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AN ECOLOGICAL STUDY OF SOUTHERN WISCONSIN FISHES

The Brook Silversides (*Labidesthes sicculus*) and the Cisco (*Leucichthys artedi*) in Their Relations to the Region

WITH 16 PLATES AND 27 TABLES

BY

ALVIN ROBERT CAHN

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Contributions from the
Zoological Laboratory of the University of Illinois
under the direction of Henry B. Ward
No. 297

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN ZOOLOGY IN THE GRADUATE SCHOOL OF THE UNIVERSITY OF ILLINOIS

1924

TABLE OF CONTENTS

GENERAL ECOLOGICAL CONSIDERATIONS

INTRODUCTION

The first section of this paper is intended to serve as a general introduction to a series of ecological studies made upon the fishes of southern Wisconsin. At the present time the writer has a record of ninety species of fishes from within the boundaries of Waukesha county alone, and upon these species a considerable number of ecological studies have been completed. Two of these studies are herewith presented, one on the brook silversides (*Labidesthes sicculus*), the other on the cisco (*Leucichthys artedi*). These have been selected as the first studies presented for three reasons. In the first place, the fishes themselves differ greatly, one being a minnow, the other a valuable game and food fish; secondly, the fishes occupy positions in the lake as widely divergent as possible, the silversides being a surface species, the cisco an inhabitant of the deepest water; and lastly because the study of the cisco brought out a series of ecological problems of approximately ordinary complexity, while the study of the silversides presented a series of problems for solution that is far more complicated than has been encountered in any of the other investigations so far undertaken. The writer feels, therefore, that, taken together, they give a comprehensive idea of the type of problems encountered in a series of ecological studies dealing with the fishes inhabiting our inland lakes.

It is altogether probable that no lakes in the United States have been more carefully or more extensively studied than those of southern Wisconsin, from the point of view of hydrography, morphometry, chemistry and yearly cycle. The pioneer limnological studies of Birge and Juday have yielded a mass of information relating to the behavior and physical and chemical status of these bodies of water which is second to none in the entire country, the closest approach being the "finger lakes" of north-central New York, which is also due largely to the work of these investigators. Their most extensive studies have been made on Lake Mendota, at Madison, Wisconsin, together with Monona and other lakes connected by the Yahara river to the Rock river, but their surveys have encompassed as well the lakes farther east, lying in Waukesha county. As a result of these researches one has very excellent hydrographic and morphometric data invaluable for the further study of aquatic biota of this region. The yearly behavior of the lakes is well known; the progress through the seasons of the thermocline and the associated phenomena have been comprehensively tabulated; the dissolved gases of the water have been extensively studied, and the seasonal variations carefully recorded. Thus, by the foundations laid down by these investigators, the road has been paved for further studies of the lakes of southern Wisconsin, and it must be admitted that, in spite of the excellent beginning that has been made, all the work so far has been only a beginning. Our knowledge of the lakes in question is still only skin deep—surface deep—if indeed it is not merely a ripple on the surface. The work of Birge and Juday has been followed by the studies of Pearse on certain fish occurring in the Madison waters, and by Muttkowski with his quantitative and qualitative study of the fauna of Lake Mendota, with special reference to insect life. Concerning the Waukesha county group of lakes, nothing has been published outside of the work of Birge and Juday, excepting only a few records of fish foods furnished by the writer to Pearse and included in one of his papers (43).

The present paper is, in a way, the result of circumstances. Having lived in Waukesha county for over twenty summers, and having, during the last twelve years, his own private laboratory for carrying on investigations, the present writer has attempted to avail himself of the opportunities lying literally at his door. A serious study of the fishes of the region was begun in 1914 when, as a graduate student at the University of Wisconsin, the writer undertook an intensive study of the life history of the cisco (*Leucichthys artedi* (LeSueur)) in Lake Mendota and in the Waukesha county lakes which contain the species. A collection of the various species of fishes of the region was begun long before this date in an effort to ascertain what fishes inhabited the lakes and rivers. While the original idea encompassed only a listing of the species, this was enlarged in 1915 to include an intensive study of every species possible. Thus the study of the biology of the cisco was subordinated to a study of the biology of the fishes of the region, and forms one of a series of studies dealing with ecological life history investigations of individual species.

This series of papers, of which this is the first, purports to be a series of ecological studies made upon the fishes found within the boundaries of Waukesha county, Wisconsin, together with certain observations made upon identical species in other regions of the state where opportunities or facilities proved more advantageous for carrying on the work. The data presented are entirely original unless otherwise specifically stated. These include the results of something over one hundred gas analyses to determine the position of the thermocline in various lakes at different times of the year in order to ascertain its effect upon the distribution of the fishes; over two thousand H-ion determinations, accompanied in some cases by oxygen determinations, in an effort to discover if either of these factors is responsible for certain behavior phenomena; thousands of temperature readings at all depths of water, and many visibility readings by means of

Secchi's disc. The fish have been collected from practically every lake, and from all rivers and streams. In collecting fish, gill nets were used. For the smaller species and the young of the larger, minnow nets of various lengths were drawn where opportunity afforded. When physical conditions rendered this method impossible and in all streams where a current made it practicable, the glass minnow trap was used with excellent results. It is impossible to state exactly how many collections were made as in the early stages of the investigation the only records kept concerned the presence or absence of species; however, beginning with 1918 the following number of collections are recorded: 1918—216; 1919—none, due to the presence of the writer in France; 1920—547; 1921—520; 1922—738; 1923—1,264; a total of 3,285. Certainly well over 4,000 are represented. Further information has been obtained by examining the catches of commercial fishermen who nearly every fall seine in the neighborhood. By this means many data have been accumulated regarding the relative abundance of species, together with information dealing with size and growth otherwise unobtainable. The investigations have been, perforce, largely carried on during the summer months, but from two to three weeks have been spent in the region every winter, during which time the condition of the lakes and the fish in winter have been investigated. All identifications have been made by the writer and in every case this has been checked by an expert ichthyologist.

In presenting this paper the writer wishes to express his appreciation to several gentlemen whose kindly encouragement and ever-ready advice have made the pursuance of the problem a real pleasure: to Dr. A. S. Pearse, under whose guidance the problem was originally begun; to Dr. Bashford Dean and to Dr. T. L. Hankinson, who have checked up identifications of the fishes involved; to Dr. H. B. Ward whose suggestions and criticisms have always been freely given, and to Dr. V. E. Shelford, at whose suggestion several hitherto uninvestigated angles of the problem were undertaken and under whose guidance the innumerable loose ends accumulated during something like twelve years of investigation were drawn together and synthesized. To these the writer finds it a rare privilege to express his sincere thanks.

REGION UNDER DISCUSSION

Waukesha county, Wisconsin, with an area of 560 square miles (Fig. 8), lies in the second tier of southern counties of the state, with its eastern boundary about twenty miles west of Lake Michigan, Milwaukee county intervening. Of this area, the northwestern quarter, comprising some 170 square miles, is the center of the investigations considered in this report, and is the so-called "Oconomowoc-Waukesha lake district." This region extends from the Ashippun river on the north 14 miles south to Hunter's lake, and from Golden lake on the west 12 miles east to Pewaukee lake and the Fox river. Within the rough rectangle thus formed lie no fewer than forty-five lakes of various sizes, ranging from Pewaukee lake with an area of 2,297.8 acres down to such small bodies of water as Washtub and Mud lakes, with an area of three or four acres only. Of these, twenty-five of the largest and most important have been surveyed, and their depth, area, shore-line and general topography recorded by Birge and Juday (1914). These lakes show a total water surface area of 9,971 acres. Besides these lakes five river systems drain the region, and there are many streams of lesser magnitude.

Outside the Oconomowoc-Waukesha group the county contains a number of lakes of considerable size, scattered over the remaining three-quarters of the area. The largest of these, Muskego, near the town of that name in the southeast corner of the county, nearly equals Pewaukee in size, but it has never been surveyed, and its exact area is unknown. Here, too, lie Little Muskego, Denoon, Muckwonago, Phantom, Eagle, and many smaller unsurveyed lakes, all of which, however, are included in this report. In the northeast corner of the county there are no lakes, but here is found the Menomonee river, which introduces the Lake Michigan drainage area into the scope of the investigation, along with which come several species of fish found in no other part of the county. The lakes and river systems will be listed subsequently.

The region under discussion is of importance in connection with the work of Dr. Stephen A. Forbes and R. E. Richardson, together with their associates in the Illinois State Natural History Survey, because within it lies the source of the Fox river of Illinois, together with a great number of lakes and several river systems which flow into the Rock River and the Illinois, on which rivers the Illinois Natural History Survey is working so intensively. The region is, therefore, one of the great tributary areas to the river systems upon which they are focusing their energies.

The lakes of Waukesha county owe their origin to the action of the great ice sheet which featured the pleistocene epoch of the quaternary period. There were several great movements north and south of the Labrador glacier and other huge ice masses hundreds of feet thick. These glaciers crawled southward from their northern source, then slowly retreated, causing great changes both in the topographic and climatic conditions of the regions invested, and it is largely to the influence of this glacial movement that is due the present day distribution of the plants and animals both within the territory concerned and the adjacent regions. There seem to have been at least three—probably five—more or less distinct advances of the ice, the three most important being the Pre-Wisconsin, the Early Wisconsin and the Late Wisconsin, and it is to the last of these invasions that is traced the origin of the Waukesha county lakes.

At this time the invasion came from the Labrador glaciers and the movement was in a southerly direction, with a slight westerly trend. The movement of the ice sheet followed in a general way the already formed basins of the Great Lakes, and overflowed into the surrounding country (Fig. 9). As a result of this guiding of the course of the glacier, the ice mass assumed a lobate form, coinciding roughly with the general shore line of the basin down which it flowed. Thus the glacier that came down the basin of Lake Michigan, known as the Michigan glacier, put out a lobe, or sub-glacier, which traveled down the basin formed by Green Bay, and is known as the Green Bay glacier, while the ice mass occupying the basin of Lake Superior sent out smaller lobes which followed roughly the larger bays of its shore line. Following the outline of the glacier westward, one finds a series of smaller lobes and glaciers, the Langlade, Wisconsin Valley, Chippewa and Superior off-shoots which, however, did not reach far into the state, and which are of no significance in so far as the present paper is concerned.

