards below the surface of the water. Such washed shores afford excellent breeding places for several species of fish, as noted elsewhere. After westerly winds, accompanied by showers, the westward returning currents along the north side of Walnut Lake could be traced for more than a quarter of a mile by the muddy water from one of the inflowing streams. This water instead of flowing out into the lake, as would have been the case but for the existence of the current, was turned westward immediately at the mouth of the stream and formed a well-marked belt, a rod or more wide, in the clear water of the lake, and flowed with considerable rapidity, even though no wind was blowing at the time when the observations were made.

It is apparent, also, that these currents in shallow water must move the finer organic debris along the bottom until bays are reached, when this material is swept into them and left as sediment in their quiet water, and in such places of accumulation conditions sooner or later become favorable for the growth of plants, and these, in turn, hasten the process of filling the bay. After the plants become established, the bays furnish a favorite habitat for some of the most important food and game fish of the lake.

From the consideration given above, it seems that many factors, not always taken into account, may enter into the problem of explaining biological relations in even so small a lake as the object of this study, and that logical relations in even so small a lake as the object of this study, and not only must the present history be studied, but also the past, for there may be important matters overlooked if this is not done.

FIELD STATIONS.

BY T. L. HANKINSON.

In order to be able to attack systematically the problem of the relation of the fish life to the environment, stations were established where different environmental conditions prevailed, and these places were subjected to careful study. The stations were located early in April, before the aquatic vegetation had sprung up, so that in some instances after the vegetation appeared minor differences were observed within the station areas first located. In such instances the smaller areas were designated as substations.

It is hardly necessary to state that the boundaries of the stations were rarely well defined, but merged gradually into each other.

The stations were located at the beginning of the field season, after a careful preliminary examination of the lake and its surroundings, during which many sample collections were made. The following characteristics were the chief ones taken into consideration in locating stations: (1) aquatic vegetation, (2) nature of the bottom, (3) depth of the water, (4) nature of the soil of shore and bottom, (5) topography of shore and bottom, (6) shore vegetation, (7) exposure to waves and winds.

Since collections and observations were made over the greater part of the lake, a large number of stations were established, the general location of which can be seen in Pl. 15. The head of the outlet (the landing place) was station 1, and all stations along the shores of the north half of the lake were given even numbers, while odd numbers were used along the south half. The stations at some distance from the shore, in water over 30 feet deep, were given numbers between 200 and 250.

The stations may be classified roughly under nine types as follows:

(1) *Barren shoal type.*—In stations of this type the shores are low, sedge-covered, and often marshy, and are replaced off shore by a shallow shelf (known as the shoal) which is broad, and has a bottom of pure marl, or marl and sand, and only *inconspicuous vegetation.* At the outer edge of the shoal there was usually a pond-weed zone, and that part of it which was adjacent to the shoal was included in the station in all cases, on account of its close relationship to it. The following stations were of this type: 3, 23, 49, 37, 46, 36, 16, 12, 6 and the central part of 4.

(2) *Firm shore type.*—In stations of this type the water conditions were similar to the last, but *the shore was high, firm, grass-covered, and without a sedge zone;* frequently also there was a narrow beach between the water and the shore vegetation. This type included stations 11, the eastern part of 19, 27, 45, and 44.

(3) *Bulrush-covered shoal type.*—Stations of this type differ from type 1 only in having a conspicuous *growth of bulrushes* on the shoals. It includes stations 15, 35, 24, 20, and the western part of 19, and the northern part of 4.

(4) *Swamp loosestrife-fringed type.*—In this type, the shoals had black bottom soils and abundant luxuriant aquatic vegetation, including a water-lily zone. The shallow water on the shoreward border had a distinct *fringe of swamp loosestrife.* There were but two stations of this type, 31 and 26.

(5) *Marsh bay type.*—This type included two small bays *with very abundant aquatic vegetation*, and a shoreward border of sedges and bulrushes growing in several inches of water. From each of these bays a ditch extended back into the adjacent marsh. Stations 7 and 41 were the only ones of this type.

(6) *Bulrush shoal type.*—The extensive area of shallow water between the island on the east side of the lake and the main shore, constituted station 54, the only one of this type. The bottom of this area was densely covered by bulrushes, flags, and many other species of plants.

(7) *Swamp shore type.*—Station 40 was the only one of this type. It was peculiar in having a *wide swamp along the shore*, and a broad shoal with an abundant growth of aquatic plants, forming complex associations.

(8) *Outlet head.*—This station included the first thirty or forty feet of the outlet, or that part of it in which lake conditions were prominent.

(9) *Deep water type.*—This type comprised all stations at which the water

was over thirty feet in depth. The bottom was usually soft and oozy, and there was little, if any, except microscopic vegetation. Stations numbered from 200 to 250 were of this type.

BARREN SHOAL TYPE.

Station 23 is a good example of the barren shoal type. It extended for about a quarter of a mile along the south shore, just west of the entrance to the bay. In this station were included the woods bordering the shore as well as the zone of pond-weeds which marks its lakeward border, for the reason that they probably determine, to a considerable extent, the fish fauna of the shoal. Altogether the station had five zones (of which three were terrestrial) with peculiar environic conditions. These zones were as follows: (1) the timber zone, (2) the sedge zone, (3) the beach or shore, (4) the barren shoal, and (5) the pond-weed zone off shore.

The timber zone was the remnant of the former forest cover, and occupied an untillable portion of the bank of the lake, partly swamp and partly steep slope, and was less than a hundred feet in width. The tree growth was sharply limited towards the lake by a ridge formed by ice shoving the soil back from the shore during its expansions in winter, and possibly also by the water in spring. Evidence of the effects of the ice movement is shown by the inclination away from the lake of many of the young trees on the shoreward border of the woods, as is shown in Pl. 16.

The chief effect which the tree zone had upon the fish life of the lake was in harboring insects which may furnish a considerable amount of fish food. In the latter part of April, for example, adult midges, whose young life stages are passed in the lake and form a large part of the food of the white fish, as well as other species, were present in dense swarms in this wooded area, while they were nearly absent from the more open places. It is probable also that other insects, breeding and developing in the trees, are at times blown into the water, where they are taken by the fish.

The sedge zone extended the entire length of the station, covering the shore from the high water level to the woods, and even invading them to some extent.

During the late summer months the water receded from the lakeward margin of this zone leaving it bare. The conspicuous plants of this area, besides the sedges, were a species of horse-tail and the common lake bulrush; the latter was common at the east end of the station, encroaching on the beach, which was here low and wet (Pl. 17). Grasshoppers were abundant in this sedge-covered area in late summer, and the plants served as resting places for the adult stages of a number of aquatic species, thus making the zone a source of food supply for the fish inhabiting the waters of the station.

The beach was a narrow zone between the water and the sedge zone. It was bare during periods of low water, especially during the latter part of summer, and was most distinct in the eastern half of the station (Pl. 17), although at the eastern end for a short distance, the shore was low with shallow pools of water scattered over it. In general, however, the beach was well above lake level, and had an evident slope to the water. Along most of the zone, plants of the sedge zone were advancing towards the water by means of their underground stems, and but for the violence of the waves created by north and northwest winds, the entire beach might be covered by vegetation. During times of strong wave action, however, sedge plants were frequently found in the process of being washed out, and where a dense

growth reached the water, masses of plants were often torn loose and moved along the shore by the waves. At the low point of the beach mentioned above, the bulrushes formed a thin growth over the entire area, while the wet soil had numerous plants of Chara, and of a small pond-weed with broad leaves, growing upon it, the vegetation thus being very similar to that of the adjacent shoal. The soil of the beach was composed of marl, small fragments and gravel, sometimes thoroughly wave-sorted, and in places of mixed small boulders and cobble stones (see plates 16 and 17). The only part of the beach where animal life, which could be counted as a source of food supply for fish, was at all abundant, was the low, wet, east end. Here during the latter part of August many young green frogs were seen, while tadpoles were common in the shallow water near by. The dry part of the beach seemed to have few inhabitants except small flies, spiders and toad-bugs, but it was often visited by the killdeers and the spotted sandpipers and occasionally by a yellow-legs.

The shoals proper averaged about 100 feet in width out to where the water reached a depth of four or five feet, at which depth it merged into the zone of dense pond-weeds; it was broadest at the east end, where it was 200 to 300 feet wide, while near the center it was not more than 60 feet. In this zone the bottom is covered with marl mixed with sand, gravel, and small cobble stones. Sand was abundant on the western part of the shoal, where the bottom is quite hard, while the gravel was more uniformly scattered over the east half (Plates 56 and 57).

There was little noticeable vegetation in this area, although during the summer the bottom was covered with the stonewort which grew an inch or so high. Bulrushes were scattered over the entire shoal, and increased in abundance towards the end of the season. They did not, however, form a distinct zone, although a tendency to do so was shown by the denser patches at the east and west ends and the poorly defined one near the center. The fauna of this shoal was large compared with that of the others, and the presence of pebbles and small stones on the bottom seemed to furnish favorable conditions for the inhabitants. Under these, numerous crayfish excavated hollows indicated in the small heaps of soil which they left in front of the holes. The stones also served to shelter many flat-bodied larvæ of the May-fly (*Heptagenia sp.*), leeches, masses of leech eggs, planarians, and small crustaceans. Three species of fish, the Johnny darter, miller's thumb, and blunt-nosed minnow also placed their eggs on the under sides of flat stones in this area, as has been noted in the discussions of these species on subsequent pages. During late May and early June, schools of blunt-nosed and straw-colored minnows, the former predominating, were common over this shoal, especially at the eastern end, where there was a considerable area of water only two or three inches deep. Some individuals of this species were noted at all times where the bottom was gravelly, but they were frequently absent from the places without stones. Perch also were often seen in this area, especially at night, possibly searching for crayfish, which are chiefly nocturnal in their habits. The other species of fish seen here were the black bass and sunfish, which were frequent in the latter part of May and early June, and the blue-gills, which used the deeper places for nesting. Two very different types of animals were sufficiently abundant near the deeper lakeward margin of the shoal to be mentioned, viz., a large fresh-water mussel, or clam, which was especially common near the pond-weed zone, and a colonial protozoan, *Ophrydium versatile* O. F. M., which at

times completely covered the bottom of parts of the shoal, with large, greenish, gelatinous colonies.

Table of Temperatures obtained at Station 23.

Date.	Time of day.	Direction of wind.	Velocity of wind. Ft. per min.	Air temp.	Water temp.
May 16	10:00 A. M.	W.	332	27.5° c.	16. °c.
May 18	3:40 P. M.	W.	Slight.	24.	17.5
May 23	10:30 A. M.	No wind.	.....	23.	20.
June 9	9:00 P. M.	No wind.	.....	22.5	21.8
June 10	9:00 A. M.	W.	898	21.2	22.6
June 19	10:15 A. M.	E.	580	25.	24.5
June 20	2:20 P. M.	N. W.	192	24.9	22.
June 24	9:30 A. M.	N. W.	360	21.2	23.
June 25	3:00 P. M.	.....	142	25.5	25.5
July 5	4:30 P. M.	N. E.	822	19.9	23.8
July 6	4:30 P. M.	N. E.	337	25.2	25.
July 19	10:30 A. M.	S. E.	152	29.5	26.3
Aug. 17	5:50 P. M.	E.	67	26.5	25.5
Aug. 22	2:45 P. M.	N. W.	350	31.	30.5

Whenever this shoal was visited air and water temperatures were taken, the latter in several places where the water was about a foot deep. The readings are given in the table above, and they are too few to be of much value for purposes of generalization.

While pond-weeds were scattered over the entire aquatic part of this station, and, as mentioned above, stunted plants even occurred above the low water mark at the east end of the beach zone, in no place did they form a considerable growth in water shallower than four or five feet. In midsummer the shoreward margin of the pond-weed zone was indicated at the surface by numerous emerged flower spikes, while lake ward the zone was limited to a depth of water less than 25 feet, and no plants were found below that depth. The width of the zone varied with the steepness of slope of the bottom, from 100 feet near the ends, to 20 to 25 feet near the middle. Fish were common in this habitat at all times, as frequent examinations with the water glass showed. The most abundant species was the perch, which was especially numerous in June, when large schools of them were noted here.

Station 32 is of the same type as the one just described, but was located on the north side of the lake. It extended east from the north bay for about a third of a mile, to a point where the shoal becomes very narrow and the shore turns abruptly to the northeast. As in station 23, there was a broad sedge zone, and, in seasons of low water, a distinct broad beach. The sedge zone terminates landward at the foot of a low bluff which is tree covered, forming a lakeward edge of a woodlot (Pl. 18). These woods in spring were the gathering place for great swarms of adult midges. At high water, plants of the sedge zone grow down into the margin of the water, but at the low water period there is a broad strip of pebbly beach mostly without vegetation. As noted in connection with station 23, many insects, especially grasshoppers, live in the sedge zone, and, falling into the water, become available as fish food. The relations of the shore zones at this station are shown in Plates 19 and 20. The shoal out to a depth of four or five feet, was about a hundred feet wide at the widest part, but was much narrower in other places. The bottom of the shoal was marl, with a little gravel in the shallower

places, and supported little vegetation, except the small form of stonewort found at station 23. The only other exception was a small patch of bulrushes at the east end, which enlarged as the season advanced, and was called substation A.

The animal life was not as abundant on this shoal as on the south side of the lake, but leeches and amphipods were taken, and in the middle of April pupæ of the midges were very abundant upon the water surface, while the larvæ of the same insect were often dredged from the shoal bottom. On August 6 many small univalve mollusks were seen near the shore in very shallow water (but a fraction of an inch deep). These proved to be *Limnæa desidiosa* Say, and were the only living snails found in numbers away from regions of abundant vegetation. Minnows and other small fish were often seen here in April, but were less common later in the season. The following species were taken on April 28, when fish were noticeably abundant: Johnny darter, blunt-nosed minnow, black bass (young) and *Etheostoma iowæ*. Late in the spring there were times when there would not be a single fish on the entire shoal, except at substation A, where perch, sunfish and bass were usually seen. It was evident, at all times, that this patch of rushes had more attraction for the larger fish than the part of the shoal at the west end. The accompanying table gives temperature readings at this station.

Time of day.	Wind. direction.	Wind velocity. Ft. per min.	Air temp.	Water temp. at surface.
5:00 P. M.	N. E.	248	11. °c	19. °c
3:30 P. M.	No wind.	.....	18.5	17.
2:45 P. M.	N. E.	Slight.	13.5	15.
5:00 P. M.	N. E.	386	13.5	15.
11:30 A. M.	S.	468	24.5	22.5
5:40 P. M.	S.	220	21.3	22.1
8:30 P. M.	S.W.	158	25.2	21.

Station 49 is a third example of the shoal type. It lay along the southeastern shore, and included most of the broad peninsula and the bay adjacent to it on the east. The shore was low, and covered with sedges both on the wet and dry parts, although the sedge zone disappeared abruptly at the edge of the high ground, a hundred or more feet from the water. This area was very similar to the sedge zone at station 32. The soil was of the same sandy character, and there were, along the shore, small, shallow bays, in which the water was an inch or so deep. The shoal was broad, and covered with gravel and sand (Plate 21). The minnows and other small fish were generally abundant here, appearing in large schools in the shallow bays, where the temperature was much higher than in the adjacent waters of the lake. As nothing could be found in these bays which might serve as food to attract these fish, it seemed probable that they were drawn to them by the warmth of the water. On May 22nd, the following species were taken in a small seine hauled through the shoal towards the mouth of one of the bays: 105 blunt-nosed minnows, 93 straw-colored minnows, 29 barred killifish, 10 Johnny darters, 2 golden shiners, 2 least darters, 1 miller's thumb, and 1 *Etheostoma iowæ*.

This shoal was further used as a nesting place by the Johnny darters and blunt-nosed minnows.

Station 46 extended along the northeastern shore of the lake, from station

54 northward almost to station 40. Its features were entirely distinct from those already described, in having no tree zone and no extensive beach, while the sedge zone was a wide marsh, and the shoal very broad (more than 700 feet in places, see Plate 22). The shore line was broken by a number of small coves with hard, sandy bottoms, and water but a few inches deep. Between the coves were narrow, sedge-covered points.

In April and part of May large numbers of minnows and other small fish resorted to these coves and the shallower water of the shoal, but after the beginning of June very few fish were found here. About the middle of April the following species were collected here: blunt-nosed minnows, straw-colored minnows, Cayuga minnows, Johnny darters and the *Etheostoma iowæ*. On the 26th of the same month another collection was made in one of the shallow coves of the station, in water from 6 to 8 inches deep, with the following results: 100 straw-colored minnows, 80 Cayuga minnows, 75 blunt-nosed minnows, 21 black-chinned minnows, and 1 golden shiner.

Late in May, besides the minnows mentioned above, the barred killifish, common sunfish, perch and Johnny darter were taken on this shoal, making, in all nine species from this habitat. In the more gravelly places in this part of the station, crayfish made their homes under stones, as at station 23, and a Johnny darter's nest was found. It was reported also that whitefish visited this shoal in November to spawn.

The sedge marsh at this station doubtless had a large fauna, but it could be given little attention. The leopard frog was abundant on April 26, and large numbers of frog's eggs and newly-hatched tadpoles were seen at the same time in the shallow water of the marsh. Adult midges swarmed here on this date, and the minnows caught at the time had been feeding largely upon both the pupal and adult stages of these insects.

Station 3 has been classed with the shoal type, but it differs from the stations discussed above in the fact that the shoal was much narrower, and had a bottom of marl without sand or gravel. It included about 600 feet of the west shore of the lake, south of the outlet, except for a small, shallow, rush-bordered bay, and the ditch running from it into the marsh. The bay, on account of the different environmental conditions, was treated as a distinct station, No. 7. The sedge zone of this station (3) was represented by a broad, wet marsh more than 500 feet wide at its broadest part, which was covered with a uniform growth of sedges, which grew during the early part of the season, at least, in shallow water. This station as seen from the northern end is shown in Plate 23.

In mid-April the pike used this marsh as a spawning ground, and a little earlier a school of blunt-nosed minnows were seen here, 200 feet from the main lake, which is the farthest point from open water where minnows were found during the season. Leopard frogs were numerous, and great numbers of their eggs, and later their tadpoles, were seen here. The marsh was a favorite resort for insects, and for several days, beginning April 19, midges swarmed over it by millions, especially near the lake margin. From a distance they appeared as a cloud hanging low over the marsh, and closer examination showed that the stems and leaves of the plants were blackened by resting individuals. Plates 24 and 25, showing groups of these insects on a fish house near the edge of the marsh, will give some idea of their abundance in this habitat. The shoal area of this station averaged less than 100 feet in width, and its marl bottom supported very little vegetation, except a few thin patches of bulrushes which appeared late in the season, and limited areas of small stoneworts. Almost daily observations were made at

this part of the station, and it was found to be little visited by fish in the daytime, but at night, especially in April when the midges were taking flight and the pupal form was abundant on the shoal, many perch and a single whitefish were seen here. Blue-gills also used the bottom as a nesting or breeding place, building their nests in about three feet of water.

The shoal was also inhabited by crayfish, which bred here, but mollusks and larger aquatic insects were rare, if present at all. Some temperature readings were made here, and are given below with accompanying data.

Date.	Time of day.	Wind direction.	Wind velocity. Ft. per min.	Air temperature C.	Water temperature C.
April 29	5:00 P. M.	S. W.	419	19.5	8.3
April 30	11:00 A. M.	N. W.	235	17.	11.
May 1	8:00 A. M.	N. E.	740	14.	12.5
May 8	2:30 P. M.	E.	Slight.	8.5	10.5
May 19	2:30 P. M.	N. W.	340	16.	17.5

The pond-weed zone of this station was from 100 to 150 feet wide, and included that part of the bottom (from a little less than 5 feet to about 25 feet in depth) which is covered by a dense growth of pond-weeds and other aquatic plants. Here, as at other stations, the water at the outer margin of the zone was found to have a depth of about 25 feet, below which the higher plants were apparently absent. The following species of fish were taken from this area in April by means of a large fyke net: Large-mouthed black bass, common sucker, rock bass, yellow perch, common sunfish and blue-gill.

The plants of this zone are discussed on a subsequent page (225). On them were found minute snails, amphipod crustaceans and midge larvæ.

Station 16 comprised the eastern shore with the adjacent shoal and pond-weed zone of a marshy peninsula, which is about 400 feet long and 200 feet wide, and forms the east side of the bay from which runs the outlet (Pl. 27). The conditions here which can affect fish life in the lake are practically identical with those described for station 3, but the shoal is slightly narrower. The latter has a pure marl bottom, and a very scanty vegetation of dwarfed stonewort. Above the water's edge a low, firm, dry, sedge-covered ridge, either ice or wave-formed, extended the length of the station, and at the north end there was a short beach covered with bleached snail shells and their fragments, which, as shown in Plate 26, were beautifully sorted into rows by wave action. The pond-weed zone proper began in about five feet of water, although there was a scant growth of these plants in the shallower water towards the shore.

The earliest observations at this station were made on April 6th, 7th and 8th, while there was still some ice in the lake, and the marsh was frozen. At this time a few specimens of *Etheostoma iowæ*, blunt-nosed minnows and a single Cayuga minnow were taken in a dip net, as they swarmed from hiding places beneath overhanging sedge-roots, along the edge of the marsh. At this time the water temperature was nearly at the freezing point, and no fish were seen moving about on the shoal, but in spite of this, crayfish, May-fly and dragon-fly larvæ and caddice worms were found rather common in the shallow water. Plate 27 shows the part of the shore along which these observations were made, as it appeared in April.

Fish were never common on this shoal, even minnows being rather in-

frequent visitors. Perch were occasionally seen at night, resting on the bottom as at other stations, and in June the north end of the shoal was frequented by blue-gills, whose nests were numerous in about 3 feet of water. A single nest each of the darter and a blunt-nosed minnow were also found here. The pond-weed zone was well-marked, and while early in the season its shoreward edge was limited by water about five feet deep, later, in July and August, the shoal was encroached upon up to about the three-foot contour, by a conspicuous growth of the characteristic plants of the zone, and scattered plants of pond-weed appeared in still shallower places. The zone extended lakeward to where the water was about 25 feet deep, below which no plants could be found. In the late summer many more fish were seen in this zone than at any other part of the station, the common species being perch, sunfish, black bass, blue-gills and minnows.

Station 6 was the west shore of the peninsula described above, with its adjacent shoal and pond-weed zone. It differed from the station just described in having no hard ridge along its shore, and in being located in a bay instead of on the open lake. The sedge marsh was wet throughout the year, and the shoal was less extensive than that on the eastern shore of the peninsula, while the pond-weed zone was broader. The station, as it appeared in early spring, is shown in Plate 28.

The marsh was apparently but rarely visited by fish, as but a single specimen, a pike, was seen in its shallow water. In early spring fish were also scarce upon the shoal, not visiting the shallow water at this time as they did in the eastern side of the peninsula. In late spring, however, minnows and darters were common here, and comparatively scarce along the other shore. The species were: blunt-nosed minnow, straw-colored minnow, golden shiner, least darter, Johnny darter, and *Etheostoma iowæ*. In July many small perch and blue-gills were seen in the shallows, and larger fish of these and other species were also observed on the shoal. During May it was a nesting place for sunfish.

As this station was located near the head of a bay, at the northern end the bottom sloped gradually from the edge of the shoal to the 25-foot line, making the pond-weed zone here unusually wide. At the southern end, on the other hand, the slope of the bottom was deep, and the pond-weed zone was consequently very narrow, only about 50 feet wide. Fish seemed usually abundant here, especially in the wider part of the zone. However, this may have been partly an apparent abundance, as it was much easier to use the drag net in this habitat. The following species were taken: Large-mouthed black bass, yellow perch, common bullhead, yellow catfish, common sunfish, blue-gill, wall-eyed pike and rock bass. Three species of turtles, the musk turtle, painted turtle and snapping turtle, were also taken in this zone.

SUMMARY.

(a) *The depth of water.* The water upon the shoal varies from less than an inch to about 3 feet in depth. The depth of water seems to have little effect on the distribution of the fish over the shoal, other than restricting the larger fish, like the black bass, sunfish and perch, to the deeper parts. The minnows kept in shallow places near the shore. This was especially true in the spring, when the minnows kept in the shallowest water in which they could swim, possibly because of food and temperature conditions.

The shallow water also was chosen for nesting by several species. Some of these were confined to certain depths, the blue-gills, for example, choosing

water about 3 feet deep, apparently regardless of its relation to the shore or the pond-weed zone.

(b) *Temperature.* The effects of the water temperature on the movements of minnows is discussed in full elsewhere (p. 202), but the statement may be made here that the shallow water of the coves and lee sides of the lake was usually found to be warmest, and that the minnows sought such places, being apparently controlled in their movements by changes in water temperature.

(c) *Bottom material.* The minnows also apparently preferred stony-bottomed, barren shoals to those with marl bottom, probably because of the larger food supply in the former.

(d) *Plants.* Almost the only plants on the shoals proper were stunted stoneworts and scattered bulrushes. Their relation to fish was not apparent except at breeding time, when they afforded places of attachment for the eggs, and protection to the young.

(e) *Invertebrates.* As noted elsewhere, these shoals were the habitat of a greenish protozoan which was very abundant in spring. Crayfish were found here at all seasons. Various insects were not abundant with the exception of the midge larvæ and pupæ in April. Living mollusks were rare, but their empty shells were numerous.

(f) *Fish.* Seventeen species of fish, as listed above, were noted on the shoals of this type; the larger species were more common here at night than during the day. During the breeding season, the blue-gills kept other species from the areas in which they had their nests.

(g) *Sedge zone.* This area affects fish life more than any other shoreward zone, by furnishing a habitat for insects, which sometimes fall into the water and are eaten by fish. In spring the flooded portions are sought by the grass pike for spawning grounds, and more rarely by other species. Where these plants grow within the lake margin they furnish hiding places for numerous minnows and other small fish.

(h) *The tree zone.* Little was learned concerning its effect on the fish of the lake.

(i) *The pond-weed zone.* This was the general habitat of most of the species visiting the shoals, and all except five of the shoal fishes were also found among the pond-weeds. These exceptions were stonecat, chub-sucker, Cayuga minnows, barred killifish and miller's thumb. The pond-weed zone may be said to determine to a large extent the fish fauna of the shoals.

BULRUSH-COVERED SHOAL TYPE.

As the chief difference between stations of this type and those of the barren shoal type was one of degree rather than kind, the conditions were about identical, except for the presence of many bulrushes in the bulrush-covered shoal type. Two examples will be sufficient to show the characteristic conditions of stations of this type.

Station 15 included the small cove on the west side of the lake, between station 11 on the north and 19 on the south, a distance of about 400 feet. The shore was marshy and covered with a dense growth of sedges which reached to the water's edge. The marsh was about 100 feet wide at the ends of the station, but much narrower at the head of the cove, where woods bordered the marsh.

The shoal averaged about 20–30 feet in width, followed the curve of the shore, and was broader at the south end. The bottom was marl, and was covered by a dense growth of bulrushes (as shown in Plates 29 and 30) from

the shore line to where the water reached a depth of from 3 to 4 feet. Growing with the bulrushes on the shoal, were quantities of small stoneworts and occasional pond-weeds, as in stations of the first type. From the lakeward margin of the shoal the bottom sloped abruptly to a depth of 10 or 15 feet, then less steeply to 25 feet. This area was occupied by a dense pond-weed zone, which began at the outer edge of the bulrush growth and ended in about 25 feet of water.

The fish fauna on the shoal could be, and was, studied with care, because of the ease with which it could be approached from the lake without startling its inhabitants. From early May to the middle of June the following species were seen or taken here: blue-spotted sunfish, common sunfish, blue-gill, large-mouthed black bass, perch, yellow catfish. In the early part of July schools of blunt-nosed minnows, golden shiners and very small perch were commonly seen among the bulrushes on the shoal. During the latter part of July and August this shoal, like most others, was almost deserted by fishes, except for occasional small blue-gills. The marl bottom here was used by at least three species of sunfish as a nesting place, and probably also by the black bass.

While but little attention was given to the invertebrates of the area, some notes relating to the more conspicuous types were made. Dragon-flies and damsel-flies were usually common, and underwent their final transformation on the marsh bulrushes. On May 25th a small flight of May-flies was seen, but, in July, Dr. Needham found only a few dragon-fly and damsel-fly larvæ, and characterized the zone at that time of the year as a desert so far as aquatic insects were concerned. Whirligig beetles and spiders were often seen on the surface of the water, among the bulrushes. An interesting development of minute animals was noted on August 8th, when the surface of the water among the bulrushes, and of the algæ and other plants, acquired a soot-like covering, which upon examination under the microscope was found to be made up of innumerable one-celled animals related to *Vorticella*.

The following table gives the surface temperature readings and related observations in the bulrush zone of this station:

Date.	Time of day.	Wind direction.	Wind velocity. Ft. per min.	Air temperature C.	Water temperature C.
May 4	4:00 P. M.	S. W.	482	16.5	12.
May 6	4:50 P. M.	W.	.....	6.5	11.
May 9	4:15 P. M.	N. W.	.....	6.	10.
May 15	11:00 A. M.	S.	Slight.	25.5	12.5
May 25	4:00 P. M.	S.	.....	23.5	22.5
July 5	3:30 P. M.	N. E.	897	19.5	24.5
July 6	4:00 P. M.	E.	266	25.5	25.
July 7	2:00 P. M.	S. E.	288	25.3	26.5
July 27	4:00 P. M.	No wind.	.....	20.5	24.2
July 31	3:30 P. M.	S. E.	183	26.3	27.3
Aug. 2	10:30 A. M.	E.	363	28.	25.5
Aug. 11	9:30 A. M.	W.	138	26.5	26.

The pond-weed zone does not become well defined nearer the shore than about 50 feet, or until the water reaches a depth of 5 feet, for while the pond-weed plants are present in some numbers among the bulrushes on the shoal, they do not form a dense growth except on the lakeward margin. The zone was broader than at some of the other stations described, extend-

ing lakeward nearly 200 feet. A list of the plants of this habitat is given on a subsequent page (226).

The fish fauna here was much like that of station 6. With a water-glass perch could be seen in large numbers as far below the surface as objects could be distinguished (here about 12-15 feet). Schools of minnows appeared above the submerged plants, and the Johnny darter and *Etheostoma iowæ* were frequently noted in the shallower parts of the zone. Both the gill net and fyke net were used in this area, as well as hook and line, and the following species were found to frequent it in greater or less numbers: The perch (most commonly), yellow catfish, bullhead, rock bass, common sunfish, wall-eyed pike, common sucker, whitefish, large-mouthed black bass, blue-gill. For further details concerning these catches see page 247.

Station 4 is the region included between the outlet on the west and the base of the peninsula forming stations 6 and 16 on the east. It is the shoal with its adjacent marsh and pond-weed zones. The marsh was a continuation of that of station 6, but it was somewhat narrower than that of station 6, averaging a little more than 100 feet in width. Shoreward it ended abruptly at the margin of a cultivated field, and on the lake side extended to the water's edge.

There were three sets of environmental conditions on this shoal, which differed so much as to deserve recognition as substations.

Substation a was an area of stony bottom, about 20 feet in diameter, at the west end of the shoal, probably formed by a load of field-stone dumped in here from the cultivated land near by, and possibly spread out to some extent by ice-action. Pl. 31 shows this substation in summer, after the bulrushes had grown, making conditions similar to those at substation c. Small fish were seen here whenever the substation was visited, either day or night, throughout the season, and were often abundant over the stones in this habitat when none could be found on the rest of the shoal.

Substation b was the barren middle part of the shoal. It had a pure marl bottom which was without visible plant covering, and fish were seldom seen here.

Substation c was the east end of the shoal. It had a considerable growth of bulrushes which made it like station 15. The bulrush zone was narrow here, and covered with water about a foot in depth; the bottom was marl covered with low stoneworts growing between the bulrushes; and it sloped abruptly to deeper water from the edge of the shoal. In April the following fish were taken in a net from this place: pike, perch, common and long-eared sunfish. In May and June, sunfish, black bass, perch, blunt-nosed and straw-colored minnows, the least darter and *Etheostoma iowæ* were common in this zone, and in July it was used extensively as a breeding place by the common, the blue-spotted, and the long-eared sunfish, which made their nests in water about 15 inches deep. Notes on their nesting habits are given on subsequent pages (210, 212).

The minnows and small individuals of other species were abundant about these nests, feeding on the eggs and newly-hatched young. Plate 31 gives a general view of station 4, including the beginning of the outlet. Plates 51 and 52 are snapshots of a long-eared sunfish guarding its nest at this station. The other inhabitants noted in the bulrush zone of this station were numerous midge pupæ (seen on the bottom in April), *Sialis* adults (common on April 23, as in other similar places at about the same time), crayfish (numerous on the deeper part of the shoal during the summer).