By referring to figure 9 it will be seen at once that the edges of the Michigan glacier and the Green Bay glacier came in contact for quite a distance. As a result of this contact, and because each glacier was acting as an independent unit, the adjacent lateral moraines also came together and were built up side by side as a continuous ridge, forming a *medial* moraine which, because of its very broken and uneven appearance, is of the type known as a *kettle* moraine, extending as a ridge of glacial deposit down the middle of the apparently united ice mass. In this manner was formed the ridge of broken hills, over one hundred and fifty miles in length, which crosses Waukesha county in a northeast-southwest direction, forming the most important topographic feature of the landscape. Within the county the highest point in this ridge is Government Hill, with an elevation of 1,233 feet. With the retreat of the glacier, not only was this great moraine left stranded, but great blocks of ice were broken off and remained imbedded in this moraine area. These melted with the advance of the warmer climate accompanying the retreat of the main body of the ice, and left innumerable depressions varying in size from "pot-holes" a few yards in diameter to lake basins having an area of over a thousand acres. Some of these depressions filled with water, the source of which was surface drainage and a multitude of springs, and formed the abundant lakes of the district. In this manner all the lakes of the county were formed, with the exception of Pewaukee lake, which lies outside the area of the kettle moraine. This lake differs, then, from the others in that it lies in the area of the ground moraine, and occupies a shallow valley which resulted from the failure of the glacier to fill in this basin with ground moraine deposits. At the same time that the lake basins were being laid out, the general plan of the river systems were being formed, with the natural result that the river beds form a series of connecting channels between the various lakes.

After the formation of the lakes, it was a simple matter, as has been said, to establish connections between the lakes by means of river systems. The second source of water in the lakes is springs, which are extremely abundant throughout the region. Practically all of the lakes, whether they have inlet and outlet or not, are spring fed. These springs are the termini of great under ground water systems, and arise in the bottom of the lakes as bubbling streams. Nothing is known at the present time concerning the abundance of these springs in any lake, but data at hand indicate that they are numerous. In many places along the shores these springs have been "captured" and show an output of a vast quantity of marvelously clear, cold water, which is none other than the famous "Waukesha water" for which the county is well known. The temperature at which these springs enter the lakes is very low, the temperature of nine springs, taken in June, being as follows: 5.1, 5.4, 5.0, 4.8, 5.8, 5.6, 5.0, 4.9, and 5.0 degrees centigrade.

The medial moraine, to which I have previously referred, divides the county into two primary drainage areas, namely that of 1) the Rock river and 2) the Fox river. The northwestern third of the county contributes either directly or indirectly to the Rock river, while the southeastern third contributes to the Fox river drainage basin. Both of these rivers are tributaries to the Mississippi within the boundaries of Illinois, the Rock river entering directly, the Fox river by its union with the Illinois river. The northeastern third of the county lies outside of the Mississippi drainage, its one river, the Menomonee, flowing almost due east into Lake Michigan.

There are five river systems within the county, and these may be tabulated as follows:

1. Rock river tributaries:
    1. Ashippun river.
    2. Oconomowoc river.
    3. Bark river.
        a) Scuppernong river and creek.
2. Illinois river tributaries:
    4. Fox river.
        a) Muckwonago river.
        b) Pewaukee river.
3. Lake Michigan tributaries:
    5. Menomonee river.

An examination of the map will show that a vast majority of the larger lakes are arranged in two chains, the component lakes being connected by rivers. These chains lie in a general northeast-southwest direction, and are the courses of the Oconomowoc and Bark rivers. Of the five river systems listed, it is of interest and importance to note that of the twenty-eight most important lakes of the county, no less than eighteen fall into these two chains, a condition which permits the passage back and forth of at least the smaller species of fishes, and of the fry of the larger species. The relation existing between the lakes and the river systems is indicated herewith:

1. Oconomowoc river system:
   1. Lake Keesus.
   2. North Lake.
   3. Pine Lake.
   4. Beaver Lake.
   5. Okauchee Lake.
   6. Garvin Lake.
   7. Oconomowoc Lake.
   8. Fowler Lake.
   9. Lac La Belle.
2. Bark river system:
   10. Nagawicka Lake.
   11. Upper Nashotah Lake.
   12. Lower Nashotah Lake.
   13. Upper Nemahbin Lake.
   14. Lower Nemahbin Lake.
   15. Crooked Lake.
   16. Golden Lake.
   17. Hunter's Lake (Scuppernong creek and river).
   18. Dutchman's Lake (Scuppernong creek and river).
3. Fox river system:
   19. Pewaukee Lake.
   20. Muckwonago Lake.
   21. Phantom Lake (Muckwonago river).
   22. Eagle Lake (Muckwonago river).
   23. Lulu Lake (Muckwonago river).
   24. Millpond Lake (Muckwonago river).
4. Ashippun river system:
   25. Ashippun Lake.

The Menomonee river receives the water from no lake within the limits of the county, while there are nine lakes of some importance that have neither inlet nor outlet:

1. Genesee Lake.
2. Otis Lake.
3. Duck Lake.
4. Mouse Lake.
5. Forest Lake.
6. Henrietta Lake.
7. Silver Lake.
8. Pretty Lake.
9. Little Silver Lake.

The Ashippun river, a small stream which rises to the northward in Dodge county, enters Waukesha county from the north, then bending sharply westward, drains a narrow valley in the northwest corner of the county. It is a slow, shallow stream which flows for the most part between low, swampy banks in a bed that is made up largely of soft muck. It varies in width from twelve to nearly fifty feet during the early summer, but the end of the warm weather often finds the stream reduced nearly to a minimum. A number of gravel areas occur and here riffles afford local swift water habitats, characterized by typical swift water species of fishes. Plant growth is abundant and during the late summer the stream becomes practically choked with thick beds of Potamogeton, Nymphaea and limnophilous species of filamentous algae, while areas of Ceratophyllum occur particularly in regions of entering springs. The stream has a total length within the county of approximately sixteen miles, and has no tributary streams of consequence. It enters Rock river three quarters of a mile west of the county line, the closest approach of Rock river to Waukesha county.

The Oconomowoc river drains a long, torturous, but rather narrow valley lying south and east of the Ashippun drainage. Serving, as it does, as a connection between a large number of lakes, and as it is a river of considerable size, it affords an important fishway. Innumerable streams and creeks, all of them spring fed, are tributary to it in the northern portion of its course, of which the Little Oconomowoc and Mason creek are the largest. In its northern reaches the river flows through a low, swampy, spring-fed country of loose black muck, varied with areas of gravel and sand. For the most part it is slow and sluggish, but there are occasional regions of considerable drop, where swift water habitats predominate. Such areas are plantless, while in the sluggish regions *Potamogeton* sp., *Elodea canadensis*, *Nymphaea advena*, *Chara* sp., and *Vallisneria spiralis* occur in considerable abundance, but not thick enough to choke the river. In stagnant backwaters local regions of *Lemna minor* are found. Important as is the river as a fishway, its value is greatly reduced by the presence of six dams—Monches, North Lake, Okauchee Lake, Oconomowoc Lake, Fowler Lake, and the outlet of Lac La Belle. These dams afford a downstream passage for many species of fish, but are impassible barriers in upstream migrations—particularly the spring and fall migrations of the pickerel (*Esox lucius*), suckers of various species, and cisco (*Leucichthys artedi*). As the river flows into Rock river six miles west of Lac La Belle, the river is a constant source of supply of valuable game fish to the Rock river, while this river can contribute nothing at all to the Oconomowoc river above the outlet of Lac La Belle. It must therefore be considered as an important fish tributary to the Rock river.

The Bark river cuts a diagonal from the northeast to the southwest just northwest of the center of the county, draining a large area lying north of the main ridge of the kettle moraine. Its course is through a rich farming country, and it is not until it approaches the western limits of the county that it encounters large swamp areas. This is due to the fact that the greater part of its course parallels the base of the moraine, but tends to leave it near the western limit of the county. For the most part it has cut a bed through rich black soil, flowing in a channel from ten to thirty feet wide. Its bed is characterized by many deep pockets located with definite relation to the innumerable bends in the course of the river, these holes affording ideal places for game fish. Areas of swift water occur, in which a fine gravel bottom affords habitat for swift water forms and offers breeding grounds in abundance for the many species of minnows choosing such localities. As a fishway it is far more important than the Oconomowoc river because of the lack of dams. A dam at Rome a short distance west of the county line has flooded a large area which abounds in game fish, and there is no serious barrier to river migration in both directions nearly across the entire county (to Merton). This is especially important because of the number of lakes involved in the course of the river. One important tributary the Bark river has in Scuppernong creek, which edges in between Bark river and the moraine as the former leaves the higher ground. This stream drains a large area of swamp land, and exchanges with the Bark river an abundant fish population. Still farther to the south the Scuppernong river intrudes between the Bark river and the moraine. This river rises in Little Silver lake, a small, spring-fed body of water, and flows through a vast swamp area in the southwest corner of the county, to unite with Bark river south of the town of Hebron in Jefferson county. Within the county limits it is a small river of very soft bottom and water stained a deep brown from the decomposition of organic matter.

The Fox river rises from a series of springs in the northeastern corner of the county, a short distance north of Lannon. From here it flows in a general southwesterly direction, its valley lying between two morainic ridges. Its course takes it through regions of rock and swamp, agricultural land of high quality and regions of gravel, so that the bed of the river offers an alternation of conditions which meet the requirements of a wide range of species of fishes. Near its source it is a tiny stream with patches of Potamogeton furnishing shelter for many head-water species of minnows as well as to the grass pickerel (*Esox vermiculatus*), this representing one of the most northern records of the species. Within eight miles of its origin the river widens rapidly and becomes a stream over a hundred feet wide as it flows through the city of Waukesha. From here it traverses vast swamp areas where it receives many small tributary creeks. It abounds in carp (*Cyprinus carpio*) whose great numbers and constant activity keep the water in a constantly muddy condition. At this point its general course is almost due south, and it leaves the county as a river more than two hundred feet wide with low, boggy, undercut banks and water of a deep brown, opaque appearance. Throughout its entire course within the county its flow is unobstructed, affording excellent opportunities for fish movements in both directions. Its chief tributary is the Pewaukee river, the outlet of Pewaukee lake.