The following temperature readings were made at the water surface:

Date.	Time of day.	Wind direction.	Wind velocity Ft. per min.	Air temperature. C.	Water temperature C.
May 19	9:25 A. M.	.....	490	20.	18.
June 28	10:30 A. M.	S.	347	25.4	25.
June 29	7:30 A. M.	S. W.	220	28.2	23.5
July 1	10:15 A. M.	N. W.	Slight.	27.	23.2
July 4	8:00 A. M.	W.	271	23.	23.

SUMMARY.

As pointed out above, the chief difference between this and the barren shoal type of station is the presence of the thick growth of bulrushes in shallow water, and since this is the only peculiarity, the relation of the plants to fish life is the only matter needing emphasis here.

From the fact that there were more large fish, chiefly bass and sunfish, on the bulrush-covered shoals during the breeding season in the spring than on those of the barren type, it was inferred that the conditions in the former habitat were more attractive to the fish than those of the latter. Four reasons for this seem to be apparent, viz.: (1) The bulrushes afford hiding places for the nests and young, as well as for the old fish during the breeding season; (2) the roots and underground stems of the plants serve as good places for the attachment of the eggs; (3) the water is less liable to be affected by strong waves where the plants are dense; and (4) these shoals are apparently better feeding grounds than the barren ones, as collections made from them indicate that the larvæ of dragon-flies, May-flies and midges, as well as crayfish, seemed more numerous among the plants than on the open shoals, except those with stony bottoms.

SWAMP LOOSESTRIFE-FRINGED TYPE.

The swamp loosestrife, which characterized stations of this type, is described at length on a subsequent page (231), and also in another publication of this Survey.* In Walnut Lake it is limited to the two areas described below, which form a very distinct type of stations.

Station 31 included a part of the west shore of the south bay of the lake and was about 300 feet long, and from 10 to 30 feet wide. It was bordered along the water's edge by a thick growth of the swamp loosestrife, which grew in water from a few inches to slightly more than 2 feet in depth. Plate 32 shows this station in April, and Plate 33 in the latter part of June.

The station had four distinct zones of vegetation. These were (named in order from the dry ground to the deep water): (1) sedge zone, (2) swamp loosestrife zone, (3) water lily zone, (4) pond-weed zone. The most conspicuous plant in each of these zones was the one which gave to the zone its name.

The sedge zone was a tract of marsh several acres in extent, and covered by several inches of water which surrounded the stools of the tussock sedge, the common sedge here.

The swamp loosestrife zone, as it appeared from the lake, is shown in Plate 34. Fish were seldom observed in the shallow water among the stools of the swamp loosestrife, and none were caught with a dip net, but on May

*Davis C. A. The Formation and Distribution of Peat Bogs in the Northern Peninsula of Michigan. Report Mich. Geol. Surv., 1906.

30, a trammel net placed along the fringe captured three species of sunfish, the blue-green, common, and a specimen of *Lepomis euryorus*.

The relationship of the pond-lily zone to the last is clearly indicated in Pls. 33 and 34. The water in which the water-lilies grew was from two to six feet deep, and the bottom was covered by a thick growth of stoneworts and some pond-weed. According to our observations, fish were never abundant here; on June 24th some young blue-gills and black bass were noted.

The pond-weed zone extended from the lakeward margin of the pond-lily zone into deep water, and unlike the other zones of the station, had a large fish population during the summer. The principal forms were young perch and minnows. Blunt-nosed and straw-colored minnows, common and golden shiners were always noted to be abundant in the shallower parts of the zone, whenever it was visited, and were peculiarly active, darting about as if at play, while in apparently peaceable association with them were seen black bass, rock bass and perch.

Station 26, the other example of the type of station under discussion, included the north shore of the bay of the lake, and was the extreme northern station. It differed from 31 in being sheltered on three sides by wooded hills, in being only 35 feet deep at its deepest part, and but 8 or 10 feet deep for about 100 feet from the shore. There were three well-defined zones of vegetation, the sedge, swamp loosestrife, and that of wholly aquatic plants, including water-lilies. Plates 35 to 40 inclusive, show various aspects of this station.

The sedge zone lay across the mouth of a small valley, in which, during the wet part of the year, runs the intermittent stream which drains the wood-covered slopes north of the lake. The vegetation of this area is well shown in Plate 35. It lay between the swamp loosestrife zone near the margin and the shrubs that bordered the woods. Near the level of the water the plants were chiefly tall-growing species of sedges, with a small area of cat-tails near the east end.

The swamp loosestrife zone followed the curved shore of the north end of the bay for about 100 feet, and was from 10 to 20 feet in width. The plant grew from the place where the soil was simply moist out into the water about eighteen inches deep. No data on the interrelation between these conditions and the fish were found.

The zone of aquatic plants extended outward for about 100 feet from the lakeward margin of the loosestrife zone to a depth of from 8 to 10 feet. It may even have extended farther, since the bottom below that depth was not studied carefully. The conspicuous plants of this area differed at different times during the season; first, water lilies appeared in early summer, forming an incomplete zone, then, the white water crowfoot covered the water with its dainty blossoms (Plates 39 and 40), and later, the outer parts of the zone were occupied by several kinds of pond-weeds. The bottom in this habitat was a black mud, incipient peat, formed from decaying aquatic vegetation, and the leaves and other parts of marsh and land plants which had blown into the lake. Immediately lakeward of the swamp loosestrife zone, in water about two feet deep, was an irregular strip where the black mud was covered by undecayed water-logged twigs, leaves and other plant debris. This strip was bare of plants, except for a few stoneworts and floating filamentous algæ. The undecomposed material was probably much increased by a mass some 50 feet long and 12 wide, of stems of white water crowfoot, which in August was swept over it by wind, and became lodged against the swamp loosestrife (Plate 39).

Large schools of blunt-nosed minnows were often seen in the parts of this zone where the vegetation was dense, and other small fish, especially golden shiners were usually found. The least darter was abundant in May and June, and probably bred here. The common sunfish used the shallow, bare area near the inner margin of the zone as a nesting place, and the shallow water of the entire station seemed a favorite resort for perch fry, in early June, and for young minnows (too small for determination) which were very abundant. Some small chub-suckers were also taken here on June 15. The musk and painted turtles were common at this station.

MARSH BAY TYPE.

Of the two stations of this type station 7 was most often visited, because it was very accessible, and because of the ease with which the large number of species of fish inhabiting it could be studied. For these reasons this station was given more attention than any other on the lake. It included the small bay, or cove, in the marsh on the west side of the lake, which was mentioned in describing station 3, and an area of yellow water-lily plants at its mouth, which was considered a part of the station, because it was the refuge of many of the fish frequenting the bay. A ditch 5 or 6 feet wide, cutting across the marsh from west to east, enters the bay. The latter was circular in form, and bordered by bulrushes and a sedge marsh. At the water's edge on the north side of the bay a group of swamp loosestrife plants were established, and another group was situated on an old muskrat house in the middle of the bay. The bulrush growth forms projecting points on either side of the bay, which nearly close its mouth, and partly cut it off from the lake. Plates 41 and 42 show the type of shore vegetation and other features of this station.

In the spring the average depth of water in the bay was about a foot, in the summer it was less than this over most of the bottom, because of the lower water level of the lake, and the dense growth of submerged plants which carpeted a large part of the area. The bottom was covered by a layer of black, soft, peaty ooze, above a different substratum, apparently marl. Many types of plants were found here, and a description of the relations of those noted during the spring will be found on a subsequent page (222). It is sufficient to say that the dense growth of vegetation at this station was never so luxuriant that it interfered to any marked extent with the fish life by restricting swimming space over any considerable area, for there were always a few inches of water over the tops of the submerged plants, besides many bare spots covered by accumulations of water-logged chips, sticks, bits of bulrushes and other coarse fragments of vegetable matter, brought here by waves and surface currents. Such a spot in the south part of the bay, having an area of three or four square yards, was covered by but a few inches of water, yet minnows were more abundant upon it than in any other part of the station.

Easterly winds drove waves of considerable height into the bay, in spite of the protecting bulrush points, and the water was sometimes turbid from this cause. This undoubtedly affected the life relations of the bay, by preventing its being clogged with aquatic vegetation.

One type of plants found in the bay, the bladderworts, may have a slightly unfavorable effect upon the fish life, by lessening the food supply of some of the smaller species. These plants are said to be carnivorous,* the bladder-

*Darwin, C. Insectivorous Plants.

like expansions on their leaves and stems serving as traps and absorptive organs for small crustaceans and other animals which may enter them. On July 5th some material from one of these "bladders" was examined, and was found to contain several minute crustaceans of the kind used as food by small fish at this station. This effect must be very insignificant, however, as the plants are few, and the bladder-like traps are only operative on such organisms as enter them.

This station was visited almost daily from about the first of May until August 15th, and, since, owing to the concealment afforded by the bulrush points, it was easy to approach the bay from either side without disturbing the fish, many very satisfactory observations were made upon their habits. Until about the middle of June full-grown specimens of black bass and sunfish were found present at almost every visit, and, as but few sunfish nested here, it is probable these species come here for food. A trammel net set across the bay at this season caught individuals of the following species: black bass, blue-gill, common sunfish, blue-spotted sunfish, rock bass and common bullhead. From the table given on a subsequent page (249) the full data regarding the food of these specimens may be obtained; it may be said here that they had been feeding largely on crayfish and the larvæ of aquatic insects.

After the middle of June large fish almost entirely disappeared from the bay, as they did from other shallow parts of the lake, but small fish were common here all the summer. During May, large schools of minnows, of which the blunt-nosed was the most common, were seen at nearly every visit to the station. With this species were associated at this time the straw-colored, Cayuga, and black-chinned minnows, golden shiner and barred killifish. In August golden shiners and black-chinned minnows were the common species, while those first mentioned became scarce. Least darters were numerous until about the middle of June, after which none were seen, while young perch, about an inch long, appeared in large numbers and were noted until the middle of July, after which few were seen. A list of important fish taken at this station will be found in the table on page (249). In addition to those given above, this list includes horned dace or chub, common sucker, yellow catfish, bullhead, tadpole stone cat, pike, rock bass, blue-spotted sunfish, wall-eyed pike, and *Etheostoma iowæ*.

The invertebrates of the station were not carefully studied, but the more conspicuous forms seen at each visit were noted and usually preserved when collected. Of these may be mentioned the red-bellied leech, crayfish, amphipods, dragon and damsel-flies in all stages of development from eggs to adults, caddice-flies, water striders, whirligig beetles *Zaitha sp.*, back swimmers, and other insects. Further information relating to the insects of this station will be found in the report of Dr. Needham, in Appendix III, page (252).

The conspicuous vertebrates (other than fish) of this station were the large green frog, and turtles of three species, the musk, painted and Blanding. The musk turtles laid their eggs in the remains of a muskrat house near the south side of the bay. The red-winged blackbird and marsh wren were common in the sedge zone, and probably bred there during the early part of the summer, and in late summer the least bittern was noted several times. A muskrat house, apparently not inhabited, was located near the center of this bay, in a patch of loosestrife, see Plate 41.

Station 41 was the second one of this type. It comprised the small enclosed cove and the adjacent shoal located at the southeast bend of the south bay.

The general appearance of the station is shown in Plates 43 to 46 inclusive. It resembled station 7 in being a small, partly enclosed body of shallow water, into which opened a stagnant ditch cut through a marsh which forms its landward margin, and in having very abundant vegetation growing on a bottom composed of very soft, black, peaty mud. It differed from the other station in that it was not exposed to the force of strong lake waves, and in being separated from the deep water of the main lake by a broad shoal. The highest part of this shoal was a wave-formed spit which was above the water level, and projected southward to form the western side of the cove (See Plate 43.) The waves were constantly driving sand and other materials down the shore of the bay, and depositing them in the quiet water at the end of the spit, thus elongating it. Other conditions that distinguished this habitat from station 7 were the greater depth of the black mud at the bottom (more than three feet), and the greater luxuriance of the vegetation in parts of the bay, especially the northern part, where from early summer the water was completely clogged with plants of a number of species (see the following pages) which formed a dense mat over the surface (see Plate 45).

The shoal adjacent to the mouth of the bay supported a growth of bulrushes (Plate 46) on the marl bottom, out to where the water was more than three feet deep. The sand spit supported a rather sparse growth of sedge with some swamp loosestrife, as shown in Plates 45 and 46.

In April and May small fish were very numerous in the shallow water of the cove, but they became fewer as the plants grew up from the bottom and decreased the depth and area of the open water. At low water level in August the water, except for spots of floating algæ, was only about six inches deep over the plants in the south part of the cove, while in the northern part the top of the water plants formed a dense mat on the surface of the water, and there were no open areas.

A number of collections of fish were made through the season at this station, the details of which may be found on a subsequent page (250). The species taken or seen here were, pike, blunt-nosed, straw-colored, black-chinned and Cayuga minnows, golden shiner, *Etheostoma iowæ*, *Notropis anogenus*, tadpole stone cat, barred killifish, rock bass, blue-spotted sunfish blue-gill, common sunfish, large-mouthed black bass, perch, Johnny darter, least darter, yellow catfish, common bullhead.

As noted above, the April and May hauls of the nets secured many more species and specimens than those of the succeeding months. An interesting observation on biological relations was made here in August, when it was found that the small fish were again abundant in the paths which had been opened across the masses of water plants in the end of the bay by muskrats or turtles. (The musk turtles used an old muskrat house on the south shore of the station as a place for the incubation of their eggs, and on June 25th ninety eggs, in groups, as shown in Plate 67, were uncovered here and photographed.)

The only notes on invertebrates made at this station were that on April 10th, large red midge larvæ were very abundant on the marl bottom of that portion of the lake included in this station, and a week later the adult insects were numerous in the air, and pupa skins covered the water.

SUMMARY.

The two stations included in this type are alike in being small, shallow coves, with bottoms composed of soft, black mud, on which plants grow in

great profusion. Each station was located in the midst of a marsh, through which a ditch had been cut, but in which water is stagnant. Station 7 was located so that it frequently received the full force of the waves caused by easterly winds sweeping across the lake open, but station 41 was free from this factor, as it was situated near the shoreward end of a protected bay, and all waves that entered it were small. Station 7 also opened into deep water, being separated from it only by a narrow shoal, while station 41 was bordered by a broad marl shoal. The greater depth and richness of mud at the bottom, and less exposure to active wave action, in station 41 permitted a denser and more thrifty growth of plants, and this, compared with station 7, limited the amount of space available for fish movements. On the whole, fish were present in greater numbers and more constantly in these two coves than in any other areas of similar size in the lake. Fish of many species and in large numbers used these stations as feeding grounds, especially the young of such important types as black bass, perch, blue-gill and bullhead. A few nests of breeding fish were found at station 7, but none at station 41.

BULRUSH SHOAL TYPE.

On the east side of the lake, 150 or more feet from shore, was a small island at low water. This island was about 200 feet long and 100 wide, but it was nearly submerged during high water, except for a small area on the south side, which is permanently above ordinary high water. The water between this island and the mainland averaged from two to three feet in depth, and only exceeded five feet along its shoalless margins. This shoal area was station 54; it had usually a marly bottom, and was covered with a more or less dense growth of bulrushes, thickest in the south half and thinner on the east end and west sides, where the stations merged into stations 46 and 49. On parts of the shoal where submerged plants grew, the marl was covered by a layer of black organic material.

This seemed to be the most important shallow water area of the lake, as far as the fish life was concerned. It is shown upon the map, Pl. 15, between the dotted lines on the peninsula marked with the station number and the shore line. The data for the map was taken while thick ice covered the area, and, with the island, this station was mistaken for a marshy peninsula. Plates 47 to 50, inclusive, show some of the characters of this station.

Stoneworts were abundantly distributed over the bottom, generally growing with the bulrushes, but one circular area of about 60 feet in diameter near the eastern border of the station was so densely covered by these plants that the bulrushes could not grow there. The stoneworts grew at least two feet high here in August, reaching almost to the surface; the open water here presented conditions so different from those where the the bulrushes grew that it was called substation 54a. A part of the margin of the clear area is shown in Plate 49.

Among the bulrushes cattails and other aquatic plants were numerous, sometimes, as in the case of the water-lilies, covering the water surface (Plates 48 and 49). The species of plants found here are given on a following page (224).

Fish were common here until the latter part of the summer, when, as in other shallow water areas, they became scarce. Large numbers of black bass used it as a nesting place in May, making their nests and laying their eggs in from 12 to 15 inches of water, but there were few young reared here.

The adults were speared from their nests by fishermen. Sunfish, on the other hand, while common, did not breed here, so far as could be determined. Other species of fish noted at the station were pike, blunt-nosed and black-chinned minnows, golden shiner, chub sucker, bullhead, yellow catfish, blue-gill and rock bass, *Lepomis eurzorus*, long-eared sunfish, yellow perch, Johnny darter, probably *Etheostoma iowæ*.

The trammel net was found most effective for catching fish at this station, and during May a number of hauls were made with it. The collections and notes made are given on a subsequent page (250). Plate 72 shows this net set across station 54a.

Next to fishes the birds were the most conspicuous vertebrates of this station, two species, the red-winged blackbird and marsh wren, being common. The blackbirds were particularly numerous, and bred among the bulrushes. When this station was visited on the night of June 12th, hundreds of these birds were found roosting on the stems of the plants. In July, large numbers of barn swallows used the bulrushes as resting places at night. Two species of turtles, the musk and the painted, were often seen; on August 1st one of the first named species was observed eating a dead black bass.

There were several muskrat houses at this station, although none of these animals were seen. Insects of several kinds were abundant, the dragon-flies and damsel-flies being the most noticeable, as they were very active when weather conditions were favorable. Late in April midge larvæ were found in collections made from the marl bottom of the station, and on May 21st adult midges of a different species from that so abundant over the marshes in April were noted on the bulrushes.

SWAMPY SHORE TYPE.

Station 40 was the only example of this kind. It was located at the northeastern part of the lake, extending about 300 feet in a westerly direction from the point (see map) where the shore bends almost at right angles, after turning northward. It included the north end of the wide northeast bay, and differed from other stations in that it supported a tree-covered swamp, and an unusual amount of aquatic vegetation.

The plant associations divided this station into four quite well-marked zones, the swamp, the sedge, the cattail and the bulrush and waterlily zones each presenting some peculiarities as a habitat for fish.

The swamp zone (Plates 51–55, inclusive) was situated on the lakeward border of a large marsh, and had a heavy growth of trees and shrubs. These plants grew in very wet soil, with pools of stagnant water, a foot or two deep, between the trees and clumps of bushes. These pools during the summer were covered by an almost unbroken carpet of duckweed (see Plate 55). Sedges and many other herbaceous plants grew among the trees and shrubs, forming a dense border in the part of the zone towards the lake.

Numerous tadpoles and three species of fish (mud minnows, young perch and brook sticklebacks) were caught in a dip net in these pools on June 16th. This was the only place where the sticklebacks were found about Walnut Lake. Plate 55 shows part of the interior of the swamp zone.

The sedge zone was distinct only in the eastern part of the station, where it consisted of a narrow belt of sedges close to the shrubs of the swamp zone. The ground here was wet throughout the season, but there was not enough water to allow fish to move in it to any extent.

The cattail and bulrush zone began at the shoreward edge of shallow water,

as shown in the figures, and was really a double zone, the cattails in very shallow water, and the bulrushes extending out to depths of five feet, in places more than 200 feet from shore. Plants other than those mentioned were present in different parts of the zone, sometimes in abundance, as at the west end of the station, where quantities of a species of horsetail grew in the shallow water with the bulrushes. About the middle of the station was a small cove, where the bulrush growth was sparse and the cattail grew in small clumps; in summer the water in this cove was covered with duckweed (Plate 53).

The waterlily zone was present along the west portion of the station, and became noticeable about the last of May, at which time the floating leaves of the lilies appeared. At the west end of the station these plants extended out from shore for some 200 feet to the edge of the broad shoal.

The shallow water of this station was frequented by many species of fish, and numerous individuals were seen at every visit made when conditions were favorable for observation. This station was not visited regularly, however, and, because of the rank vegetation over much of its area, but little collecting could be done. According to observations, the large fish, like black bass and sunfish, were common on this shoal, as upon the others studied, only during the spring and early summer, although sunfish nested here in shallow water. Minnows abounded both in the spring and summer, but were most numerous in May, when the following species were seen: blunt-nosed, straw-colored, black-chinned and Cayuga minnows and golden shiner. On May 21 the Cayuga minnow appeared to be spawning on the shoal. Other fish seen or taken here were the mud minnow (very common in the dense growth of plants near the shore) chub-sucker, yellow catfish, common bulhead, barred killifish, rock bass, perch, *Etheostoma iowæ*, and least darter. The young of several species of fish were very numerous here in early summer, among others, those of the perch and sunfish.

Of the invertebrates casually noted at this station the dragon-flies and damsel-flies were common, and numbers of their empty larval cases were attached to the bulrushes. A leaf-eating beetle, *Donacia*, was common about lily pads. The whirligig beetles were common in the summer. Sialis adults appeared in large numbers among the bulrushes late in May, and one was observed laying eggs on the stem of one of these plants on May 29; at this time and later, black, waxy, oblong masses of eggs of these insects were often seen on the bulrushes.

The shoal here was one of the few places where living snails were common, although empty shells were abundant on most shoals and on the shores of the lake. On May 16, numbers of small specimens of these mollusks were seen on filamentous algæ, and proved to represent four species, *Planorbis parvus, Amnicola limosa, Valvata tricarinata,* and a species of Pisidium. In April two species of leeches were collected at this station. Of vertebrates, large green frogs were usually seen or heard throughout the summer. Birds were common in the swamp, but were not studied. The red-wings were abundant, and lived and nested among the cattails, as did also the marsh wrens. Kingfishers were common at this station.

DEEP WATER TYPE.

As already stated, the types of stations thus far discussed generally include portions of the shore, and extend only to the lakeward boundary or deepest part of the pond-weed zone, which does not extend deeper than about 25 feet deep. Around much of the shore this depth is reached about

200 feet out, as shown by the 25 foot contour line on the map, Plate 14. In one region (station 46, at the eastern end of the lake), however, this line is some 700 feet from shore, while at the north end of station 24 (near the extreme north end of the lake) it is only about 50 feet from the shore. As indicated above, the average width of the belt of water shallower than 25 feet is probably between 200 and 300 feet, so that by far the larger part of the bottom is more than 25 feet from the surface. All stations within this area are called deep-water stations.

Observations seemed to show that the conditions in the entire deep-water area were similar, the chief differences being the depth of water, and as this undoubtedly affects fish life directly or indirectly, differences in depth were made the basis for classifying stations. The observations and collections made in this deeper part of the lake all point to the fact that microscopic algæ, chiefly diatoms, constituted almost the only plant life of deep water, the higher plants, when found at all, being of scant growth or restricted to small patches in the shallower places.

The bottom in deeper water appeared to have three distinct zones of quite different types of soil, according to the depth. Marl was the chief bottom soil over the shallow parts of the lake, and it extended only to a depth of about 39 feet. At depths of 40 to 50 feet, a loose textured brown mud covered the bottom, and was replaced at a slightly greater depth than this by a thick layer of fine-grained blackish mud which covered the bottom of the deepest part of the lake.

Station 200, the first deep-water station to be considered, was in that part of the bay at the west end of the lake, west of the marshy peninsula and of a line running straight south from it. It had an area where the water was from 30 to nearly 60 feet deep. The method used to discover the nature of the bottom at this station was to draw a hook-and-net drag across it in several directions. In May, while dredging with this along the eastern border of the station, a mass of water-moss caught on the hooks and was brought up to the surface, but, as it was not found again in several trials, it seems probable that it was drift material, or occurred over but a small area of the bottom. On July 20 three hauls more made over the east and central parts of this station, in water from 40 to 50 feet deep, but none of the larger plants were found, except a small fragment of hornwort, which is a generally rootless form, hence without significance.

In each case the net part of the drag was brought up filled with grayish-brown mud, the temperature of which, taken as soon as possible after reaching the surface, was 15° C. A few midge and *Corethra* larvæ were found in this mud.

As it was impossible, on account of the depth of the water, to make observations on the fish life at this station, except rarely when fish were seen near the surface, practically all the information gained concerning the fish life was through collections. One of the few direct observations was made on July 19, when a large school of perch-fry was seen near the surface, about 300 feet from shore, where the water was about 40 feet deep. These fish averaged about an inch and a half long. The following species of fish were taken by the fyke and gill nets at this station during the season: perch, common sucker, whitefish, and wall-eyed pike. The suckers and whitefish netted here had been feeding on midge larvæ and on the crustacean, *Daphnia*. A tabulated statement regarding the collections will be found on a subsequent page (251).

Station 225 was that area on the southwestern part of the lake, where the

water was from 60 to 80 feet deep. It began just east of station 200 and completely surrounded station 250, which included that part of the bottom over 90 feet from the surface. The bottom material at station 225 was a fine-grained, compact deposit of black muck which was light in weight, and supported a considerable microscopic fauna and flora. The former included, during late summer, numerous midge larvæ and the latter, diatoms. (See descriptions of the bottom samples taken at station 200 above, which were more carefully studied than those from this station.) In July, while making collections of midge larvæ at this and other deep-water stations, an apparent relation was observed between the numbers of larvæ taken and the depth of water in which the collecting was done, in that the larvæ seemingly increased in numbers as the water became deeper, but much more work needs to be done to confirm this observation. However, it should be pointed out that if the deep water has more of these organisms than the shallow, there would be more food for fish in the deeper parts of the lake, and certain species would probably tend to congregate there. In April a few temperature readings were made at this station, by the use of a thermophone, which later got out of order and could not be used. The results are given below:

Date	April 16	April 17	April 18
Time of day	11:00 A. M.	4:40 P. M.	4:30 P. M.
Temperature C. at surface	7.	7.5	7.4
Temperature C. at 20 feet	5.4	5.6	5.2
Temperature C. at 40 feet	5.3	5.5	4.9
Temperature C. at 60 feet	5.3	5.3	4.8
Temperature C. at 80 feet (bottom)	5.	.....	.....

Fish taken here (by the use of the gill-net) were the whitefish and common sucker. Details of the food and other data relating to these fish will be found on pages 244–251.

Station 250 included the deepest part of the lake, where the water ranges from 90 to 101 feet deep. As shown by the contour map (Plate 14), it was located on the southwest side of the lake, from 500 to 1000 feet north of station 23. It was elliptical in shape, and about 200 feet wide and 700 feet long.

It is evident from the study of many samples that the soil of the bottom at this station was the same constitution over its entire area. It is dark gray, almost black in color, and is made up of very fine particles, so small and light that it takes more than an hour for them to settle to the bottom of a shallow dish. A microscopic examination showed black and light-brown inorganic particles, and the remains of organisms such as shells of diatoms and Entomostraca. Living diatoms, rotifers and other microscopic forms of plant and animal life were abundant, and midge larvæ, in cases made of soil particles, were present in great numbers, especially in late summer. *Sayomyia* larvæ were also common. (See the report on insects, Appendix III of this report).

The only fish caught at this station were whitefish which were taken by means

of the gill net, and but few specimens of these were secured. The identifiable material in the alimentary canal consisted chiefly of midge larvæ.

The following table gives such temperature readings as were made here; the surface readings were made with a standardized thermometer, and those from deep water with the thermophone, except those made on August 25, in which maximum and minimum thermometers were used.

Depths, feet.	May 5	May 7	May 27	May 28	May 29	June 9	August 11	August 14	August 25
Surface	.....	.....	.....	16.5	16.5	.....	24.	25.5	25.6
2½	.....	.....	.....	.....	.....	.....	.....	.....	25.7
5	.....	.....	.....	.....	.....	.....	.....	.....	25.6
7½	.....	.....	.....	.....	.....	.....	.....	.....	25.4
10	.....	.....	.....	.....	.....	.....	.....	.....	25.3
12½	.....	.....	.....	.....	.....	.....	.....	.....	23.9
15	.....	.....	.....	.....	.....	.....	.....	.....	24.5
17½	.....	.....	.....	.....	.....	.....	.....	.....	22.
20	.....	.....	.....	.....	.....	.....	.....	17.8	18.4
22½	.....	.....	.....	.....	.....	.....	.....	.....	16.
25	.....	.....	.....	.....	.....	.....	.....	.....	13.5
27½	.....	.....	.....	.....	.....	.....	.....	.....	10.4
30	.....	.....	.....	.....	.....	.....	.....	.....	10.4
32½	.....	.....	.....	.....	.....	.....	.....	.....	10.1
35	.....	.....	.....	.....	.....	.....	.....	.....	8.7
37½	.....	.....	.....	.....	.....	.....	.....	.....	8.8
40	.....	.....	.....	.....	.....	.....	7.5	8.1	8.2
45	.....	.....	.....	.....	.....	.....	.....	.....	7.2
50	.....	.....	.....	.....	.....	.....	.....	.....	6.8
55	.....	.....	.....	.....	.....	.....	.....	.....	6.4
60	.....	.....	.....	.....	.....	.....	6.5	6.4	6.4
65	.....	.....	.....	.....	.....	.....	.....	.....	6.6
70	.....	.....	.....	.....	.....	.....	.....	.....	6.6
80	.....	.....	.....	.....	.....	.....	6.5	6.4	6.4
90	.....	.....	6.	.....	.....	.....	.....	.....	6.4
100	5.9	5.3	.....	6.1	6.1	6.	6.5	6.4	6.4

On August 25 and 26 Dr. John Eastwood, with the assistance of Professor Jacob Reighard, determined the gas contents of the water at this station at different depths where the bottom was a hundred feet below the surface. The purpose and results of this work are given in the following report written by Professor Reighard:

"At a depth of nearly 30 meters, there are found living in the bottom ooze of Walnut Lake numerous larvæ of a species of midge or *Chironomus*, and in the water immediately overlying the bottom, is an abundance of *Daphnia*. Whitefish were found to feed on both of these forms. Since in most lakes of this depth and area the oxygen is practically exhausted in the deeper waters during the summer, so that *Chironomus*, *Daphnia* and fish cannot live there, an effort was made to learn what the conditions at the bottom of Walnut Lake were which made it possible for these animals to thrive there in mid-summer.

"The methods used were those described by Whipple and Parker* and the results are given in the following table.

*Whipple, George C., and Parker, Horatio N., 1901. On the amount of Oxygen and Carbonic Acid Dissolved in Natural Waters and the Effect of these Gases on the Occurrence of Microscopic Organisms. Transactions of the American Microscopical Society, Vol. XXII, pp. 103–144, pls. XIX–XXII.

Table showing the amount of dissolved oxygen and carbon dioxide at various depths in Walnut Lake, Oakland Co., Michigan, on August 26, 1906.

Depth in meters.	Temperature in degrees centigrade.	Carbon dioxide in parts per million.	Oxygen in cubic centimeters per liter.
0	25.8	—3.5	5.486128
1	26.4	—3.15	5.176206
2	25.6	—2.55	
3	25.3	—1.95	5.078379
4	25.2	—2.10	
5	23.6	—1.65	5.40917
6	19.	—2.4	5.6618
7	14.9	+0.5	5.1947
8	12.5	+1.	3.9202
9	10.3	+2.	3.886
10	9.1	+3.	3.1606
15	7.4	+7 +5	1.782
20	6.8	+6.5 +7 +7	1.0008
			1.315*
25	6.4	+7.	1.4456
		+8.	1.0324*
		+7.	
28	6.4	+7.5	.9823
29			.9545*
		+6.5	.5809
			.727*

"The results are also shown in graphic form in the diagram, Fig. 18. From these results it appears that the volume of oxygen present at the surface is that usual in lakes at this time of the year, as shown in Birge's (1907) chart† of Lake Mendota on August 31.

"To a depth of about five meters the oxygen diminishes somewhat and then increases until at six meters it is slightly greater than at the surface. In this respect the lake resembles Elkhart lake and Beasley lake, as described by Birge, except that the increase is much less than in those lakes. As pointed out by Birge this increase in oxygen is due in Beasley and Elkhart lakes to the presence at a distance of five or six meters below the surface, of algæ, which in their ordinary metabolic processes use up carbon dioxide and liberate oxygen. In this way the water at this depth comes to have in solution an amount of oxygen in excess of that in the more superficial layers, and the total volume of water capable of supporting animal life is thus materially increased. Below seven meters in Walnut Lake the volume of oxygen per liter of water rapidly diminishes. At a depth of twenty-eight meters it is still about one centimeter per liter, and at twenty-nine meters it is six or seven-tenths of a centimeter per liter. As a glance at the map shows (Pl. 14), a depth of twenty-nine meters occurs over a very small part of the lake bottom, so that we may safely say that over nearly the whole bottom in mid-summer there is present not less than one cubic centimeter of oxygen per liter of water, while at depths of fifteen meters or less there is two or more times that amount.