The Menomonee river rises in Washington county just north of the northeastern corner of Waukesha county, through which it flows in a northeasterly direction. It is a very small stream, flowing almost entirely through limestone (Niagara) formation. Its bed is a mass of limestone rocks which afford no footing for plant growth, so that both plants and fishes are few. Occasional areas of swamplands bound the river as it progresses eastward, and here there is an abundance of minnow life very different in composition from the other river systems, none of which are tributary to Lake Michigan into which the Menomonee empties via a short connection with the Milwaukee river within the city limits of Milwaukee. Within Waukesha county it has but one tributary stream, the Little Menomonee, which joins it from the north. Within the county there is no place at which the river is large enough to offer game fish habitation, but it is of importance to the fish fauna of the county, introducing as it does a number of species not found in the western part of the state—the Rock river and the Illinois river tributaries.

As has already been mentioned, the vast majority of the lakes of the county fall into a series of chains with river connections. There remain, however, a great number of small lakes, almost too many to count, unless one designates a minimum size as to what constitutes a "lake"—which lie outside of these river systems, and which have neither inlet nor outlet. The larger of these I have already listed. However, many small lakes abound. North of Okauchee lake lies a series of lakes, some seventeen in number, all containing fish life, which are known as the Skidmore ponds, and similar areas are found scattered over the county. All of these are relatively small in size and all occupy depressions in morainic areas. Most of them are quite deep—much deeper than their size would lead one to infer—and all are spring fed, relying upon springs and surface drainage and rainfall as their source of water supply. Many of these lakes lie in swamp areas, and are the last remnants of former lakes of considerable size,though of little depth. In many cases the former shoreline of these old bodies of water is plainly visible, being indicated by gravel terraces.

Although all of the lakes are of practically the same age, the smaller ones in many cases already show marked indications of old age. The encroachment of the shore vegetation upon the lake is very evident, as shown in the photograph of Laura Lake, while the old lake bed and an island which is now a point is clearly shown in Plate I. The larger lakes, naturally, show less evidence of ageing, though of course the process is going steadily on.

The water of all of the larger lakes is remarkable for its purity and clearness, and none of the lakes within the county suffer from the pollution so common to the lakes and streams of Illinois. The clearest of all the lakes is Upper Nashotah, with Oconomowoc second and Lower Nashotah third. By use of the Secchi disc, a white enamel disc 10 cms. in diameter, the visibility of these lakes has been tested, with the following results:

	June	February
Nashotah, Upper	605 cms.	728 cms.
Oconomowoc	587 "	697 "
Nashotah, Lower	524 "	632 "
Lac La Belle	354 "	572 "
Fowler	368 "	570 "
Nemahbin, Upper	365 "	368 "
Nemahbin, Lower	330 "	345 "
Pine	345 "	340 "
North	351 "	334 "
Pewaukee	258 "	316 "
Dutchman's	195 "	287 "
Silver	208 "	281 "
Laura	84 "	103 "

The shoreline of all of the lakes is constantly undergoing change and, although this alteration is almost imperceptible from year to year, yet it has an important effect upon the lakes. This action is two-fold: 1) that of the waves, and 2) that of the ice. The constant attack of the water upon the shores is constantly eating away the shoreline and the material thus removed is carried out to be deposited eventually in the lake. This action has in the course of time profoundly changed the shoreline of the lakes, and has built up a characteristic series of sand bars which extend around the lakes at a varying distance from the shore. This is particularly true in the case of all lakes lying in a sand-gravel formation and less true in the case of those small lakes lying in a loose, black muck soil. This muck tends to a far more uniform deposition and consequently is deposited more nearly over the entire lake bottom, and bars do not occur. Such facts are of extreme importance to the fish life of the lakes as the presence or absence of bars may in many cases mean the presence or absence of breeding grounds, which in turn limits the possible species population.

As has been stated, most of the larger lakes of the county have been surveyed by the Wisconsin Geological and Natural History Survey, and their hydrography and morphometry is well known. The results have been published by Birge and Juday (1914) and the reader is referred to this work if details are desired. The following table has been compiled from that source in order to bring the general facts into this paper for ready reference.

TABLE 1
DATA ON THE LAKES OF THE OCONOMOWOC-WAUKESHA GROUP
(Compiled from Birge & Juday)

Lake	Area in Acres	Max. Depth: Meters	Ave. Depth: Meters	Shore-line: Km	Volume: Cubic Meters.
La Belle	1,137.4	14.2	3.3	12.5	15,165,000
Fowler	83.5	15.2	4.4	1.5	1,478,500
Oconomowoc	631.3	19.1	9.5	7.5	24,303,000
Oconomowoc, Bay	170.8	15.0	7.9	3.7	5,750,000
Okauchee	1,056.7	28.6	12.1	17.9	43,721,000
Mouse	90.4	20.2	9.1	3.9	3,092,000
North, East	329.0	23.7	12.7	5.2	17,020,000
North, West	115.3	22.4	11.4	2.7	5,329,000
Pine	755.5	27.4	12.1	10.9	37,015,000
Beaver	305.5	15.0	5.1	5.4	6,312,000
Nagawicka	917.6	28.8	11.0	11.3	40,961,000
Pewaukee	2,297.8	13.8	3.9	19.5	36,694,000
Nashotah, Upper	136.8	15.6	7.0	3.5	3,885,000
Nashotah, Lower	100.5	14.1	6.1	3.0	2,498,000
Memahbin, Upper	270.9	18.9	9.0	4.5	9,958,000
Nemahbin, Lower	265.5	10.8	2.5	4.1	2,670,000
Crooked	54.8	4.8	1.9	2.9	425,000
Genesee, South	62.7	14.5	6.7	1.9	1,717,000
Genesee, North	102.0	11.1	4.5	2.4	1,865,000
Silver	231.9	13.4	4.8	4.6	4,499,000
Garvin	21.7	11.0	5.0	1.3	435,800
Otis	40.0	8.6	4.9	1.9	789,000
Eagle	211.2	1.5	. .	. . .	. . .
Keesus	236.8	12.5	. . .	. . .	. . .
Golden	256.0	13.0	. . .	. . .	. . .
Denoon	185.6	19.0	. . .	. . .	. . .
Five	128.0	5.0	. . .	. . .	. . .
Muskego, Big	2,739.0	8.0	. . .	. . .	. . .
Muskego, Little	518.4	14.0	. . .	. . .	. . .
Phantom	108.8	8.5	. . .	. . .	. . .

CLIMATOLOGY

Waukesha county lies within the zone of influence of Lake Michigan, which tends to temper the summer heat. Winds off the lake lower the temperature and tend to increase the relative humidity. Winters are ordinarily severe, with the temperature dropping as low as −28 (Jan. 17, 1924). Precipitation (Fig. 10) is abundant and affords an enormous supply of water directly to the streams and indirectly to the lakes. This causes a seasonal fluctuation in the water level of the lakes, which has a certain influence upon some species of fish. It is of particular importance to the pickerel (*Esox lucius*) as the excessive amount of water inundates the swamps bordering the lakes, affording excellent weedy breeding grounds for the species, but the drop in level occurs often before the eggs mature and a majority of them are left stranded and never hatch. During the winter the formation of the ice plays an important part in the life of the fish of some lakes—as Mud lake north of Pine lake—where, if the ice forms in excessive thickness and so completely as to leave no free water, thousands of fish of all species are killed from a lack of oxygen. Such lakes are deficient in springs, and with the cutting off of the contact between the water and air, oxygen deficiency occurs. Such a condition a number of years ago completely robbed Washtub lake of its entire larger fish fauna—sunfish, perch, bass, pickerel, carp—leaving it almost a dead lake. Winter fishing through the ice is of great importance as thousands of perch, silver bass, pickerel, cisco, white bass and wall-eyed pike are caught at a time when the species (excepting only the cisco) are heavy with spawn. The result is a serious drain on the fish population, which is offset only to a slight degree by the food value of the fish—most of the fish caught are sold in spite of the law—with the maximum amount of waste and the minimum amount of sport.

TABLE 2

CLIMATOLOGICAL DATA FOR WAUKESHA COUNTY, WISCONSIN

(City of Waukesha; elev. 864 ft.)

	1913	1914	1915	1916	1917	1918	1919	1920	1921
Maximum Temperature......	97	95	87	103	98	102	101	93	100
Minimum Temperature......	−12	−20	−23	−17	−18	−23	−21	−15	−3
Average Temperature........	47.2	43.8	43.6	45.7	42.7	46.5	46.3	45.9	50.2
Maximum Monthly Precipitation..................	7.06	6.90	10.0	6.60	7.44	5.60	6.97	4.71	9.50
Month of Maximum Precipitation..................	9	9	6	6	9	5	5	3	9
Minimum Monthly Precipitation..................	.49	?	.65	.41	.38	1.29	.32	.38	.30
Month of Minimum Precipitation..................	12	?	12	7	11	9	1	2	1
Total Precipitation..........	39.7	32.7	32.68	42.3	35.0	30.4	36.9	30.5	40.4
Total Snowfall..............	39.4	47.1	?	58.0	35.9	71.0	43.7	35.0	31.9

Mean annual temperature for 25 years...........46.0
Mean annual precipitation for 28 years..........30.16 inches.

LAKE CONDITIONS

One of the most significant features of the lake environment is the seasonal cycle which the waters undergo. These changes are both thermal and chemical, and are the direct results of atmospheric, or at least non-aquatic conditions. The prime cause of these changes is the warming of the water due to the activity of the sun's rays during the spring and summer, and the subsequent cooling again as the sun drops to the north. During the winter, when the lake is covered with ice, the aquatic environment is in a state approaching stable equilibrium and a constant temperature, equal oxygen and carbon dioxide distribution is found from top to bottom. Under these conditions there is a complete circulation of the water and, because of the uniform distribution of the gases, the entire lake is accessible—at least insofar as the gas content of the water is concerned—to fish life. This is particularly important for the deep water species as *Leuciscus artedi*, for example, as will be discussed in the section dealing with the cisco. Thus the lake starts out in the early spring with a uniform temperature normally below 4°C, and a uniform gas distribution. With the warming of the surface water, the complete circulation of the water is checked and the lake becomes divided into two regions, separated from each other by a sharp break in temperature. This break is the thermocline, the warmer region above it is known as the epilimnion, the cooler region below it as the hypolimnion. The position of the thermocline is at first in deep water, but with the continued warming of the water the thermocline crawls slowly upward until in mid-summer the hypolimnion greatly exceeds the epilimnion in depth. These temperature changes which check the free circulation of the water result in marked changes in the gas content of the water, as the oxygen content cannot be restored, nor the carbon dioxide distributed. The result is that the hypolimnion becomes an area deplete in oxygen and replete in carbon dioxide, forming a region into which fish may venture only for a short period of time. Thus, through the formation of the thermocline, a large portion of the lake becomes unsuited for fish life, and a consequent movement of the deep water fish to shallower waters results. This seasonal cycle has been well worked out for many Wisconsin lakes by Birge and Juday, including many of the Waukesha county lakes.

The importance of these seasonal changes in oxygen, carbon dioxide content and temperature variations of the water will be fully discussed in their relation to the distribution of fish life in the section dealing with the life history of the cisco (*Leuciscus artedi*). Suffice it here to say that the behavior of the thermocline offers barrier conditions which force the deep water species of fish to leave the deep places and seek more favorable conditions of gas content of the water. The serious results which accrue when the thermocline forces these deep, cold water species up into the zone of warm surface water to which they are not tolerant, will also be discussed in that section.

Still another problem that assumes an important rôle in the life history of various fish is the hydrogen ion concentration of the water. Insofar as the lakes are concerned, the range of variation is not great within the county, all of the lakes investigated being alkaline from the surface to the bottom. This is in spite of the acid condition of much of the spring water which forms one of the main sources of water supply to the lakes. Throughout the summer of 1923 a total of 634 hydrogen ion concentration determinations were made by the colorimetric method in the various lakes, at different depths, day and night. During the first ten days of February, 1924, a series of 160 readings was made to determine the winter conditions in respect to the ionic concentration. In collecting the samples of water for the determinations, a special apparatus designed by Shelford (1923) was used, consisting of a specially designed pump with two-way pet cocks, by means of which a vacuum is established within a small test tube and a sample of water drawn in without contact with air. Into this tube the two drops of indicator were injected through a rubber membrane by means of a hypodermic outfit, and the concentration read and compared with the standard series of tubes. A long rubber hose with a hole diameter of 1 mm. was used in bringing up the sample, and for bottom work a pan designed for the purpose of confining a local area of water assured the sample being of the region desired.

The results of the field work show that there is a definite relation between oxygen content of the water and the H-ion concentration, which may be stated: 1) As the oxygen content of the water *decreases*, the H-ion concentration *increases*. 2) While ordinarily there is an increase in CO_2 accompanying a decrease in O, the H-ion concentration seems to bear very little if any relation to the CO_2 changes: that is, changes in O are regularly accompanied by changes in the H-ion concentration in the opposite direction, while changes in the CO_2 content either may or may not be accompanied by a change in the H-ion concentration.

The following table, 3, gives a partial summary of a part of the data:

TABLE 3

Showing Gas and Temperature Conditions at Different Levels in Characteristic Wisconsin Lakes

Date	Lake	Depth in meter	pH	O	CO_2	Temp.
June 12, 1923	Oconomowoc	0	8.3	10.1	−3.0	22.1
		5	7.7	10.8	−2.2	18.2
		10	7.6	8.6	1.5	13.8
		15	7.3	5.6	1.7	9.6
		20	7.3	5.1	1.7	5.6

June 29, 1923	Oconomowoc	0	8.2	10.3	−3.1	23.0
		5	7.8	10.1	−1.9	19.3
		10	7.3	5.6	−1.2	14.7
		15	7.2	5.5	1.8	9.2
		20	7.2	5.2	1.6	5.4
July 1, 1923	Lac la Belle	0	7.9	6.2	0.8	27.3
		5	7.8	6.6	−0.2	25.7
		10	7.8	5.9	0.6	13.6
		15	7.3	4.4	1.2	9.4
July 25, 1923	Oconomowoc	0	8.2	8.1	−4.3	28.6
		5	7.5	6.8	−4.2	23.1
		10	7.5	5.6	−1.2	15.2
		15	7.2	1.7	1.1	8.0
		20	7.2	1.1	1.0	6.9
August 24, 1923	Oconomowoc	0	8.2	7.6	−6.2	30.4
		5	8.0	6.8	−4.1	26.8
		10	7.4	1.0	1.0	13.7
		15	7.2	0.7	1.7	9.1
		20	7.1	0.1	2.1	7.4
February 3, 1924	Oconomowoc	0	7.8	7.4	1.9	2.9
		5	7.6	7.4	1.9	3.5
		10	7.6	7.4	1.9	3.5
		15	7.6	7.4	1.9	3.6
		20	7.5	7.4	1.7	3.6

The work of Shelford (1923), Powers (1921), Wells (1915), and others has indicated that the H-ion concentration plays an important rôle in the distribution and behavior of fishes. That this is true has been demonstrated by the writer both in the laboratory and in the field, and will be discussed in considerable detail in the subsequent sections of this paper, and in later papers dealing with the life histories of the different fishes.

ECOLOGICAL HABITATS OF FISHES

It is well to glance for a moment at the various aquatic habitats existing within the area. For this purpose one can divide the fresh water environments as follows:

- I. Rivers and streams.
  1. Rapids or rock-bottoms.
  2. Sand or gravel-bottoms.
  3. Silt, or sluggish-streams.
     - a. Bare bottom.
     - b. Vegetation.
- II. Lakes.
  1. Open water.
  2. Eroding rocky-shores.
  3. Depositing sandy-shores.
  4. Vegetation.
     - a. Submerged vegetation.
     - b. Emerging vegetation.

Rapids or rock-bottoms: In this group one finds those species which are found commonly associated with swiftly flowing water which, in the region under discussion, is normally over a rock bottom. These fish have a common ability to maintain themselves in the swiftly flowing water, and agree in an ecological sense in at least two factors: 1) a thigmotactic reaction to large objects; and 2) a positive rheotaxis. Among the most typical fishes are the darters, the miller's thumb, the stonecat and the hog-nosed sucker.

Sand or gravel-bottoms: Normally a habitat of less swiftly flowing water and a bottom of finer material than the preceding. This is the habitat which comprises most of the rapid water streams of the region. It is for the most part without heavy vegetation, though islands of Potamogeton and other aquatic plants intrude and afford regions of very temporary shelter to the fish of the open waters. Here one finds the chubs, shiners, various species of darters and stone rollers as typical species.

Silt or sluggish-waters: These are the waters found commonly in regions where the streams traverse swampy lowlands. The banks are usually steep, the bottom offering very uncertain footing to one who would seine. The current is slow and sluggish, the water often a dark color both because of the organic matter in solution and because of the black silty nature of the stream bed. The non-vegetated areas are in this condition because of the lack of solid bottom for the insertion of the roots of aquatic plants, and the shifting nature of the bottom material. Such habitats ordinarily have fairly deep water, and are inhabited by carp, suckers, pickerel and a few darters. The vegetated associations are of a similar structure but with a bottom hard enough to afford footing for Potamogetons, Elodea and various other aquatic plants, including masses of filamentous green algae.

Open waters: The deep water habitats of the lake, and including everything from the surface over deep water to the bottom. These are the least populated habitats of the lake; the fish are mostly suckers and ciscos on the bottom, and silversides and gar on the surface, with a large zone between which is for the most part uninhabited by fishes or at best receives but a transient population. The lower regions of this habitat are rendered uninhabitable during the summer by the formation of the thermocline.

Eroding rock-shores: For the most part shallow water habitats, which are characterized by the eroding action of the waves. These are rough of bottom, and afford certain ecological affinities with the rocky-bottom communities of the streams and rivers. Vegetation is practically lacking, due to the character of the bottom and the action of the waves. It is the home of various darters, minnows of many species and the young of several species of the Centrarchidae.

Depositing sandy-shores: Another habitat scanty in vegetation, this time because of the constant deposition of sand and shore material by the water. The bottom is much less rugged, and shows affinities to the sand and gravel-bottom stream communities. (Fig. 4.)

Vegetation covered areas: These are characteristically of two kinds: 1) the submerged vegetation of the mediumly deep water; and 2) the emerging vegetation, characteristically in shallow water. The submerged vegetation reaches its maximum depth at the edge of the sand bars in water of from fifteen to thirty-five feet in depth, depending on the specific character of the lake. Here great beds of Potamogeton, Nymphaea and Vallisneria afford the normal habitat of the basses, pickerel, dogfish, adult sunfishes, silverbasses and other species. The zone of emerging vegetation, largely rushes, arrow-head and lilies, offers protection to hosts of minnows and the young of many of the larger game fishes.

FISHES OF SOUTHERN WISCONSIN (WAUKESHA COUNTY)

Order RHOMBOGANOIDEA

Family LEPISOSTEIDAE

1. *Lepisosteus osseus* (Linn.). Long-nosed Gar; Billfish.

Common in all of the larger lakes in the Oconomowoc and Bark river systems, as well as in Pewaukee and Ashippun lakes. During the greater part of the year the gar is a characteristic species of the topmost stratum of the pelagic environment. A gregarious species, it spends most of its time just under the surface, most commonly over deep water. In the spring and during the breeding season (May and early June) the fish often ascend the rivers to spawn, or deposit the eggs over the weed beds of the shallower waters. The young hatch in from six to eight days, depending upon the temperature of the water, and show a marked tendency to come inshore shortly thereafter. During late June young gar two inches or less in length are often taken from weeds by means of minnow seines drawn along the lake shores. Their growth is very rapid, the young fish attaining a length of five to six inches by the end of the first summer. As they grow, they tend to leave the shore environment and assume their position over the deeper water. The food of the adult is almost exclusively minnows, such as *Labidesthes sicculus*, *Fundulus notatus*, *Notropis blennius*, but the young of game fish are sometimes found in stomach examinations. Thus I have taken *Micropterus salmoides*, *M. dolomieu*, *Leucichthys artedi* and *Roccus chrysops* on numerous occasions. The food of the very young consists almost entirely of entomostraca of a variety of species, but very small minnows appear early in the diet of the fish. About 50% of the food of a gar two and a half inches long is fish life. Minnows are always captured sidewise, after which the gar is likely to descend to a considerable depth while the prey is juggled about and worked into position to be swallowed head first. Economicaliy, the species is of little importance; they are of no food value and do considerable damage by the destruction of the young of food fishes.

The short-nosed gar, *Lepisosteus platostomus* Raf., has not been taken by me within the county, but there are records of the species from Rock river near the mouth of the Oconomowoc river, only a short distance from the Waukesha county line.

Order CYCLOGANOIDEA

Family AMIIDAE

2. *Amiatus calvus* (Linn.). Dogfish; Bowfin.