"If we compare this condition with that found by Birge in Wisconsin lakes, it appears that in Lake Mendota the oxygen is entirely exhausted at the end of August at a depth of about thirteen meters. This exhaustion is attributed by Birge to the decay of the abundant organic matter present in the form of plankton in the surface waters of the lake. As this plankton falls to the

*The values given for oxygen were those obtained in the last of three series of observations except the starred values, which are the averages of all observations made.
All values obtained for Co^2 are given in the table.
†Birge, E. A., 1907. Gases Dissolved in the Waters of Wisconsin Lakes. Transactions of the American Fisheries Society, 1906, pp. 143–163, 12 figures.

bottom in mid-summer and decays the oxygen is exhausted, since in the process of oxidation it enters into combination with the organic matter. The bottom waters of this lake are thus devoid of oxygen during the greater part of summer, and at the end of that season no fish or other higher animals can live in them. At other seasons these deeper waters contain oxygen. Lake Mendota is thus in sharp contrast to Walnut Lake whose waters contain oxygen at all depths even in mid-summer. Not only are the deeper waters of Lake Mendota unfit to support fish in summer by reason of their lack of oxygen, but they are unfit on account of the absence from them of sufficient animal life to serve as food for fish 'to support any considerable amount of fish life at any time of the year' (Birge).

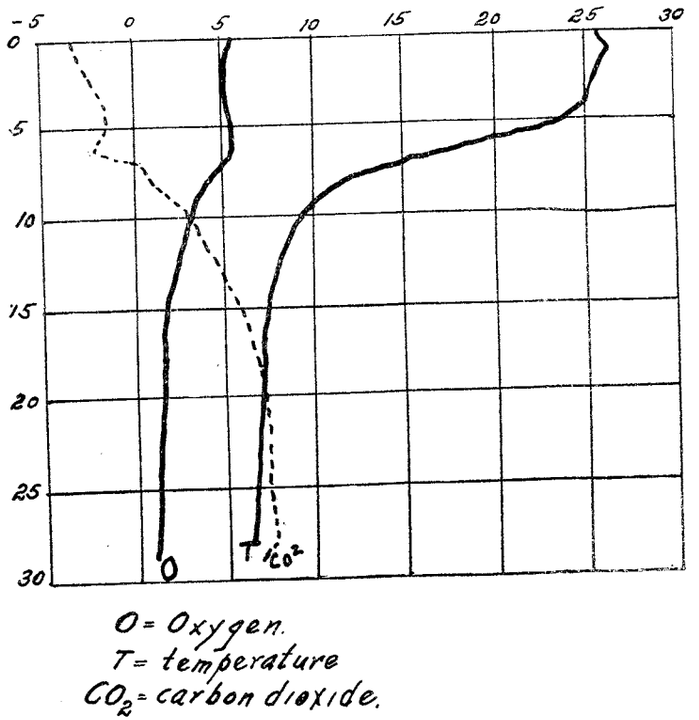

Fig. 18.—Diagram showing results of gas analyses of water at different depths at Station 250.

"In contrast to Lake Mendota is Trout Lake, Wisconsin, also investigated by Birge. At the bottom this lake contains about the same amount of oxygen as Walnut Lake, but between the bottom and the eight meter level it contains a good deal more. Above the eight meter level it contains about

the same amount of oxygen as Walnut Lake. The lake was examined on September seventh. Birge reports that the true whitefish and the lake trout inhabit its deeper waters during the summer. It thus appears that these fish are able to live where the oxygen content of the water is not more than one cubic centimeter to the liter. This amount of oxygen is present in the bottom water of practically the whole of Walnut Lake during the summer. It is its presence there which enables the lake to support whitefish. Not only does the water at the bottom contain sufficient oxygen to support the whitefish, but what is quite as important it contains sufficient oxygen to support the food upon which the whitefish largely lives, the Chironomus larvæ and the Daphnia.

"No investigation has been made of the amount of organic matter or of plankton in the waters of Walnut Lake. It is to be presumed that Walnut lake, like Trout Lake, contains relatively little plankton. Of lakes otherwise alike that one which contains the greatest amount of plankton will contain the least oxygen in midsummer, while that one which contains the least plankton will contain the greatest amount of oxygen in midsummer. Lake Mendota belongs to the first of these classes, while Trout Lake, and presumably also Walnut Lake, belongs to the second class. In lakes of the first class the oxygen of the deeper waters becomes exhausted in summer by the decay of the abundant plankton and these waters are therefore unable to support animal life. In lakes of the second class the oxygen does not become exhausted by the decay of the plankton and the deeper waters are able to support fish and fish food throughout the year".

FISH OF WALNUT LAKE.

BY T. L. HANKINSON.

As the work of the party was concentrated on problems concerning the fish-life of the lake, efforts were made to obtain specimens of all of the species in the lake. Thirty-one species were taken, and, although other species are probably to be found, this collection may be taken as highly representative of the fish fauna of the lake. Among the species that we may have overlooked is the lake trout, several plantings of which have been made in the lake at various times, both by the Michigan Fish Commission and the United States Fish Commission. The following table will show the number and date of each planting.

Michigan Fish Commission	6000	in 1878.
" " "	3000	" 1879.
U. S. Fish Commission	1500	" 1889.
" " "	500	" 1892.
" " "	2700	" 1900.
" " "	7996	" 1901.

Those planted by the U. S. Commission were yearlings. In 1890 the Michigan Fish Commission examined Walnut Lake, and, with a gill net set in from 70 to 80 feet of water, caught 6 lake trout, the largest of which weighed one and one-half pounds. The planted fish thus appear to have lived, and there is little reason why the species should not be present in the lake now.

The fish fauna of Walnut Lake was found to be very different from that of the few others in its neighborhood which were examined. Two of these,

Simpson Lake and Orchard Lake, will serve as examples. The first named is a small body of water less than a half-mile west of Walnut Lake, whose outlet joins that of the latter, thus forming a water-way between them. This lake abounds in calico bass, *Pomoxis sparoides*, but none were found in Walnut lake. In Orchard Lake 21 species of fish were taken at the single visit made on June 18, six of which were not collected at Walnut Lake. These six species are as follows:

1. Bow fin, *Amia calva* Linnæus. One found dead near shore.
2. Lake herring, *Argyrosomus artedi*, (Le Sueur). One found floating dead.
3. Rosy-faced minnow, *Notropis rubrifrons* (Cope). Abundant.
4. Brook silversides, *Labidesthes sicculus* (Cope). Abundant.
5. *Schilbeodes miurus* (Jordan). One taken.
6. Manitou darter, *Percina caprodes zebra* (Agassiz). One taken.

The remaining fifteen species taken on this day and also found in Walnut Lake are as follows:

Blunt-nosed minnow, Cayuga minnow, straw-colored minnow, common shiner, *Notropis anogenus*, barred killifish, blue-green sunfish, long-eared sunfish, blue-gill, common sunfish, black bass, perch, *Etheostoma iowæ*, Johnny darter and least darter. These observations show the value of detailed examinations of different lakes from the standpoint of fish environments, for the differences in fish faunas are possibly due to differences in the environmental conditions.

CONDITION OF FISH.

In a general way it may be said that fish thrive in Walnut Lake. The mortality of individual fish, due to natural causes, was apparently small, and relatively few dead fish were found, although in early spring, dead sunfish, chiefly blue-gills and blue-spotted sunfish (the latter more often), were occasionally found floating or cast ashore. In summer, perch were commonly found dead, while on the other hand, not more than six dead whitefish were seen during the entire season. All of the fish caught appeared in a normal or healthy condition, and some, notably the black bass, were conspicuously fat.

SPECIES, RELATIVE NUMBERS AND ECONOMIC IMPORTANCE OF THE FISH.

Of the total number of thirty-one species of fish collected in this lake, two-thirds, including practically all of the food fish in the list, may be considered common. These are given in the list below, as nearly as possible in the order of their apparent abundance: perch, blunt-nosed minnow, straw-colored minnow, blue-gill, common sucker, whitefish, common sunfish, large-mouthed black bass, pike, least darter, rock bass, wall-eyed pike, yellow catfish, common bullhead, golden shiner, black-chinned minnow, Johnny darter, blue-spotted sunfish, Cayuga minnow, *Etheostoma iowæ*, and barred killifish.

The species of fish that may be considered rare or uncommon are listed also in the order of their apparent abundance: chub sucker, tadpole stonecat, *Lepomis euryorus*, common shiner, little pickerel, miller's thumb, brook stickleback, *Notropis anogenus*, and chub or horned dace.

It will be noted that more than a third of the forms known to occur in Walnut Lake are well-known food fish, some species being prized for their excellent flavor and high value as food, as well as for their gaminess when

taken with rod and reel. These facts make the careful inquiry into their habits the more interesting and important, since it is fair to infer that these do not materially vary in other places where the same species are found.

METHODS OF FISHING.

Although good sized individuals of species most sought after for food and sport abound, yet Walnut Lake is reported to be a poor place for fishing with hook and line. The black bass, grass pike and wall-eyed pike, all excellent game fish, are common, but few are caught with the hook, judging from the reports of the people living in the neighborhood. Some attribute their failure in this sport to the great numbers of small fish and crayfish in the lake. It is possible that this abundance of natural food, combined with the facts that unattractive baits are used, and unfavorable fishing places are chosen, may account for the poor success reported. A most pernicious and unwise destruction of the larger fish is being carried on by methods of fishing contrary to the fish and game laws of the State. Illegal fishing, such as by gill net and spearing, was not uncommon, and jack-lights were often seen moving about on the lake on dark, still nights in the spring. In the spring fish were frequently caught by us with spear wounds thickly covered with water mold, and fish dead from the same cause were often found. Spearing is particularly disastrous to the more important fish, since the grass pike, black bass and whitefish resort to shallow water to breed, and not only the breeding adults are reduced in numbers by spearing, but the eggs and young are left unguarded and fall prey to numerous enemies against which, in the case of the bass at least, the old fish in part protect them.

The practice of spearing ought to be stopped, since the laws against it are based on sound biological principles, which must be observed if the fish are to maintain themselves in present numbers.

ANNOTATED LIST OF FISH IN WALNUT LAKE.

The following accounts of the habits and habitats of each of the thirty-one species of fish obtained is a summary of the field work of the party during the summer:

FAMILY *Salmonidæ*.

1. Common whitefish, *Coregonus clupeiformis* (Mitchill). This species is rated by many people the best of fresh-water food fishes. It was found apparently abundant in Walnut Lake, where it was possibly native, since Mr. Frank Crawford, a farmer living in its vicinity, reported that his father and Mr. Henry Grinnell caught these fish from the lake as early as 1840. Three plantings, aggregating over 100,000 artificially propagated individuals, were made by the Michigan Fish Commission as follows: 3,000 in 1874, 40,000 in 1878 and 60,000 in 1879.

Habitat.—At present the whitefish is an abundant resident of the deeper parts of the lake, where there are practically no plants except the microscopic one-celled algæ. It does not seem to visit the pond-weed zone to any extent, since but three of the 47 specimens taken were captured in that region, and those were found where the water was about 20 feet deep. A single specimen was taken in water about a foot in depth near the shore of station 3, on the night of April 18th. As pointed out below, all of these visits of the fish to the shoaler parts of the lake may be correlated with the movements of the organisms used for food.

Food and feeding habits.—One of the most important observations made relating to the whitefish was that of its almost exclusive use of midge larvæ for food during part of the year. The larvæ mentioned are small, reddish, worm-like insects from about one-half to two-thirds of an inch long, and are the young of the two-winged midges which closely resemble mosquitoes, and which in the spring appear in vast numbers about many lakes and ponds. The young, or larval stage, is passed in the mud at the bottom of the lake. In early spring the larvæ begin to change to pupæ, and from the last two weeks of April to early summer seek shallow water, and emerge as the adult, winged midges; these, after the eggs are laid in the water, soon disappear.

During early spring, and until June 2, when fishing in deep water with the gill net was suspended, the stomachs of 30 out of 38 specimens of whitefish taken or found dead were examined. These were all large fish, from 14 to 20 inches long, and weighing from 1½ to 2½ pounds each. Eleven had no identifiable food in the stomachs, and one had but a few mollusks shells. In the remaining 19, midge larvæ and pupæ were by far the most conspicuous and abundant material, constituting a large part, or in a number of cases the entire, food mass. Several of the fish in the last lot had 200 or more midge larvæ in their stomachs, and one speared near shore in a foot of water contained 200 pupæ. Larvæ of Sayomyia, Sialis, and other insects, mollusks shells, and in a few examples fish remains, constituted a small part of the food in each of these stomachs. It appears that at this season the whitefish are bottom feeders, since the midge larvæ are probably found only at the bottom, and appeared to be most abundant in the deeper parts of the lake. The pupæ seek the shoaler water, and, as the fish taken in the pond-weed zone and on shoals had been feeding on these, it is probable they were in shallower water seeking their favorite food.

In August, after two months' disuse, the gill net was set again in deep water for a few days, and 9 additional fish, weighing from 1¼ to 2¼ pounds were caught. An examination of these specimens showed that there had apparently been an entire change of food since early June, for these fish had eaten no midge larvæ, but had been feeding exclusively upon small entomostracans of the genus *Daphnia*. As the masses of this food found in the stomachs were clean and free from dirt of any sort it was inferred that the entomostracans had been taken from above the bottom.

Breeding habits.—The field season closed before the breeding time of the whitefish, but the farmers on the vicinity of the lake reported that the fish visit the shoals at the east end in large numbers in November, at which time they are caught by spearing. The visit to shallow water at this season is undoubtedly for the purpose of spawning, and the gravelly shoals of stations 46 and 49 presented conditions similar to those in which the species is known to spawn in other waters. The reproductive organs of most of the specimens studied were in a well-developed condition. No small fish were taken under a pound and a quarter in weight, which was probably due to the large size of the mesh of our gill net.

From the evidence obtained it seems very probable that the species does breed in Walnut Lake, and that those examples caught were probably not those planted by the Fish Commission from 25 to 30 years ago (see table of data given on another page.)

FAMILY *Cyprinidæ*.

THE MINNOWS.

Minnows of eight species were found (some in great numbers), and the species are named in the order of their apparent abundance: (1) blunt-nosed minnow, (2) straw-colored minnow, (3) golden shiner, (4) black-chinned minnow, (5) Cayuga minnow, (6) common shiner, (7) horned dace, (8) *Notropis anogenus*. These small fish were often found in great schools in shallow water, especially during the spring and early summer, but the pond-weed zone seemed to be their permanent habitat. From this zone they migrated to the shoals in an irregular and seemingly erratic manner, being common on certain shoals on one day and scarce or absent the next, or even a few hours later on the same day.

The minnows were undoubtedly controlled in these movements by a number of factors of which the following seem most important: (a) food, (b) character of the bottom, (c) temperature of the water, (d) force and direction of the wind, (e) breeding impulses.

(a) Food.—This is apparently an important factor in directing movements to the shoals, as indicated by the numbers of minnows on the shoals bordering the marshes of the east shore (station 46), in the spring, when the midges were numerous there. An examination of stomachs at this time showed that midge larvæ and adults were then the chief food of these fish. After the latter part of May, when the midges became scarce, the fish also became much less common on these shoals. Minnows were also usually abundant about the nests of larger fish on the shoals, and were often seen eating the eggs and young, showing that they were probably attracted to the shallow water by the presence of this food.

(b) Character of the bottom material.—Minnows were more often seen on shoals with gravelly bottom, or those supporting a good growth of plants. This factor is undoubtedly closely related to (1), for such shoals certainly furnish more fish food than those with marl bottom, or those with scant vegetation.

(c) Temperature of the water.*—While variations in the temperature of the shallow water were marked, and an attempt was made to correlate them with the movements of the minnows, the data obtained were insufficient to establish any relationship, especially as this factor was very difficult to separate from the others. Certain observations, however, seem to indicate that minnows gathered on those shoals where the water was warmest, as shown by the following data:

Station 40, May 29.

Time.	Water temperature.	Minnows.
8:00 to 11:30 A. M.	18° C.	Scarce.
2:00 P. M.	21° C.	Abundant.

At station 3 on the same date the fish were seen moving towards the part of the shoal where the temperature was 19° C., from places where it was only

*The observations on the effect of temperature and wind upon the movements of minnows were made by Mr. E. L. Michael, and most of the data given under this head are obtained from his notes.

17° C., and over a bottom which was of a similar nature throughout; it is doubtful if food conditions varied sufficiently to account for the movement of the fish at this time. On May 31st, from 7:30 to 9:30 in the morning, nine of the barren shoals with similar bottom conditions were visited, and the results given below were obtained.

Table showing relations of minnow movements to water temperature on barren shoals, on May 31.

Station.	Temperature of water, C.	Minnows.
3	16.°	Few.
11	16.°	None.
19	16.°	Very few.
23	15.5° —16°	Very few.
37	16.5°	Common.
45	16.5°	Common.
46	19.°	Very abundant.
32	19.°	Very abundant.

As shown by this table minnows were most common where the water was warmest. While making observations on the barren shoals, notes were also made on those covered with plants, and the data obtained are given for comparison.