A very common species in practically every lake of any size in the county. An inhabitant of weed beds, the dogfish is found most commonly just over the edge of the bars where heavy beds of Potamogeton offer a congenial environment. Breeding begins early, probably often late in April but more frequently early in May, the nesting site preferred being weed beds in water from three to five feet in depth. As I have seen many nests guarded by the parent fish, I conclude with Reighard that it is always the male that protects the nest and guards the young after they leave the nest. The eggs hatch in from nine to twelve days, depending upon the water temperature, and the young fish remain for a little over a week within the confines of the nest. Thereafter they all leave the nest together, traveling in a compact mass and zealously guarded by the very pugnacious male. As the young grow, the compactness of the school slowly lessens until, when the young are nearly four inches long, the mass formation disappears and the young go about their business on their own responsibility. While guarding the young, the male dogfish will attack anything that threatens the precious mass of youngsters. I have had the parent attack nets, rakes, sticks—anything I thrust toward the ball of young; a vicious attack, a strike at the intruding object, and a dash away to a distance of about six feet; a swift turn and another vigorous attack. During this performance by the old fish, the school breaks up in every direction, the young going to the bottom and scurrying toward deeper water under the protection of the vegetation. The food consists entirely of animal matter, varying between fish and crayfish at different seasons of the year, the late summer and fall finding the latter the dominant food. Among the fish, over and above many species of minnows, which I have taken from the stomachs are: *Lepomis pallidus*, *Lepomis gibbosus*, *Micropterus salmoides*, *M. dolomieu*, *Perca flavescens*—in fact, small specimens of all of the game or food fishes. Economically, then, inasmuch as the dogfish is never considered as of any food value in this region, it must be classed as a species destructive of game fish. Commercial fishermen always destroy every gar and dogfish they catch in their nets. The species attains considerable size, specimens that I have taken weighing as high as eight pounds.

Order ISOSPONDYLI

Family SALMONIDAE

3. *Coregonus albus* (Le Sueur). Whitefish.

The whitefish is not a native of the inland lakes, and is included in this list because an attempt was made to introduce the fish, an effort which was only temporarily successful. In 1887, according to the report of the game warden department, 350,000 whitefish were planted in Oconomowoc lake. Nothing was seen of the fish for several years. About 1891 whitefish were caught in winter by fishermen working through the ice, along with ciscos, from which they apparently were not distinguished. The weight at this time was four and five pounds. During the few years following, the original planting was entirely caught out, and there is no evidence of the whitefish ever having reproduced while in the lake. The writer has examined many thousands of ciscos caught in this lake during the winters but has never seen any sign of the whitefish. It is concluded that the species has become extinct. The inland lakes of southern Wisconsin are not of sufficient depth or coldness to accommodate whitefish, the thermocline forcing the deep (and therefore cold) water species into near-surface water of a temperature too warm for their existence.

4. *Leucichthys artedi* (Le Sueur). Cisco.

The cisco, a deep water fish, is confined to those bodies of water having a considerable depth. I have taken ciscos from the following lakes: Lac La Belle, Fowler, Oconomowoc, Okauchee, North, Pine, Nagawicka, Upper and Lower Nashotah, Upper Nemahbin, Golden and Dutchman's. Of these, La Belle, Oconomowoc, Okauchee and Pine contain the species in the greatest abundance at the present time. Lower Nashotah and North lake ciscos average the largest in size, while Pine lake is literally full of small ciscos averaging not over a fifth of a pound. In the other lakes mentioned, the numbers are not great. When cisco fishing first began, the average size of the catch was somewhere around two and a half pounds each; today a cisco weighing a pound causes a sensation and is an object of admiration. As a result of observations during winter fishing over a long period of years, I come to the conclusion that Oconomowoc lake alone yields not less than 40,000 ciscos each winter.

The cisco normally inhabits the deepest and coldest parts of the lake. With the formation of the thermocline, however, the fish are forced up from the depths into water uncongenially warm. During exceptionally hot summers the fish are forced into water so warm that they can not adjust to it, the result being "epidemics" of dead fish, during which seasons literally thousands of ciscos perish in each of the lakes so affected. I have witnessed this in Oconomowoc, Pine and Okauchee lakes during the last six years. The summer of 1925 witnessed such an epidemic in Okauchee lake. On September 1 I counted 72 dead ciscos on ten feet of shoreline! The entire lake shore was strewn with dead fish, and after a careful survey, an average of two and a half fish per foot of shoreline was estimated. Since Okauchee has 8.1 miles of shoreline, it is estimated that on that date there were no less than 116,700 dead ciscos on Okauchee shores. The epidemic lasted for about six days, which gives some idea of the toll taken of the species. During the winter, when the thermocline does not exist, ciscos are normally caught in water 45 to 55 feet deep.

Spawning occurs in the fall, usually early in November, at which time the fish come into the shallow water along the shore or ascend the rivers to lay their eggs. Development follows very slowly, the young fish hatching sometime early in the spring, probably just prior to the breaking up of the ice. The young ciscos go immediately into deep water. The food consists almost entirely of plankton organisms, principally Cyclops, Daphnia, Diaptomus, Bosmina, Chydorus, rotifers and other organisms of a similar nature, as well as large numbers (in one case 376) of *Sayomia albipes* larvae. From an economic point of view, the cisco is a valuable food fish, particularly in the winter when the meat is firm and solid. Every effort, including the artificial propagation of the species, should be exerted to save these fish which are rapidly nearing the point of extermination. While the fish remain in deep water they have but few natural enemies; when they come into the shallower regions they are preyed upon voraciously by large pickerel (*Esox lucius*) and to a lesser extent by the gar (*Lepisosteus osseus*).

5. *Oncorhynchus tschawytscha* (Walbaum). California Salmon, or Chinook.

Like the whitefish, this fine species was introduced into Oconomowoc lake, but without success. The state fish commission reports show that in 1877, 4,800 fingerling California salmon were planted in this lake, and in 1879, 1,500 somewhat larger individuals were liberated in Nagawicka lake. Some of the fish were caught in the years immediately following, but the fish never reproduced and are now entirely extinct. The lakes are not cold enough to accommodate these fish, so that such transplantations are utterly fruitless.

6. *Salmo sebago* (Girard). Landlocked Salmon.

In 1879 the reports of the state fish commisson at Madison show that 12,000 of these fish, in fingerling size, were planted in Nagawicka lake. Like the above species a few were caught shortly after the transplantation occurred, these weighing in the neighborhood of a pound to a pound and a half, but the species failed entirely to establish itself and quickly became extinct.

7. *Salmo irideus* (Gibbons.) Rainbow Trout.

The rainbow trout is not a native species in southern Wisconsin, but, notwithstanding this fact, the transplantation of the fish into the suitable trout streams of the county has resulted in the firm establishment of the species. Planted in such admirable streams as Rosenow's creek, flowing into Lac La Belle on the east, and Scuppernong creek farther south, the rainbows have bred and successfully maintained themselves amid the water-cress beds and the clear, cold spring water. Traveling down stream, the fish have entered various lakes, so that at least two—Lac La Belle and Dutchman's—contain the species in some numbers. I believe that I have taken the record rainbow for the county: a fish weighing four and three-quarters pounds, from Dutchman's lake, August 29, 1912. Since then many smaller specimens have been taken from that lake. The seining of Lac La Belle for carp has revealed the presence of many fine rainbows in that lake. So far as I can see, the planting of the fish has in no way altered their breeding habits. Those fish that are in the lakes have been repeatedly seen going up the trout streams during the breeding season. The food of the fish consists almost entirely of insect life—flies, gnats, caterpillars, grasshoppers—anything that drops upon the surface is eagerly snapped up. Nothing need be said of the high quality of the rainbow as a food fish, and it is to be hoped that continued and enlarged plantings will proceed.

8. *Salmo fario* (Linn.). German Trout; Brown Trout.

Like the rainbow, an introduced species. Scuppernong creek, together with Waterville and Rosenow creeks, are the main sources of this very fine trout, which seems to do exceedingly well in its new environment. Dutchman's lake contains some very fine specimens up to three and three and a half pounds, and Lac La Belle likewise harbors some fine individuals. Under existing conditions, the brown trout seems to grow somewhat more rapidly than the rainbow, but tends to average about the same in ultimate size. I have records of several weighing between three and four pounds, taken mostly from the Rosenow stream, and a record of one "whopper" caught by Dr. F. F. Maccus, which weighed $4\frac{1}{2}$ pounds. A fine fish, whose table qualities, however, hardly equal those of the rainbow trout.

9. *Cristivomer namaycush* (Walbaum). Great Lake Trout.

Another fish that was introduced in the early years of experimental transplantation. Like the California and Land-locked salmon, the lake trout was planted in lakes in the county. The records give no account of which lakes were stocked, but probably Oconomowoc and Nagawicka were the ones chosen. In 1877 and 1878 some 690,000 young were liberated. There is no evidence that any survived and it is certain that not one exists to-day. This is another well-intentioned experiment which went wrong because of the unsuitable lake conditions. These northern species can not withstand the warm water and relatively shallow conditions which exist in Waukesha county lakes.

10. *Salvelinus fontinalis* (Mitchill). Brook Trout; Speckled Trout.

Brook trout have been introduced into a great many spring fed streams throughout the county and there are few which meet the requisite conditions of cold, fast water which do not contain the species in some abundance. Scuppernong, Waterville and Rosenow creeks abound in brook trout from six to ten inches in length, and an occasional "monster" weighing over a pound and a half. I have records of three brook trout weighing over two pounds: $2\frac{1}{4}$; $2\frac{3}{8}$; $2\frac{5}{8}$. I can see no modifications of general habits of these transplanted fish. Their food, behavior, breeding habits, all are similar to those I have observed on the same species in their home environment. If these trout leave the streams and enter the lakes, I have little evidence to show for it. Nets drawn in Lac La Belle have shown me only two brook trout, but this may be due to the smaller size of the fish and their consequent escape through the mesh of the nets. However, I am inclined to believe that the species shows less tendency to migrate than either of the other common trout—the rainbow and the brown.

Order APODES

Family ANGUILLIDAE

11. *Anguilla rostrata* (La Sueur). Eel.

The eel is a rare fish in the Waukesha county lake district. During the years I have been gathering data on the fishes I have seen but five eels taken in the county, though there are records of an equal number at least that have been hooked, lost or seen. Four of the fish I have handled come from Lac La Belle, under the falls at the outlet of Fowler Lake. These fish measured: 2 feet 9 inches, 3 feet 6 inches, 3 feet 7 inches, and 4 feet 2 inches in length. Two were caught at night by men fishing for white bass in late May, worms as bait; the other two were speared. The fifth specimen came from the Oconomowoc river at the outlet of Lac La Belle and was speared. I have no doubt but that eels are more plentiful than these data seem to indicate, but these are all the records I have.

Order EVENTOGNATHI

Family CATOSTOMIDAE

12. *Ictiobus cyprinella* (Cuv. & Valen). Big-mouth Buffalo; Buffalo-fish.

This, the commonest of the buffalos, is found in those streams tributary to the Rock River, in which water it is more common than in any of the Waukesha county streams. Found also abundantly in the Fox river, particularly south of the city of Waukesha. A fish of considerable size, often reaching ten pounds, it is taken in nets during carp seining and never, so far as I know, on hook and line. I have seen the fish taken from the Oconomowoc river near its entrance to the Rock, and in Lac La Belle, but never in numbers. My figures show an average of 91 carp (*Cyprinus carpio*) to 1 of this species. The food consists almost entirely of vegetable matter—algae, leaves and seeds of aquatic plants (Potamogeton, Elodea, etc.), together with a considerable number of zooplankton organisms, insect larvae (Chironomus) with mollusca represented occasionally by small Sphaerium. These forms are all sucked in and strained out of the water by the gill rakers which pass the mud and silt out with the water. Locally the fish are not looked upon with much favor as a food fish, there being plenty of bass and other high grade food fish available, but they bring a good price when shipped by commercial fishermen.

13. *Ictiobus urus* (Agassiz). Round Buffalo; Mongrel Buffalo.

The various species of buffalo fish inhabiting local waters are not distinguished by local fishermen. This species is far less common than either the preceding or the following, and I have seen it only twice, both times from Lac La Belle, into which it has undoubtedly come directly from the Rock river. These two seinings yielded 7 of the species weighing from 3 to 5¾ pounds. The food and habits are almost identical with those of the preceding species, though a distinctly greater proportion of the food seems to be mollusca—Sphaerium, Valvata, Planorbis and Pisidium predominating.

14. *Ictiobus bubalus* (Raf.). Small-mouthed Buffalo; Quillback.

This is distinctly a deeper water species than either of the other two buffalo fish, and has been taken from the deep holes in the Fox river near Waukesha and in Lac La Belle. The species is much more common in the Rock river where conditions seem to be more congenial. A smaller species than either of the preceding, the small-mouthed buffalo averages about 4½ pounds within the region under discussion, though I have seen one specimen from the Fox river that weighed 13 pounds. The food consists of about equal parts of animal and vegetable matter, the former being algae, Potamogeton, Ceratophyllum, the latter entomostraca, crustacea (small crayfish occasionally, as well as zooplankton), and in one instance, bass eggs (*Micropterus salmoides*). The buffaloes are all considered valuable food fish, greatly preferred to carp (*Cyprinus carpio*) but none are eaten especially eagerly in this vicinity.

15. *Capriodes velifer* (Raf.). Quillback Carp; Silver Carp.

Not common within Waukesha county, but occurring in the Oconomowoc river between Lac La Belle and the outlet into the Rock river; the Fox river west of Duplainville and down the river to the southern county limits; and in Lac La Belle. A small species which, when caught in nets, is not distinguished by the fishermen from the buffaloes, and it has no value as a food fish, the average size being under 12 inches. Its food consists very largely of vegetable matter—fragments of aquatic vegetation and algae, with occasional insect larvae (Chironomus) and quite a variety of gastropod mollusks (Planorbus, Physa) and small clams, mostly young individuals. It is distinctly a shallower water form than the buffaloes.

16. *Erimyzon sucetta oblongus* (Mitchill). Chub Sucker.

The first records I obtained of this species, and for a long time the only records, came from the Menomonee river in the northeast corner of the county, a stream draining into Lake Michigan. Here the species is not uncommon and it was only in 1924 that I discovered the species in Fowler lake, the only other record I have. The fish is small in size; five inches is the longest individual I have taken, the majority being under four inches long. In the river habitat they prefer flowing water of not great depth, where they have the darter habit of maintaining their position on the gravelly bottom by means of the pectoral and pelvic fins, head upstream. In Fowler lake, however, I have seen no indication of this habit, the fish behaving in normal minnow fashion. They are bottom feeders, taking in much silt from which the plankton organisms are strained and retained as food. Diatoms, algae, Sphaerium, small bivalves, Physa and Planorbis, insect larvae and an occasional insect form the chief items of food, the vegetable matter dominating to the extent of about 70%. Of no value as a food fish because of its small size.

17. *Catostomus commersonii* (Lacepede). Common Sucker.

A common sucker in the Oconomowoc, Ashippun, Bark, Muckwonago and Menomonee river systems, being almost wholly confined to these streams. In the rivers the fish attain a length of from 10 to 12 inches, rarely more, but I have taken specimens 13 and 15 inches long from Oconomowoc lake. Those individuals which inhabit the lakes of these river systems often ascend the streams soon after the ice goes out in the spring, and spawn on the riffles, usually about the middle of April. The young remain for the most part in the rivers, going down to the lakes only when they are nearly fully grown. That some of the fish spawn in the lakes is indicated by the presence of young fry taken in minnow nets along the shores of Oconomowoc, Silver, Golden, Keesus, Pine and La Belle lakes. The chief economic value lies in their being used as food for bass, pickerel and other valuable food fish.

18. *Hypentelium nigricans* (Le Sueur). Hognosed Sucker; Stone-roller.

This sucker is confined strictly to the rivers, and I have no lake records for the species. The Bark river contains the greatest numbers of these interesting fish, and I have taken them in the Oconomowoc river as well. They show a preference to swiftly flowing water, avoiding those reaches of the river where silty bottom or deep water slows up the current. Like the darters they come to rest heading upstream, the large pectoral fins acting as a brace against the current. Very fast of movement, when disturbed they dart off at great speed, but only for a very short distance, while the dark mottled coloration of the back acts as a protection, rendering the fish almost invisible against the mottled river bottom. The food consists almost entirely of animal matter, largely insects and larvae, with only a small proportion (6%) of mollusca, and 12% of vegetable material. Of no economic value.

19. *Moxostoma aureolum* (Le Sueur). Common Red-horse.

A very common sucker of the Rock river, the red-horse is found in all streams tributary to the rock, and only as far as dams prevent their distribution. Thus they are found abundantly in the spring in the Oconomowoc river as far as the Lac La Belle dam, where many are speared every year. The Ashippun river and the Bark river, together with the Scuppernong river also contain red-horse and the fish are caught in some numbers from all of these streams. They are used as food by many, but during the summer (August) when they can be caught on hook and line, the meat is soft and of poor keeping quality. Though the average weight is about two pounds, I have taken specimens weighing $3\frac{3}{4}$ and $4\frac{1}{2}$ pounds. The smaller individuals are occasionally found in the stomachs of wall-eyed pike and pickerel, and less frequently in the black and green bass. While the species may prefer clear water and a gravel bottom, the fact that they are found in water rendered turbid by the activity of the carp, speaks for a wide range of tolerance if no actual impurities exist. They can not stand pollution.

20. *Moxostoma breviceps* (Cope). Short-headed Red-horse.

Somewhat less common than the preceding, though of the same distribution, this species is not separated ordinarily by local fishermen. I have taken the species in all of the rivers named for the preceding, but the fish are more numerous in Rock river and in the Rubicon river in Dodge county to the north.

Family CYPRINIDAE

21. *Cyprinus carpio* (Linn). German Carp; Leather Carp.

"The day will come when the people of the state (Wisconsin) will thank the men who have introduced and planted this extra fine species of fish (carp)." So said Dr. Lapham in a paper published in 1882. Since that time, this "extra fine" species of fish has spread to almost every lake in the county, and is in all the river systems. So abundant has it become in certain lakes (Lac La Belle) that periodic seining is necessary to save the game fish and their protecting weed beds. There is no mystery as to how the carp has become so widely distributed: young carp were formerly used as bait (being easily caught in the rivers) and being tenacious of life, the minnows left over were thrown overboard, to live and establish themselves. It is difficult to name a single lake in the county that does not contain carp. The only one of the larger lakes in which I have never seen a carp is Oconomowoc lake, on which I have lived for twenty-two summers. Yet Okauchee which flows into it, and Fowler into which Oconomowoc flows, both contain carp, and the rivers between are alive with them. The average size of carp in the county is from four to six pounds, though I have weighed specimens from Lac La Belle that went to 31 pounds, and the Rock river contains specimens up to 42 pounds. The fish prefer soft-bottomed lakes, in which they nose around, much like so many pigs. The result is the uprooting of the vegetation, the destruction of weed beds, and the dispersal of the game fish that habitually frequent such beds. Not only this but the water is muddied by the digging to such an extent that in many cases it is opaque. This sediment of course tends to settle over deposit-eggs, and many are destroyed. I had opportunity in 1924 to examine the entire fauna of a large lake as it was drained, and in a future paper I shall show just how the carp affects a lake.

Spawning is in late May or early June, the carp coming into the shallow waters and depositing their eggs in tremendous numbers on the shallow water plants and roots of trees that may extend out into the water. Thus I have seen roots of willows so loaded with eggs that the roots themselves were invisible. There is a very high mortality among the eggs, many of them dying before gastrulation takes place. The young carp, like the old, are gregarious, and often come up into the shallow waters along the shore. I recall a school that tried to ascend the Oconomowoc river from La Belle. In a single dip with a net twelve inches in diameter, I scooped out 291 carp. Growth is rather slow; by the end of the first summer the fish are just approaching four inches. The food consists of a tremendous amount of bottom debris which is sucked in and the minute organisms strained out. The fish bite readily usually on such bait as clam meat and put up a very vigorous fight. A carp caught on a fly rod is about as good sport as one could ask for. As a food fish it is little used, though many of the farmers "put them up sour" as they are not bad. However, the damage they do outweighs their food value so far as local consumption goes, though the commercial seiners, catching anywhere from five to fifteen or twenty tons a year, make good money selling them outside of the state at eight cents a pound. A determined effort should be made to rid the lakes of the carp, and then to keep them out. This can be done if systematically undertaken.

22. *Carassius auratus* (Linn.). Goldfish.