Table showing the relation of minnow movements to the water temperature on plant-covered shoals, on May 31.

Station.	Temperature of water, C.	Minnows.
7	15.°	None.
31	16.°	None.
41	17.9°	None.
54	16.° —17.°	Abundant.
49	17.7°	Abundant.

At these stations conditions were much more varied than at those in the first set, and the food factor was doubtless more important in its influence. It is difficult to understand the absence of fish from station 41 at this time, but in the afternoon of the same day, when the temperature had risen to 25° C., minnows and other small fish were numerous here, and a large collection was made.

As a whole, our observations (extending from early April to June 1st) indicate that from early April to June 1 minnows were found most common on shoals where the water temperature was from 17 C. to 27 C. Furthermore the temperature of the water also seemed to affect the activity of the minnows for in the early spring, when the temperature of the water was only slightly above the freezing point, they were very sluggish.

(d) Force and direction of the wind.—These factors apparently affected the movements and distribution of minnows, but probably through their influence upon the temperature. It was commonly noticed that when a strong wind was blowing the water would become cooler along the windward, and warmer on the lee, shores of the lake, and that at the same time minnows

were usually most numerous near the lee shores. On May 29 it was noticed that minnows were common in a particular part of station 7, which, it will be remembered, is a shallow bay, nearly circular in outline, and with its mouth opening to the east (see another page 187). At the time the observation was made the wind was blowing from the northeast, producing currents towards the south side of the bay, where minnows were collecting. They could be seen moving toward this area from all parts of the station, following the currents so clearly that bits of paper placed on the surface, moved in the same direction, and collected in the same place.

During the colder parts of the year, strong winds must destroy large numbers of minnows and other small fish which frequent the shallows, since they are unable to move freely at such times, and the waves caused by the winds dash them ashore. On April 8th the waves, driven by an easterly wind with a velocity of twelve miles an hour threw up a ridge of drift material in which were found on the next day many minnows, darters and small sunfish, some of which were still living when found. Such winds are of frequent occurrence during the fall and spring, and must cause much mortality among the shoal-frequenting fishes.

(e) Breeding impulses.—The minnows undoubtedly collect on certain shoals, or certain parts of them, for spawning purposes, but to what extent is not known, as there were but few chances to study the breeding habits of these fish. Nests of the blunt-nosed minnow were common in shallow water where the bottom was gravelly, which may be taken as evidence that the breeding impulses must cause these minnows to come to shoals of this type.

Economic importance of minnows.—Our observations indicate that the minnows are used as food by the larger and more important fish to but a very slight extent, as very few of them were found in the stomachs of any species examined. They were often found in company with large black bass, sunfish and bullheads, but in all cases this association seemed a peaceable one, for the larger fish were never seen making attacks on the minnows, except to drive them away from their eggs or young. Fishermen also report that fishing with minnows as bait in Walnut Lake is not attended with success.

At least two species of minnows, the blunt-nosed and the straw-colored, do much damage by eating the eggs and young of other fish more important to man. All minnows feed on midge larvæ in spring, and these insects form the chief food of the whitefish, and an important part of the diet of other useful species, so that in so far as the minnows deplete the food supply of the larger fish they must be considered as an unfavorable factor in the environment of the food-fish.

(2) The blunt-nosed minnow, *Pimephales notatus* (Rafinesque).

Habitat.—This is the most common minnow in Walnut Lake, being found on shoals of all kinds, and also in the pond-weed zone. Its visits to the shoals were somewhat irregular, owing to the influence of the factors given above, but it was almost constantly present where the bottom was gravelly, and was more generally abundant where there were submerged plants than where the bottom was marly. During the summer it became much less common in shallow water than in spring, as did other minnows.

Food.—The food of this species varies very much, but consists chiefly of small organisms taken from the bottom, from water plants, and from the water. Individuals were frequently seen feeding on the eggs of black bass, Johnny darter, miller's thumb, and sunfish of three species. At station 23, on July 14, they were found eating newly-hatched fry of their own species. The contents of the alimentary canals of many specimens were examined

during the spring, and from those studied it appears that midges, in various stages of development formed the chief food of this species, in April and May. Besides midges, filamentous algæ, desmids, entomostracans, and, in one case, beetles were found in the stomachs.

Breeding habits.—Many nests of this species were found between May 22 and July 14, but it is certain that this interval does not include the entire breeding season. The eggs were always found close together, attached to the flat, under surface of some object, usually a stone, but more rarely a piece of bark, a sunken board, or a fence rail. Each of these egg-clusters was guarded by a darkly pigmented male with pearl organs. The fish remained constantly in the hole beneath the eggs until they were hatched, but apparently did not attend the young after hatching.

A nest, with the attendant male, was placed in an aquarium at our head quarters; the fish immediately went under the stone, stood guard as usual, and remained even after the minute young had hatched and swam away. A similar case was noted in the lake, where the male fish remained guarding the empty nest for more than a day after the eggs had all been hatched. Plate 58 shows a piece of bark found at station 35 on June 24, with eggs of the blunt-nosed minnow attached, Plate 56 a nesting place of the blunt-nosed minnow on the gravelly shoal of station 23 (a nest was under the stone marked "y" when the photograph was made on May 20). Plate 57 is another view of a part of the bottom at station 23, where, on June 27, there was a nest under the largest stone shown in the picture.

(3) The chub or horned dace, *Semotilus atromaculatus* (Mitchill).

The chub was very common in the outlet, but only a single specimen was taken in the lake, station 9. A few were caught near the lake, in one of the small inlets in the swamp zone of station 40. The species bred in the outlet, and a number of nests and spawning fish were found there on June 1st.

(4) The golden shiner, *Brama chrysoleucas* (Mitchill).

This species differs from the other minnows of the lake in having a flat body, so that seen from above it appears long and slender. The largest individual seen did not exceed five inches in length.

Habitat.—It was common in all places where there were many water plants, but its favorite haunts were stations 40, 54, 41, 7, 26 and 31. It was also taken on the shoals of stations 46 and 49 in the spring, at the time when other species were abundant there.

Food.—The stomachs of several specimens taken at station 46 on April 26 and May 21, were examined, and midge larvæ and filamentous green algæ were the chief food-materials found. Seven examined between July 8 and August 11 had been eating filamentous algæ, with which the intestines were distended.

(5) Cayuga minnow, *Notropis cayuga* Meek.

Habitat.—The favorite haunts of this fish were the plant-covered shoals of stations 40, 54, 41 and 7, where it was abundant. In early spring a few specimens were taken on the barren shoals of stations 16, 46, and 49.

Food.—The stomach contents of the specimens examined in April and May were chiefly midge larvæ, entomostracans and filamentous algæ.

Breeding notes.—On May 2, at station 40, a large, gravid female of this species was seen several inches above the sand, in company with many smaller ones, possibly males. She was apparently in the act of spawning, although no eggs were seen falling. The water at this place was about a foot deep, and the bottom hard and sandy, and covered with algæ.

(6) *Notropis anogenus* Forbes.

This species was apparently rare, as only two specimens were caught in the lake (at station 41 on May 31); a third was taken at Orchard Lake on June 18. The species closely resembles the black-chinned minnow in form and coloration, and has the same black margin to the lower jaw, but its mouth is very much smaller. The identification of the specimens was confirmed by Mr. R. E. Richardson.

(7) The black-chinned minnow *Notropis heterodon* (Cope).

Habitat.—The distribution of this form was similar to that of the Cayuga minnow. It was usually quite common at stations where vegetation was abundant, as at 40, 54, 41, and 7, and was also found at the east end of the lake, in the spring, when the midges were abundant on the shoals. On the night of June 21, at station 23, it was seen swimming near the surface over the pond-weed zone, apparently attracted by the searchlight used in making observations.

Food.—Specimens taken from the shoals in the spring had been feeding largely on the adult midges, the rest of the stomach contents being made up of filamentous algæ and a few entomostracans. On July 16th, three out of four specimens taken at station 7 had only filamentous algæ in the digestive canal, and the fourth a few insects.

Breeding habits.—The only records obtained on the breeding habits of this species was the capture of three gravid females at station 54 on June 16th.

(8) The straw-colored minnow, *Notropis blennius* (Girard).

Habitat.—This and the blunt-nosed minnow were the most widely distributed minnows in Walnut Lake. Both were common on the shoals, where they schooled together, but the straw-colored minnow seemed to inhabit deep water to some extent, as shown by the following records: On April 8th a specimen was dredged (with the triangle dredge) from the bottom in water from 20 to 30 feet deep. On August 13, about 25, small very light-colored specimens measuring from $\frac{3}{4}$ to $1\frac{1}{4}$ inches in length were taken from a large school of this species from near the surface in the middle of the lake. At station 3A this species was often seen with other minnows in deep water off the pond-lily zone.

Food.—The alimentary canal of the specimens taken in the shoals at the east side of the lake, in spring contained principally midges in various stages of development, with some entomostracans and filamentous green algæ. This species was often seen eating the eggs of other fish, and on May 24 a sunfish egg was found in the intestine of a specimen taken in a sunfish nest.

Breeding habits.—Nothing definite was learned of the breeding habits of this species. Of 30 specimens taken on June 25, from the deepest water of station 31, 8 were males with pearl organs in the form of minute granules over the head and body.

(9) Common shiner, *Notropis cornutus* (Mitchill).

Habitat.—This species was found to be common only in the south bay, chiefly at station 31 and occasionally at station 45. During the summer large individuals were often seen in these habitats, swimming either within a few feet of the surface or in water from 10 to 15 feet deep.

Breeding habits.—Shiners were abundant in the outlet of the lake, where they were seen spawning in June.

FAMILY *Catostomidæ*.

THE SUCKERS.

(10) The common sucker, *Catostomus commersonii* (Lacepede).

The individuals of this species taken were very uniform as to size and color, having an average weight of about $2\frac{1}{2}$ pounds. Their backs were almost black, sides brassy, gradually changing to white below, and the lower fins were reddish brown in all the specimens studied.

Habitat.—Judging from the numbers taken in the gill net, this fish was very abundant, and seemed to be an inhabitant of water of from 15 to 40 feet in depth, although in April and May several were obtained at station 225 in about 80 feet of water. Owing to the fact that they lived in such deep water, no direct observations were made on their habits, but a farmer who spears fish through the ice in winter made the statement that in winter immense schools of suckers, roving close to the bottom in such numbers as to "make it look black," were often seen through spear holes in the ice. This fish was common in the outlet, where large specimens were sometimes seen at night (with the searchlight) near the lake (station 1). A few were again noted in this habitat on the night of April 10th, and on a single night in the middle of April a dozen or more large specimens were speared in the outlet Some days later the gill net was set in about 20 feet of water in the pond-weed zone of station 3, in such a way as to intercept fish going from deep water to the outlet, and when raised two days later about 50 large suckers, averaging $2\frac{1}{2}$ pounds in weight, were found. This was the largest catch of this species made.

Breeding habits.—The abundance of individuals in the pond-weed zone, just mentioned, may have been due to the fact that they were on their way to the outlet to lay their eggs at this time. The outlet is undoubtedly a spawning place for those individuals which live in the lake, and April is apparently the month when they resort to the stream in the largest numbers to breed. Ripe fish were caught in the lake as late as May 20th, but there was no evidence to indicate that the species spawned in the lake, except that individuals were often found in pairs in the gill net. No young were seen in the lake, although they were common in the outlet. Pearl organs were present on the rays of the anal fin, and those of the lower half of the caudal fin of many of the male fish taken in April and May.

Food and feeding habits.—The contents of the alimentary canals examined were as follows: Four, taken May 12th, had been eating caddice-worms with their cases, small bivalve mollusks, amphipods, some insects and marl. Nine specimens taken in August, at station 200 (in about 40 feet of water), had fed on nothing but midge larvæ, and the small entomostracan, *Daphnia*. In one of these fish *Daphnia*, only were found; in two, a mixture of *Daphnia* and midge larvæ; in the other seven, only midge larvæ. It is interesting to compare the food of the specimens taken in August with that of whitefish caught in the same haul of the net; the whitefish were feeding upon *Daphnia* only, apparently away from the bottom, while some of the suckers were feeding on midges at the bottom, and others on the *Daphnia* apparently above it.

(11) The chub-sucker, *Erimyzon sucetta oblongus* (Mitchill).

Habitat.—So far as observed, this fish was limited to places where the vegetation was abundant. It was noted at stations 7, 26, 40, 54, and 41. At station 7 they were seen occasionally in small openings among the bottom plants, into the protection of which they would dart when disturbed.

Because of their habitat, they were not easily caught, and but few were obtained.

Breeding habits.—A few small specimens, about ¾ of an inch long, were taken on June 16, at stations 26 and 40, and on May 3rd an adult male with four pearl organs on each side of its snout and many small ones on the anal fin was netted at station 40. Most of those seen were between 7 and 8 inches long. The larger fish of the lake feed on this species to some extent, for, on May 13, the caudal half of a large female containing many eggs was found in the stomach of a black bass.

FAMILY *Siluridæ.*

THE CATFISHES.

(12) The yellow catfish, *Ameiurus natalis.* (Le Sueur).

Description.—It is probable that this species is not distinguished from the common bullhead by most of the people fishing in the lake. While the two species are similar in form, the one under consideration has a broader head and a larger anal fin than the bullhead, and is distinctly yellowish-green in color, while the true bullhead is almost black.

Habitat.—The species was taken or seen at ten different stations, and seemed generally frequent in the pond-weed zone, from which it went into shallow water at night. Small individuals, under 4 inches in length, were common in shallow water where vegetation was dense, as at stations 7, 41 and 40.

Food.—The stomach contents of four specimens examined consisted of crayfish fragments, May-fly larvæ, midge larvæ and pupæ, and other insect remains.

(13) Common bullhead, *Ameiurus nebulosus.* (Le Sueur).

Habitat.—This fish was seen or taken at nine stations, with the yellow catfish, and in about the same abundance. The two species were undoubtedly closely associated in habitat and feeding habits.

Food.—Like the yellow catfish, this species is an omnivorous feeder, and in ten stomachs examined, crayfish, small fish, mollusks, entomostracans, leeches, beetles, and the larvæ of Hexagenia, Heptagenia, midges and dragon-flies were found.

Breeding habits.—One June 28, a school of small bullheads about a half-inch long, attended by two old ones 12 to 14 inches in length, was seen in water a few inches deep near the shore of station 4. At the approach of the observer the adults swam away, but returned to their charges several times in the course of two hours.

(14) The tadpole stone-cat, *Schilbeodes gyrinus.*

This is a small species of catfish, about 5 inches long, and was found in but two parts of the lake, stations 7 and 41 and the adjacent stations 3 and 37, where they were quite common in the dense vegetation of the shallow, almost stagnant water of the bays.

Food.—The stomach contents of a specimen caught at station 7, on May 23, consisted chiefly of a mass of insect fragments.

Breeding habits.—On June 26th, a fish of this species, 2⅜ inches long, with a cluster of eggs was found in an old tin can at station 35. The water at this place was three feet deep, and the bottom was marl. The eggs are shown in Plate 59.

FAMILY *Esocidæ.*

THE PIKES.

(15) The little pickerel, *Esox vermiculatus.* (Le Sueur).

A single specimen of this species was taken in the trammel net at station 36, on May 2.

(16) The pike or pickerel, *Esox lucius.* (L).

This is called the "grass pike" by fishermen of the region. In early spring, as soon as the ice disappears from the marshes, the pikes seek these habitats to lay their eggs, and are at this time much sought after by gunners. The species is very common, judging from the number of individuals seen in shallow water in the breeding season; at this time one or more would swim from every shoal approached, where there were bulrush stems or other plants remains, which afforded partial concealment. The largest number of specimens was taken in the trammel net at station 54, which seemed a favorite shallow water habitat.

The fish caught in the lake were mostly between 12 and 18 inches long; the largest was a little over 2 feet long and weighed 3½ pounds. A still larger fish was seen, which had been shot while spawning in a marsh near the edge of the lake, on April 2nd. It was a female, 28 inches long, with very large egg masses, and weighed 8¾ pounds.

Food.—Food was present in but nine of the many specimens examined. It consisted of a single perch in six cases; of two fish of the same species, about 3 inches long, in another, and 3 darters in another.

FAMILY *Umbridæ.*

MUD MINNOWS.

(17) The mud minnow, *Umbra limi.* (Kirtland).

Habitat.—This small fish was common only where the aquatic plants formed a dense growth in shallow water. It was never seen swimming in open water, all the specimens found being picked from masses of plant drawn from the bottom at stations 40, 41 and 7.