Although, of course, an aquarium fish, many goldfish have been liberated in Oconomowoc and La Belle lakes, where they have established themselves, reproducing in considerable numbers. Two schools of large fish, weighing up to two pounds, exist in La Belle, and one school in Oconomowoc lake. That the fish are breeding successfully is indicated by the varying sizes of the individuals forming the schools, and by the presence of individuals under three inches in length. They frequent the deep water off the bars during most of the year, but spring (late April and early May) finds them up in the shallows, where they are quite a sight for a few days.

23. *Campostoma anomalum* (Raf.). Stone-roller.

A very common minnow of the Ashippun, Bark, and Menomonee rivers, with a few of the species found in almost any gravelly stream. They avoid muddy or stagnant water entirely, being most abundant just under rapids of clear water. They attain a size of five inches, rarely more, though the average is not over four inches. In June the males of the species, in full nuptial coloration and adorned with tubercles over the entire body, can be seen carrying stones for the construction of the nest. Many small pebbles measuring up to $\frac{3}{4}$ inch in diameter, are carried in the mouth upstream to a clear gravel area and deposited in a pile eighteen inches in circumference. In Bark river I have seen piles of nearly half a bushel above the nest. The work is done entirely by the males and it would appear that several work together on a single nest. The food consists entirely of vegetable matter, mixed with a large amount of fine mud and silt, all of which is passed through the digestive system. Algae, diatoms, desmids and particles of larger aquatic plants are the principal food I have found. The species is hardy and makes very good casting bait. An inhabitant of shallow water, it apparently has few enemies among the fishes, though many are eaten by herons and bitterns.

24. *Chrosomus erythrogaster* (Raf). Red-bellied Dace.

One of the most beautiful of our fresh water fishes. The brilliant coloring of the male, together with the very fine scales, has confused the species in the local minds with trout, for which it is often mistaken. It is abundant only in the Ashippun river, but occurs sparingly in the Oconomowoc and Scuppernong rivers. In the Ashippun it is found over gravel bottom, in clear, running water and associated with *Notropis cornutus* and *Hybopsis kentuckiensis*. Breeding occurs late in May or early in June, and the male carries traces of his brilliant red belly late into the summer. The food consists entirely of entomostraca, algae and particles of aquatic vegetation, with an occasional Hyalella or Gammarus.

25. *Hybognathus nuchalis* (Agassiz). Silvery Minnow.

A very rare species, recorded only from the Menomonee river, and therefore found only in the Lake Michigan drainage area. Three specimens are all that I have taken. These came from water slightly muddy in quality, over a fine silt bottom, and with only slight current. Two specimens were examined for food, and showed an abundance of entomostraca, diatoms and algae (mostly Spirogyra) abundantly mixed with fine silt.

26. *Hybognathus nubila* (Forbes).

Another rare species, found most commonly in the Scuppernong creek, where I have taken thirty-eight specimens. The water here is dark grayish brown in color due to a large amount of fine silt and muck in suspension. The bottom is soft, the water eighteen inches deep and normally with little current. The food seems to consist almost entirely of algae (Spirogyra, Zygnema, Closterium) with occasional entomostraca and small insect larvae. Nothing is known of the breeding habits.

27. *Pimephales promelas* (Raf). Fathead Minnow.

Like *Hybognathus nuchalis*, with which it is associated, this species is recorded only from the Menomonee river, where, however, it is extremely abundant. In this river it is the dominant fish species, and I have taken two hundred or more in a single sweep of a minnow net. It is most common in muddy water, and entirely absent from those parts of the river flowing over clear gravel. It is a bottom feeder, apparently grubbing in the soft bottom for insect larvae which form over 90% of its food. The species breeds in June, usually rather late in the month, the nests being shallow depressions near or under the banks. In this region the fish are characteristically infected with the small black cysts of a fluke probably *Diplostomu-*

lum cuticola, so heavily, in fact, that the fish often appear entirely black in color.

28. *Hyborhynchus notatus* (Raf.). Blunt-nosed Minnow.

One of the very commonest of the local minnows, found in nearly every lake and every stream. It shows little preference as to lake or stream habitat, but is distinctly more abundant in clear than in muddy water. It prefers the shallows, seldom venturing into water more than three feet in depth, and in the lakes, at least, is most often taken in water of a foot or eighteen inches in depth. The fish breed in June, though I have found females carrying eggs well into July. The eggs are laid on the underside of stones, cans, boards, or even pieces of paper provided the material is not actually buried in the bottom. How the eggs are deposited in this position I can not say. I have taken many nests along the shores of Golden and Oconomowoc lakes, with invariably one of the parents on guard, usually the male, as can be told by the group of tubercles on the snout. The eggs hatch in eight or nine days in water varying from 70° to 75°F. The fish are used abundantly as bait for bass, perch and silver bass.

29. *Semotilus atromaculatus* (Mitchill). Horned Dace; Chub.

Abundant in the Ashippun, Oconomowoc, Bark and Fox rivers, together with such of their tributary streams as afford congenial environment. Very gregarious, these minnows are found in schools of many hundreds, or at times thousands, in streams of moderately swift water and gravel bottom. During the warm weather, when the water level of the streams lowers, the minnows retire to the deeper holes, from which they are easily caught on hook and line with small angle worms as bait. Breeding occurs in early June, nests being constructed of much the same type as those of *Camposto-ma anomalum* with which they are frequently associated. This species, together with *Hybopsis kentuckiensis*, is the best bait available for bass, pike and pickerel, and many thousands are captured in the glass minnow traps for this purpose every year. So long has this been going on that the species is in danger of extermination in the not far distant future. A very game minnow, they feed on animal matter entirely, a large part of the food being insects which fall upon the water.

30. *Clinostomus elongatus* (Kirtland).

This exquisite fine-scaled minnow has been taken by me only in the Menomonee river, and is therefore represented only in the Lake Michigan drainage area. In this river it is associated with *Pimephales promelas* and *Hybognathus nuchalis*, inhabiting slightly muddy water of 18 inches depth and little current. The species is not common, and I have taken only 10 specimens. The food consists of entomostraca, with a few insects and insect larvae and quite a bit of algae (Spirogyra). The spawning apparently occurs in June as I have a specimen heavy with eggs taken June 14. It is rather surprising to find this species so far west; until I obtained my specimens I believe that Michigan was considered the western limit of its range.

31. *Opsopoeodus emiliae* (Hay). Small-mouthed Minnow.

Rather an uncommon species, taken by me only in the Oconomowoc and Ashippun rivers. Small in size—usually under two inches—the fish often escapes notice, as it frequents water somewhat muddy in quality and of considerable depth. In the Ashippun the species inhabits the deeper holes over soft bottom, where the fish feed upon entomostraca and small crustacea such as Hyalella.

32. *Notemigonus crysoleucas* (Mitchill). Golden Shiner.

A species with a very peculiar distribution within the county. For a long time I knew it only from Washtub lake, where it is extremely abundant. In 1924 I found it in shallow weedy water along the shores of Lac La Belle, and in 1925 I took it from shallow water weeds in Oconomowoc lake. In Washtub, which is a small lake nearly choked with weeds, the species seems to be at its optimum. The fish reach a length of four inches or less, and are not particularly hardy if used as bait. A great variation in color exists locally. Those from Washtub are very dark with a brassy tinge, while those from La Belle are very light and show almost no trace of yellow. The food consists largely of entomostraca Hyalella, with a large number of young water-boatmen (Corisa sp.) and backswimmers (Notonecta sp.), and occasionally young leeches (*Placobdella parasitica*). Aquatic vegetation comprises about 20% of the food. Gravid females have been taken early in June and well into July, while spawning apparently occurs normally about the middle of June.

33. *Cliola vigilax* (Baird & Girard). Bullhead Minnow.

Locally common, but very circumscribed in distribution. I have taken the species in the Menomonee River, closely associated with *Pimephales promelas* and *Hybognathus nuchalis*, and in the Ashippun river in association with *Campostoma anomalum* and *Catastomus commersonii*. The food consists of about equal parts of aquatic vegetation, entomostraca and occasionally mollusca, such as small Physa and Planorbis.

34. *Notropis cayuga* (Meek). Blunt-nosed Minnow.

A very abundant species in the Mukwonago river, and present to a much less extent in the Fox and Oconomowoc rivers. I have taken the species several times in Oconomowoc lake, but it is very rare in lakes. Usually found associated with *Notropis cornutus* and *N. whipplii*, it prefers gravel bottom, medium current and relatively shallow water, seldom being taken in water more than twenty inches deep. The food-is largely entomostraca, though insect larvae and a little vegetable matter in the form of algae are often found in the stomachs. Although I know nothing of the breeding habits, it would seem that the species is a late breeder, as gravid females have been taken commonly in July and several as late as August 10. A good bait minnow.

35. *Notropis heterodon* (Cope). Black-striped Minnow.

Common locally in most of the larger lakes—Oconomowoc, La Belle, Golden, Keesus, Pewaukee, Pine—where the species goes in schools often numbering two hundred individuals. Seldom taken in streams, the only record I have being the Oconomowoc river below the outlet of Oconomowoc lake from which the fish may well have come. The Milwaukee Museum has specimens from Stonebank creek at Hartland. The fish feed almost entirely upon entomostraca, though I have found insect larvae and Hyalella, very small snails (Physa) and leech cases (*Placobdella parasitica*) in a number of instances. A hardy bait minnow, much used for silver bass fishing.

36. *Notropis blennius* (Girard). Straw-colored Minnow.

Probably the most abundant minnow in all of the large, sand-and-gravel lakes. In such lakes as Oconomowoc, La Belle, and Pine it is the dominant shore minnow, present in incredible numbers. The species is gregarious and I have seen schools in Oconomowoc lake containing at least 5,000 individuals. They are commonly associated with *Fundulus diaphanus menona* and the young of *Lepomis pallidus, L. cyanellus, Perca flavescens* and *Ambloplites rupestris*. Spawning occurs along the shores in water from twelve to eighteen inches deep in late May and early June, usually under the protection of shallow water submerged vegetation. The standard small bait minnow of the region. I have found the fish in Oconomowoc lake often infected with large tapeworms (Ligula sp.). In August, 1925, I took a minnow 5 cms. long whose body cavity contained a Ligulid 6.2 cms. in length.

37. *Notropis hudsonius* (DeWitt Clinton). Spot-tailed Minnow.