Food.—Of the four specimens examined for food, two were taken in April and two in July. The food was about the same in all of them, entomostracans, green algæ, water mites, midge larvæ, Planorbis shells and miscellaneous insect material being present.

FAMILY *Poeciliidæ.*

THE KILLIFISHES.

(18) The barred killifish, *Fundulus diaphanus.* (Le Sueur).

Habitat.—The killifish was seen at seven stations. It was most common along the east side of the lake, where, in the latter part of the spring, it was associated with minows.

Food.—Four specimens caught at station 41, on May 10, had fed on midge larvæ, water-fleas, and a small amount of filamentous green algæ. The stomach contents of specimens from station 46, taken on May 21st, was composed chiefly of midge larvæ, beetles, and water-fleas, and several that were caught on May 31st had been feeding on midge and May-fly larvæ. In general, it may be said that these fish seemed to take the same kinds of food as the minnows with which they were found associated.

FAMILY *Gasterosteidæ*.

THE STICKLEBACKS.

(19) The brook stickleback, *Eucalia inconstans* (Kirtland).

Habitat.—This species was only found in the stagnant, duck-weed covered pools in the swamp at station 42.

FAMILY *Centrachidæ*.

THE SUNFISHES.

(20) The rock bass, *Ambloplites rupestris* (Rafinesque).

Habitat.—The rock bass was a very common species at Walnut Lake. It was often seen in shallow water, but apparently the pond-weed zone was its principal habitat, and it visited the shoals in search of food and breeding grounds. It was abundant on the bulrush-covered shoal at station 54, and a number were caught in the fyke net collections made in the pond-weed regions of stations 15, 12, 3, 6 and 26.

Food.—The stomach contents of 19 individuals taken between April 19th and June 26 were examined, and the following animals found: Crayfish in 10; dragon-fly larvæ in 6; midge larvæ in 2; small fish in 1; May-fly larvæ in 1. Crayfish thus seemed to form the most important part of the food of this species in Walnut Lake.

Breeding habits.—Four nests of rock bass were found at station 24. They were all in water less than two feet deep, and on a marl bottom covered by a scant growth of bulrushes. The first nest was found on June 6th; it was about 20 feet from shore, in about a foot of water, and was guarded by a large adult. No arrangement of the bottom material to form a nest could be seen, but in the area guarded by the bass, among the small stoneworts which here, as elsewhere on the shoal, formed a dense growth, were some very young fish about $\frac{1}{4}$ inch long. The parent fish was not frightened when the water-glass was placed above it, and was so bold that it would bite a hand placed in the water near it. On two succeeding visits made within a few days, this fish was watching the young ones and showed the same boldness in their defense.

A second nest was found on June 12th, near the end of the same shoal, in water 17 inches deep. This was in a shallow depression of two or more inches. The depression did not, however, differ from the rest of the bottom (which was of marl and covered by small stoneworts), and showed no signs of recent disturbance. The attending fish was about 10 inches long, and had no fear of the observer, being even bolder than the first described; it seemed very successful in keeping away minnows. The young were not found on the next visit, but their presence was apparent by the actions of the fish, and the empty gelatinous egg-cases fastened to the stoneworts. Two days later a young fish $\frac{5}{8}$ of an inch long were found among the plants in the bottom of the nest. The fish was still guarding this nest on June 16th. On the latter date, a similar nest was found on another part of the same shoal, in 17 inches of water. Many eggs were found attached to stoneworts in this nest.

(21) The blue-spotted sunfish, *Lepomis cyanellus* Rafinesque.

Habitat.—But little information was obtained concerning the distribution of this species. Few specimens were taken, and these were caught in a trammel net, chiefly from shoals where plants were abundant. They were seen more often than caught, and are recorded from stations 26, 7, 41, 31, 15, 19 and 20, but none were ever taken from the pond-weed zone by the drag seine or fyke net. In early spring individuals of this species were often found dead in the water.

Food.—Of eleven stomachs examined, crayfish were found in seven and dragon-flies in three; other organisms found, but which were apparently of minor importance, were leeches, small fish (including a small sunfish), water-mites, and miscellaneous insect remains. The crayfish seems to be the most common food of this species.

Breeding habits.—The first nest of this sunfish was found early in July. It was in water nearly a foot deep, and near the shore of the east end of the swamp loosestrife zone of station 26. It consisted of a depression about a foot wide and three inches deep in the black mud of the bottom, and was situated close to a sedge clump. In the depression there were many sedge roots, to which numerous eggs were attached (Plate 60).

Above the nest was a large, dark-colored male, with a coloration so similar to that of the bottom that its almost motionless body could scarcely be seen; it was further concealed by the light-colored border of its dorsal fin, which appeared like a blade of grass in the water. A small female was seen to deposit eggs in this nest July 3rd, and when revisited on July 7th there were still a few unhatched eggs in it. It was vacated before the 13th, for on that date neither eggs, young, or attending fish were found; at that time, however, two other nests similar to it were found within a few feet, each attended by a fish of the same size and coloration as the first, and in one of these new nests there were minute young about 1-5 inch in length.

During July a number of nests of this species were found at station 4, which had the same general form as those described, but the eggs were attached to the roots of bulrushes. At this point the bottom was of marl, and the fish guarding the nests were, in all cases, much lighter in color than those at station 26, thus harmonizing with the light color of the marl bottom; the fins had the same light markings as those of the fish at station 26. This species, in Walnut Lake, resembles the common and long-eared sunfish and rock bass in its habit of choosing shallows for nesting, but makes a deeper and more conspicuous nest. The attending fish was also found to be less restless than those of the other species, remaining apparently motionless over its nest, from which, however, it is much more easily frightened than are the other sunfish studied. When disturbed, it darts away into deep water, and seldom returns to its post until the object of its fear is gone.

(22) *Lepomis euryorus* (McKay).

Habitat.—This is apparently a rare species in Walunt Lake, since it was found only at stations 31, 54 and possibly 4, while but one was taken in the first mentioned habitat, and only a few at 54. All of these specimens were caught in May. The single individual taken at station 31 was kept in an aquarium until June 16, and photographed while alive (Plate 61). It was $6\frac{1}{4}$ inches long, which was about the average length of those taken. The determination of this species was made by R. E. Richardson.

Breeding habits.—On June 28 a sunfish nest was found in the bulrush zone of station 4, in 15 inches of water. It was watched by an individual which, although not carefully examined, was probably of this species. It was so fearless as to allow itself to be taken from the water for a moment, and a chance was thus afforded to see that it differed in a marked degree from the long-eared sunfish, which it resembled in its coloration. The nest was a nearly circular depression three inches deep, in the marly soil

of the bottom. The gelatinous egg-capsules were attached to the roots of the bulrushes, at the bottom of the nest, where there were also newly-hatched young. The parent fish was protecting the nest from numerous blunt-nosed minnows and several small sunfish, which were waiting to attack the contents. In the ten minutes or so which it took the owner of the nest to recover from the fright of being taken from the water and to return to the nest, one of the little long-eared sunfish from the attacking party rushed into the nest and began to drive out the minnows and sunfish. This small sunfish and some of the minnows were caught, and one of the latter contained four young fish like those of the nest.

The large fish was left on the nest, because it was so tame it was thought best to study its habits and photograph it, but on returning later it was gone, and was not seen again, hence was not positively identified.

(23) The long-eared sunfish, *Lepomis megalotis* (Rafinesque).

Description.—This species is very much like the common sunfish in general form and coloration, but differs from it in having shorter dorsal spines, a more rounded snout, and, in many adults, long, conspicuous opercular flaps or "ears." It was by no means as numerous in Walnut Lake as was the common sunfish, with which it appeared to associate.

Food.—Three specimens, the only ones taken in spring, caught at station 54, on May 9, had all been eating May-fly larvæ, dragon-fly larvæ, caddice-worms and leeches.

Breeding habits.—The species was more conspicuous in summer than in spring, and, after June 15th, nests were found at stations 4 and 54. In the former habitat two typical nests were found on July 1st near substation 4a, in the bulrush patch shown in Plate 62, and close to the outlet of the lake. The water at this place was 14 inches deep. The nests were shallow, nearly circular depressions, exposing the bulrush roots, to which the eggs were attached. Highly colored fish with long, conspicuous, opercular flaps were tending these nests (Plates 63 and 64.)

(24) The blue-gill, *Lepomis pallidus* (Mitchill).

Habitat.—The blue-gill was by far the most abundant species of sunfish in the lake. Its principal habitat was the pond-weed zone, in which it was common throughout the field season. It also frequented the shoals, especially those of stations 7, 15, and 54, on which, in the spring, many specimens were captured in the trammel net.

Food.—The stomachs of 18 specimens of this species were examined and, until the middle of May, caddice worms, crayfish, midge larvæ and pupæ, and the larvæ of *Heptagenia*, *Hexagenia* and *Sialis*, constituted the bulk of the food, the midges predominating. After that time, crayfish, grasshoppers, crickets, beetles and other land insects, together with entomostracans were the chief articles of diet.

Breeding notes.—The breeding season of the blue-gill was long. The first nests were found on June 4th, the first eggs on June 6th, while young only one-fifth of an inch long were found at station 12 on July 7th. The species is gregarious in its nesting habits, and many groups of from 9 to 15 nests were found on the barren shoals at stations 16, 3, 19, 23, 32, and 12, which were the chief breeding haunts. Groups of nests were also noted on the bulrush-covered shoals of stations 15 and 24.

The nests were always found in water from five to six inches to two feet in depth, and every nest was tended by a very shy fish, which was so timid that it was difficult to get near enough to see it at its station. All of the nests were of the usual sunfish type, i. e., circular depressions in the bottom soil. They were about two feet in diameter, from which the material had been cleaned away to expose the bulrush roots, to which the eggs were attached.

(25) The common sunfish, *Eupomotis gibbosus* (Linnæus).

Habitat.—This was the second sunfish in point of numbers in Walnut Lake. It seemed to have a greater preference for shallow water than the blue-gill, especially in spring, when they were very common on plant-covered shoals. In the summer, they were seldom seen in such places, except where the bottom vegetation was abundant, as at stations 7 and 41, where small individuals, about three inches long, were usually common.

Food.—The stomachs of 32 specimens of this species, taken between April 13th, and August 11th, were examined, and, while May-fly larvæ of the genera *Hexagenia* and *Heptagenia* seemed to be the favorite food, crayfish, amphipod crustaceans, snails, leeches, midge larvæ, caddice-worms, and other insects were all found in the contents. The midge larvæ were apparently eaten only in small quantities.

Breeding habits.—Like the blue-gill, the sunfish was found to be somewhat social in its nesting, but the nests were not placed so close together, nor in such deep water (usually between one and two feet only). The breeding season extended from May 21st, when the first nests were found at station 40, at least until July 7th, when two females were seen spawning at station 20.

The nests were shallow, circular depressions in the shoals, extending down to the bulrush roots. The eggs were attached to the bulrush roots, generally to one side of the center of the nest. Each nest was guarded by an adult male, some of which were very shy, while others paid little heed when observations were being made near them. Some of the adults were even very fierce in attacking intruders, while others would calmly watch the minnows help themselves to the contents of the nests. A list of the stations where this sunfish nested is given below, with notes on the character of the environment, and the date on which the first nest was found at each place.

May 21, station 40, on sand bottom.

June 3, station 26, on sand bottom.

June 14, station 24, on marl bottom, with scant bulrush growth.

June 24, station 4, on marl bottom; few bulrushes about the nest.

July 7, station 20, on marl bottom, bulrush-covered.

(26) The large-mouthed black bass, *Micropterus salmoides* (Lacepede).

Habitat.—This fish was a very common species, dwelling chiefly in the pond-weed zone, but, in the spring, frequenting the shallow water with the sunfish. In May and June it was almost constantly present in the shallow cove, station 7, and, during the same months, it was frequently seen in the bulrush zone of station 15. It was also a common occurrence on warm days to see a number of individuals swimming close to the surface of deep water over the pond-weed zone.

At station 54, in the spring, specimens, seven or eight inches or more in length, were common, and were often caught in the trammel net. The largest specimen taken was 17 inches long, and weighed $4\frac{1}{4}$ pounds. Besides these larger fish, extensive schools of bass fry, an inch or so long, were occasionally seen in June, and in August small bass 3 or 4 inches long were common on plant-covered shoals, such as those at stations 7 and 54. The numbers and uniform size of these fish indicate that they were hatched during the season.

Artificial introduction.—Black bass have frequently been placed in Walnut

Lake by the Michigan Fish Commission. The latest introduction was in the spring of 1906, when several thousands, obtained from the Fish Commission, were planted.

Food.—Data on the food habits were gathered from the examination of the stomachs of 24 fish caught between April 11th and June 10th. Nearly all of those examined had been feeding on crayfish, five had eaten one or more small fish, and one, taken April 28th, had in its stomach about 350 midge larvæ and pupæ, besides *Sialis* and damsel-fly larvæ. From these facts, it appears that crayfish are the most important food of this species in Walnut Lake.

Breeding habits.—Nests were found at stations 19, 20, 7, 40 and 54, but most frequently at 54. They were placed on shoals, in from one to two and one-half feet of water. The first nest was found on May 16, in the midst of a tract of water-milfoil plants, and in about 15 inches of water. It consisted of a circular mass of blackened roots from which the soil had been removed, and upon these were fastened great numbers of light-colored, small but conspicuous eggs. Other nests, having about the same appearance, were found later among the bulrushes, with eggs attached to the cleaned roots of these plants.

The nests were guarded by one, or sometimes two, fish. In some instances the guarding fish was quite fearless, and could be approached near enough to be studied carefully. Minnows were numerous in the vicinity of most of the nests, and, if the guardians were driven away, would rush in and eat the eggs. The nests were often deprived of their guardians by fishermen, who speared them at night, and such nests were soon stripped of their contents by minnows.

Economic.—This is one of the best and gamiest of the fresh-water food-fishes, and from its size and abundance in Walnut Lake should yield excellent sport, as well as quantities of good food. It is hardly necessary to say that it should not be speared from the nests.

FAMILY *Percidæ*.

THE PERCHES.

(27) The wall-eyed pike, *Stizostedion vitreum* (Mitchill).

This species was reported to be common in Walnut lake, but only ten were taken. These measured from 15 to 25 inches in length, and weighed from one to five pounds each.

Habitat.—Nine of the specimens obtained came from the pond-weed zones of stations 15, 6, 46 and 7, and the other one from the deep water of station 200.

Food.—The stomachs of all these specimens were examined, but were empty, except two. Of the latter, one from station 15 contained a perch 8 inches long, and the other from station 200, caught on August 6th, contained five small fish, each about an inch long, which seemed to be small straw-colored minnows, then very numerous near the surface of deep water.

Breeding notes.—A ripe male was caught on April 26th from the pond-weed region of station 6, and two females with large and numerous ova were found in the gill net on the same day, so it is probable that this date is included in the breeding season of the species in Walnut Lake.

(28) The yellow perch, *Perca flavescens* (Mitchill).

Habitat.—This is apparently the most abundant fish of Walnut Lake. It

chiefly inhabited the zone of pond-weeds, but was commonly seen on the shoals in two or three feet of water, either singly, or, as was often the case, in large schools. Like the sunfish and bass, it was more often seen in shallow water in the spring than in the summer, during the day, but was seldom (except in the case of very young fry in the summer) found in less than two feet of water. With the aid of a searchlight it was found to be an abundant visitor to the shoals at night, when large numbers of scattered individuals could be seen resting quietly on the bottom at various depths, during both spring and summer. The fyke net, set in the pond-weed zones of stations 3 and 15, often caught from one to several hundred specimens after being down about a day.

Food.—Only thirty-two stomachs of the many which were examined contained food; of these 13 had numbers of midges in several stages of development, and 11 had crayfish. Other food material, in relatively small quantities, was found to include May-fly larvæ and a variety of other insects, besides snails, leeches and entomostracans. The few fry opened contained chiefly entomostracans, among which were copepods and ostracods.

Breeding season.—Perch were found breeding during the latter part of April. On April 23rd in the pond-weed zone of station 15, about 400 specimens were taken in the fyke net. Most of these were mature males, but there were four females, three of which were spent, while the fourth had eggs protruding from the body. Gelatinous masses of eggs were also found in the net. These females were much larger than the males taken with them. Schools of very young perch, sometimes containing several hundred individuals, were very common in June and early July, especially on shoals with much submerged vegetation, such as those at stations 7, 40, 26, 54 and 31. They were also observed in bulrush zones, and, less often, near the surface in deep water, several hundred feet from shore, in some cases as far out as station 200.

Economic importance.—The perch is one of the best of the smaller fish, ranking high as a pan fish, and if properly taken (with a light tackle) furnishes considerable sport. Its numbers and hardiness make it a valuable species in such lakes as the one under consideration.

(29) The Johnny darter, *Boleosoma nigrum* (Rafinesque.)

Habitat.—This very interesting little fish was a common inhabitant of the shallow water, ranging to depths of six or seven feet; beyond the latter depth it could not be detected with the water-glass. While noted on barren and bulrush-covered shoals, and on those with much submerged vegetation, such as stations 41 and 54, the barren shoals with gravel bottoms seemed to be the chief habitat.

Food.—The few specimens obtained in late April had been feeding on midge larvæ alone, or on filamentous green algæ, the same food which minnows, taken at the same time and in the same place, had been eating. A specimen caught on May 21st had been feeding on midge larvæ and entomostracans, but several taken on the next day contained only midge larvæ.

Breeding habits.—The eggs of this species were only found on the under side of small objects lying on the bottom in shallow water. The many nests found were under flat stones about the size of a person's hand, or smaller, a single exception was one that was placed beneath the valve of a mussel shell which lay concave side down.

The favorite breeding places were the gravel-covered, marly shoals of stations 23, 49 and 45, and nearly all of the nests noted between May 16 and June 19 occurred in these places. These nests were each guarded by a

black-pigmented male, which was tireless in his attempts to drive away the numerous blunt-nosed and straw-colored minnows which were trying to get at the eggs, but his small size prevented the darter from injuring the intruders, and they gave him little attention. Doubtless the eggs were more protected by being covered than by the energy of their guardian.

(30) *Etheostoma iowæ* Jordan and Meek.

The habitat of this species appeared to be similar to that of the Johnny darter, but it was much less abundant. It was especially common in the shallow parts of the shoals of stations 6 and 16. At the latter place just after the ice had left (early in April), numbers of them could be seen swimming out into the lake, from beneath the sedge roots which fringed the shores. After the first of July it was not found on the shoals.

(31) Least darter, *Microperca punctulata* Putman.

This is the smallest species of fish found in the lake. Its maximum length is given as 1½ inches, but none were found in Walnut Lake that exceeded 1¼ inches.

Habitat.—In the spring the species was found on shoals having much aquatic vegetation, as at stations 7, 26 and 41. They were also common in the spring on the bulrush-covered shoals of stations 1, 15 and 4, but were scarce at all times on barren shoals, a few only being taken at station 49, late in May. Like most other species, the least darter practically disappeared from the shoals in summer. Some were caught, on July 9th, in the pondweed zone off station 6, in water from 15 to 20 feet deep, and it is possible that the fish seeks this area in summer.

Breeding habits.—Nothing definite was learned of the time of spawning or other breeding habits of this species. During May, pairs were often seen with the individuals united in what may have been the spawning position, the female resting near or on the bottom, and the male above. No eggs were seen, but this may have been due to their minute size. Males were also seen chasing females at this time.

FAMILY *Cottidæ.*

(32) The miller's thumb, *Cottus ictalops* (Rafinesque).

Habitat.—This fish was very common in the outlet, but only two specimens were caught in the lake. Both of these were seen on gravelly shoals, one at station 49, and the other at station 13.

Breeding notes.—The specimen noted at station 13 had a nest beneath a small stone on an area of stony bottom such as was used by the blunt-nosed minnows, for nesting purposes. The eggs were fastened to the under side of the stone, which is indicated in Plate 56 by the mark x.

THE FLORA.

BY C. A. DAVIS.

In an investigation of the character of the one upon which this report is based, it is impracticable to cover thoroughly all phases of the biology of any considerable part of the region around the spot where the intensive studies center, or to divert attention too strongly from the main problem under consideration. Therefore, while the plant relations of the broader field furnish a theme of great interest, but little space can be devoted to it here, and, so far as plants are concerned, attention will be directed chiefly to the flora of the lake and its immediate surroundings, since the fish, the central objects of this investigation, are directly affected by this.

Relations of plants to animals.—Plants are the organisms which stand between the highly specialized and complicated animal world and the inorganic or mineral kingdom, converting the gases and mineral matter of the latter into substances which can be assimilated by the former. Plants, then, may be termed the primary food of animals, even when these, as is the case with many fish, do not use them directly for food, for, if the history is traced back far enough, it will be found that there is one or more vegetable feeding organisms constituting the intermediate step from the mineral world to the animal.

Aside from this relation, plants furnish places of nesting, of refuge, and of rest for fish, and a study of the Walnut Lake records shows that the abundance of many fish and their permanence at any station was largely correlated with good plant growth.

Requirements of plants.—Before taking up in detail the flora of the lake, however, a brief statement of principles governing the distribution of plants over even the most limited areas, may not be out of place.

All green plants require for their growth and development, light, heat, water, the gases, oxygen and carbon dioxid, which they get from the air, and soluble mineral salts, obtained primarily from the soil, with the water taken in by the roots.

Adaptation of plants.—The absolute amount of these required by each species may differ, as may also their powers of resistance to unfavorable deprivation or excesses of some of them, hence we find plants growing in almost every kind of habitat, where all of these essentials are found, and presenting peculiarities of structure or form, which seem to fit them for the particular environment in which they occur. It is said of such plants that they are "adapted" to the conditions under which they grow.

Thus we find plants which grow in very dry places provided with extensive, wide-spreading root systems, with relatively small leaves protected from loss of water by a thick epidermis, covered densely by hairs, scales, wax or other forms of covering, or, as in some desert plants, the leaves themselves may be wanting. In like manner, plants growing in shaded places

often have large, broad, thin leaves, and, to increase the light-absorbing surfaces, green bark on their branches.

Law governing plant distribution.—Since the requirements of the factors essential for plant growth are absolute, and if one only of these falls below the minimum amount needed by a plant to maintain itself, it perishes, it follows that plants unable to find all of the conditions necessary for existence in their environment must give place to those which can. This statement may be illustrated by the commonly observed fact that, if the water supply in the soil of a field decreases below a certain amount, crop plants cease to grow, and, if the unfavorable conditions continue, the plants die. All other conditions may remain favorable, but the failure of this one is effective in destroying the plants. On the other hand, at the time when one set of plants may perish, another set, because of a lower limit of tolerance, may not be injured at all, but may even flourish, a state of affairs sometimes seen during drought on cultivated lands, when weeds cover the ground, though the crops are dried up. Again, the presence of an excess of water in the soil may drive from it the air necessary to keep the roots of most land plants alive, and thus many species which might find all other conditions favorable are kept from very wet habitats, so that in marshes, where the soil is saturated with water, there are relatively few species of plants. It must also be apparent that if a single unfavorable condition for growth reduces the number of species, two such conditions will reduce the number still more, so that there are a great many less plants which will live with their leaves and roots submerged than if the roots only are below the water.

The flora of a lake and its immediate surroundings, therefore, must differ to a marked degree from that of the highlands in its vicinity, not only in species, but in the number of species, which will be much fewer than occur on the uplands, in the kinds of adaptations to conditions of growth, and in other ways, but especially in the number and simplicity of associations found. Above the water level of a lake, on those shores where the soil is simply wet, there will usually be more kinds of plants than are found growing in the water, because there are fewer necessary factors of growth affected, and until a certain optimum condition for rooted plants is reached, for practically every inch which the land surface is raised above the water level, there is an increase in the number of plant species which will grow on it and in the complexity of the associations into which these group themselves,

Types of water plants and their associations.—Where the soil is covered by water, within the margin of the lake itself, as has already been suggested, more than one factor of growth is different, and unfavorably so, from that of the normal environment of land plants, and we have fewer seed-plants and simpler associations. In the aquatic environment, some of the more highly organized plants grow entirely submerged, some send their leaves to the surface where they spread out, and still others have parts of their vegetative bodies entirely above the water, thus avoiding some of the difficulties of submergence.

Factors controlling plant distribution in a given lake.—The distribution of these types of species must be limited to those parts of a lake where they find favorable places for the growth of their underground parts (roots and stems), and to those from which, after they are established, they can grow upward to a place where sufficient light and heat reach their leaves to enable these to carry on their work of carbon assimilation. Most plants living in water, or wet places, propagate extensively by underground stems, which radiate horizontally from the established part of the plant. They are thus

able to take possession of the lake bottom over large areas, and to such depths as the species extending its range in this way is unable longer to get enough heat and light, or is forced to meet other unfavorable conditions.

The lake a desert.—Since but few species, and still fewer orders, of seed-plants can tolerate aquatic conditions, the flora of lakes is monotonous, and consists of great numbers of individuals of few types; in other words, the lake is like a desert in that it usually has a sparse flora of highly specialized plant forms, which differ radically in structure and form from the plants of the higher lands adjacent, and have slight relation to them.

Reasons for zonal arrangement of plants.—Water and marsh plants because of the lack of competition with other more aggressive forms, and because of their habit of spreading below ground in soil very favorable for this purpose, will usually arrange themselves about the shores of the lake in about the order in which they can endure submergence, so that, if the slope is uniform and gentle, and the soil all of the same nature, the plants will form a series of rings or zones, of greater or less width, according to the steepness of the slope of the bottom, being wide if the slope is gentle, and narrow if it is steep.

Invariable order of the zones.—Each one of such zones will be characterized by the dominance of some plant or group of plants, so that it is easily differentiated from others and may be given a distinctive name, and while species may vary, and any zone may be wholly or in part wanting from a given lake, their vertical order of occurrence is invariable when they are present.

Limits of the different zones.—Beginning in the deepest water, the larger and more highly organized plants are absent, if the depth is more than twenty-five or (very rarely) thirty feet deep. Microscopic algæ are found at the bottom in water more than thirty feet deep, and the stoneworts, closely related to the algæ, frequently occur at depths of thirty feet or more, if the water is very clear. Seed plants of the submerged types, especially the pond-weeds, begin to appear sparsely in water about twenty-five feet deep, and are the only ones visible until the water is about 15 feet deep, when plants with floating leaves, like the water-lilies, begin to show themselves, and characterize a zone which extends shoreward until the water is about 5 feet deep. Then if the soil conditions are favorable, these monopolize the part of the lake where they grow, since the floating leaves crowd close together, and cut off the light from the water below, and prevent, or restrict, the growth of submerged plants. In water 5 feet deep, plants with aerial stems, like the bulrush and other grass-like plants, with some others, are able to establish themselves, and these may cover the marginal region to above the water level about the whole lake, providing other elements do not come in to interfere with the ideal conditions. The plants with aerial stems and leaves make a strong, dense growth where the composition of the bottom soil is favorable for this, and so cut off the light from the submerged types and from those with floating leaves, so that these either take a subordinate position or disappear from the association entirely.

Zones above the water level.—Above the water level, sedges in considerable variety, ferns, and many other types of herbaceous plants, displace the bulrushes and those forms which can grow in the water, and these in turn give way a short distance up the slope to the true grasses, which often form a distinct zone. At about the same level, and frequently covering the same area with the grasses, shrubs and sphagnum appear, and develop an extensive zone and a complicated plant association. In the landward edge of the last

zone, coniferous trees, like the tamarack, arbor vitæ, and black spruce form the first zone in the arboreal series, and this, in turn, is replaced still farther shoreward by a border of the broad-leaved swamp trees from which, when natural conditions prevail, there is a gradual transition to upland forest, which presents a great number of species and many different and complex associations.

Ideal classification of the plant zones of the region about Walnut Lake.—Not only will the vegetation in the lakes and depressions have a zonal arrangement, but in the region of southern Michigan in which Walnut Lake lies, if ideal conditions of slope and soil exist, the entire flora would be found to be in zones around the depressions. The ideal slope would be a gentle one; the ideal soil would be a homogeneous, moderately porous loam, which would readily absorb and retain a sufficient amount of the annual rainfall to supply all plants with sufficient water for their needs. As the slope was ascended, however, the water would sink farther from the surface than at the foot, and the level of permanent moisture would be deeper below the ground surface, thus making it difficult for the shallow-rooted plants to get sufficient moisture, so that those with deep roots would displace them.

As outlined above, and if uniformly favorable temperature and rainfall conditions prevail throughout a long cycle of growing seasons, the zones would be as follows: (1) The deep water zone of Algæ and Characeæ (stoneworts), (2) Pond-weed zone, (3) Water-lily zone, (4) Bulrush zone, (5) Sedge zone, (6) Grass zone, (7) Shrub-Sphagnum zone, (8) Coniferous tree zone, (9) Swamp forest zone, (10) Hard maple-beech zone, (11) White oak-hickory zone, (12) Black oak zone, (13) Scarlet oak zone, (14) White pine zone, (15) Norway and Jack pine zone.

It must be noted, however, that with the type of soil and conditions of temperature and rainfall postulated, the elevation of the top of the slope would have to be considerably greater than any now existing in the region to have the zones of pine present. However, on a dryer type of soil, the white pine still exists in a nearly pure stand within a few miles of Walnut Lake, while near by, "Pine Lake" indicates by its name the former closer proximity of this noble tree.

Reasons for variation from the ideal arrangement.—The ideal conditions for the complete development of plant zones outlined above do not exist in Michigan, where soils are rarely homogeneous, even over a single square mile, or for more than a few feet deep, and the slopes are very irregular. The climate and rainfall are also capricious, the latter often being reduced below minimum requirement of many upland species, for periods of years and through frequently recurring cycles, thus profoundly lowering the ground water-level. This causes even aquatic habitats to vary considerably, since the water-level in lakes and marshes may be lowered several feet below the normal for a period of years by prolonged deficiency of rainfall, and thus temporarily give chances for the plants of shoreward zones to advance lakeward, opportunities which they immediately take advantage of. At such times, shrubs will invade the sedge zone, and trees the shrub zone, while the sedges and other plants more tolerant of water will make inroads along the zone left bare by the falling water of the lakes, from which the aquatic forms disappear.

The plant zones of a lake affected by the soils of the bottom.—Water and marsh plants are often restricted in distribution, and form broken and incomplete zones because of irregularities of the slope of the bottom, and the distribution of the soils on the bottom of the basin, as well

as by the presence of soils whose situation or whose physical or chemical composition is unfavorable to the growth of most types of plants. Unfavorable factors such as steep or irregular slopes, exposure to strong wave action, very compact, stony, or sandy soils, or soils with too little plant food, or too much soluble mineral matter of a poisonous nature, are all likely to be present in those parts of lakes available for the growth of the seed-plants. Any of such areas may be sterile, and cause interruption in the continuity of the zones. Again, and by no means least in importance, species of the type necessary to give character to a definite area may be absent, in which case the plants of another zone, usually the one from deeper water, may occupy the place of those absent.

Application of principles to the flora of Walnut Lake.—The study of the contour map, Plate, 14 as already pointed out on a preceding page (165), shows that the slope of the basin of the lake is far from regular in those parts where vegetation can occur. In some places very steep slopes descend below the critical line of 25 feet, while over other large areas the water is less than 5 feet deep for long distances from the shores. However, the slopes from 5 to 25 feet are steep except in a few places, hence the zone of possible growth of the submerged seed-plants, and those with floating leaves, is quite narrow and also very unsymmetrical in its relations to the shore lines. The area which should be covered by partly emerged plants, bulrushes and sedges, is much broader and more conspicuous.

Relations of soils to zonal distribution.—Within the irregular marginal area, soil conditions are quite diverse, and often consist of those types which are unfavorable to the growth of aquatic vegetation. The kinds of soil have been mentioned in the descriptions of the stations and need no further discussion here, except so far as is necessary to show how they affect the development of the zonal distribution of the plants.

Marl.—It will be seen by referring to the detailed accounts of the stations, given on the preceding pages that the chief bottom soil on the zone of possible vegetation is marl. Marl is a chalky, white substance, more or less granular at the surface, but very fine-grained and compact below, which makes it physically a poor substratum for the growth of the underground propagating stems of plants. Chemically marl is even more unfavorable, since it is composed chiefly of calcium carbonate, with only traces of other mineral salts, and small and varying amounts of organic matter. This composition makes it an unfavorable soil for plants, since they require for their growth several other mineral substances besides those found in it. Besides the small amounts or total absence of necessary salts, another unfavorable feature of the marl is the fact that the included water is saturated with calcium compounds, which makes it toxic to the roots of some plants. As shown by their failure to penetrate the marl. The marl as a dominant soil is, then, capable of supporting only those plants that can grow with a minimum amount of most of the mineral salts essential to plant growth, and can also tolerate an unfavorable excess of calcium compounds. Exceptions are to be found in those plants that have roots simply for holding them in place (if we have any such) and are able to take the necessary mineral matter for their growth directly from the water through stems and leaves.

As a matter of observation at this lake, as in many others, the flora growing on the pure marl is poor in species and individuals, but when there is a slight addition of organic matter, it seems able to support a much larger