Exceedingly abundant in Bark, Ashippun and Oconomowoc rivers; less so in the Fox river and its tributaries. To some extent found in Oconomowoc lake; rare in Okauchee, Pine, La Belle, and North. In the rivers, which seems to be its normal habitat, the species prefers clear water, and gravel bottom with not much current. It is associated with *Notropis cornutus, Hybopsis kentuckiensis*, and *Semotilus atromaculatus*. A hardy bait minnow, though very small in size, seldom reaching a length greater than 3 inches. While Forbes and Richardson feel that the species intergrades with *N. whipplii*, I can see no evidence within the region to bear out such a conclusion. To the extent of 80% the food is animal matter, being entomostraca, small crustacea, and occasionally young mollusca of any species that may be at hand.

38. *Notropis whipplii* (Girard). Silverfin Minnow; Lemon-fin Minnow.

The name used locally for these minnows depends on the season of the year and on the sex of the minnow in question. Extremely abundant in the Muckwonago river, and quite common in places in the Oconomowoc and Fox rivers. It is a swift water, clear gravel-bottom species, which avoids heavy vegetation except for momentary protection. I have taken the species in Lac La Belle, where it is established and breeding. In rivers it is usually associated with *Notropis cornutus*, *Hybopsis kentuckiensis* and *Campostoma anomalum*. A beautiful minnow, but not hardy enough for bait purposes.

39. *Notropis cornutus* (Mitchill). Common Shiner.

The characteristic minnow of Ashippun, Bark, Mukwonago and Fox rivers where it is exceedingly abundant. In the Bark and Ashippun rivers I have often taken a glass minnow trap so full of these shiners (as many as 277 in a single trap) that movement within the trap was impossible. The fish attain a large size, often reaching 6 and 7 inches, and are excellent, though short lived and tender mouthed bait. They are commonly used for clear water trolling, not for casting. They prefer clear water (in fact they cannot survive in muddy water), gravel bottom with protecting weeds near at hand, and some current. As a result of excess bait being thrown overboard, the species is sometimes found established in lakes—Oconomowoc, Pine, North (very abundant), and Okauchee. The food is about equally divided between entomostraca, crustacea and insect larvae as animal food, and algae, slime, and particles of aquatic plants on the vegetable side.

40. *Notropis atherinoides* Raf. Shiner.

Taken by me only in the Menomonee river, where it is not very common. Here it was associated with *Pimephales promelas*. The food consists almost wholly of animal matter, largely insect larvae, but many adult insects which have fallen on the surface are eagerly snapped up. I have found these fish likewise infected with a species of Ligula.

41. *Notropis rubrifrons* (Cope). Rosy-faced Minnow; Skip-jack.

The only place I have taken the species is in the Mukwonago river, where it occurs in large numbers at certain seasons of the year. It would appear that the species comes up from the Fox river in late spring, returning to that river again about October. In no other way can I explain the complete disappearance of this species which is so common in the Mukwonago during the summer. Inhabiting water two feet or more in depth, the species is often eaten by bass (*Micropterus salmoides*) and pickerel (*Esox lucius*). A very interesting minnow, about which little is known.

42. *Rhinichthys atronasus* (Mitchill). Black-nosed Dace.

This peculiar little minnow which, because of the profusion of small black pigment spots looks as if it were heavily infected with cysts of *Diplostomulum cuticola*, has been taken only from the Lake Michigan drainage in the Menomonee river. Here it is quite common, associated with *Pimephales promelas* and *Clinostomus elongatus*. It prefers rapid, clear water, and gravel bottom with some vegetation. The mouth is rather sucker-like and the food consists largely of vegetable matter, together with what entomostraca and small crustacea and insect larvae may come with it.

43. *Hybopsis kentuckiensis* (Raf.). Chub; Horny-head.

One of the most abundant fish in the Ashippun, Bark and Mukwonago rivers, together with their tributary streams. Formerly abundant in the Oconomowoc river, but the numbers here are now greatly reduced. This fine minnow, reaching a length of 6 and 7 inches, is, together with *Semotilus atromaculatus*, to which it is superior for the purpose, the best casting minnow, and tens of thousands of them are captured yearly for the purpose. I personally know two guides who have taken not less than 600 of these chubs a week for five months a year for more than forty years, from the Ashippun river, and still the fish are abundant. This is to say nothing of dozens of other bait catchers who also frequent this productive stream. The fish breed in May and June, spawning over clear gravel in which a nest is constructed of pebbles. I have frequently seen several females spawning in the same bed, the construction of which is undertaken by the horny-headed males. The chubs bite readily on hook and line, by which method they formerly were captured for bait. However, the glass minnow trap has superseded this method, and hundreds can now be caught in an hour without injury to the fish.

Order NEMATOGNATHI

Family SILURIDAE

44. *Ictalurus punctatus* (Raf.). Channel-cat.

An introduced species which is in the process of establishing itself. Since the reclamation service along the Mississippi has been functioning, many of this species have been shipped in and planted in various lakes. Thus Oconomowoc received about 700 fingerlings in August 1925, and other plantings have been made in Nagawicka, Golden, Fowler and La Belle. In 1909 ten fish of this species, weighing about half a pound apiece were planted in Nagawicka lake. In July, 1923, one was caught in that lake weighing just under 5 pounds. I have no evidence to show whether or not the species is breeding.

45. *Ameiurus natalis* (Le Sueur). Yellow Bullhead.

The characteristic bullhead of the Rock river and its tributaries, as well as of most of the larger lakes. I have taken the species in Fowler, Oconomowoc, La Belle, Okauchee, Pine, Nagawicka, both Nashotahs and Nemahbins, Pewaukee, and Ashippun lakes. A lover of soft bottom and heavy weeds, usually Potamogetons. Usually about ½ to ¾ of a pound in weight, an occasional individual weighing 2 pounds is taken. The species seem to do equally well in clear and muddy waters, lakes or rivers. The fish are for the most part inactive during the day so far as feeding is concerned, but they bite well as dusk approaches, and far into the night. The fish spawn in the lakes in heavy banks of weeds; in the rivers usually up under overhanging banks or at the entrance of deserted muskrat burrows. Their food is anything that may come to hand: they feed almost wholly on animal matter, alive or in any stage of decomposition, fish, crayfish, and any refuse they can find. Notwithstanding, an excellent pan fish.

46. *Ameiurus nebulosus* (Le Sueur). Brown Bullhead.

By far the least common of the native bullheads, taken by me only in Oconomowoc, Ashippun and Laura lakes, in the Oconomowoc river near its entrance into Rock river and in the Pewaukee river near its entrance into the Fox river, and only sparingly here. They seldom attain a length of more than fourteen inches, and are not ordinarily separated from the preceding species by fishermen. A good table fish, whose diet is entirely animal food, but much less of the scavenger type.

47. *Ameiurus melas* (Raf.). Black Bullhead.

This is an abundant species in all of the soft-bottomed lakes and muddy streams. It is characteristic of small ponds. I have caught dozens in the Skidmore ponds and the small pot-holes near Okauchee lake. They live among submerged vegetation, and a characteristic sight of June and July is the little balls of young bullheads herded about by the adult, up near the surface of the water and along the shoreline. The nests are made either at the base of the weed beds, or under the overhanging banks. The old fish are very solicitous about their young, and attack any small fish that approaches the family school. On being disturbed the little black babies disappear into the weeds in every direction, but soon come together again in deeper water. The smallest of our bullheads, seldom exceeding 6 or 8 inches, and hence of little food value.

48. *Leptops olivaris* (Raf.). Mud-cat.

Like *Ictalurus punctatus*, the mud-cat has recently been introduced from the Mississippi overflows and is thriving in Nagawicka and Oconomowoc lakes. There are, apparently, only a few of these large catfish in the lakes, and I have no evidence of their spawning. One of these fish, weighing 16 pounds, was caught on August 7, 1923, in Nagawicka lake, the bait being "night-crawlers."

49. *Noturus flavus* (Raf.) Stonecat.

I have taken this little fish in two localities: the headwaters of the Fox river near Lannon, and the Oconomowoc river at Stonebank. The stonecat is a fish of clear water and fast current exclusively, living under stones in the midst of the fastest riffles and rapids. Habitually headed upstream, the fish are very quick in their movements, and escape almost miraculuously under a minnow sein. The food seems to be entirely animal matter, largely insects and Chironomus larvae, though small mollusca are sometimes found in the stomach. I have twice found in the stomach a considerable number of Planarians.

50. *Schilbeodes gyrinus* (Mitchell). Tadpole Cat.

This little stonecat is, like the members of the entire group, an inhabitant of clear rapid water, where it is associated with *Noturus flavus* and various darters. I have taken it only in the Oconomowoc river at Stonebank, where it lives in the riffles under stones, cans, logs or any other available covering. The food is entirely animal matter, similar in composition to that of the preceding species. That breeding occurs late in May is indicated by the fact that while I have taken many gravid females before May 15, I have never seen one after May 25.

51. *Schilbeodes exilis* (Nelson). Slender Stonecat.

Also from the Oconomowoc river at Stonebank, and twice I have taken the species in the Mukwonago river. The rarest of the genus within our limits. Food and habits apparently very similar to the preceding species.

52. *Schilbeodes miurus* (Jordan). Brindled Stonecat.

Strangely enough, this species, while inhabiting very similar waters, has never been taken by me in association with either of the preceding. My specimens have come almost entirely from the Menomonee river, and for a long time I thought the species was limited to the Lake Michigan drainage area. But in June, 1925, I took two specimens from the very headwaters of the Fox river near Lannan. The fish inhabit running water but seem to avoid the fast current preferred by the two preceding stonecats. They likewise live largely under stones, logs or other protecting objects but seek water of a somewhat greater depth, two feet as against a foot or often less for the other species. They also show a somewhat greater tolerance for muddy water but are never found in water that approaches opaqueness. The food is, again, entirely animal, largely larvae of Chironomus, Hydropsyche, Aconeura and various species of mayfly, and small dragon-fly nymphs. The stonecats are not separated by natives and are all grouped together as "young bullheads."

Order HAPLOMI

Family UMBRIDAE

53. *Umbra limi* (Kirtland). Mud Minnow.

An abundant inhabitant of the innumerable small, muddy vegetation-choked ponds scattered throughout the region, and also in streams of a similar character. Among the latter I have taken the species from the headwaters of the Fox river in association with *Esox americanus*, *Schilbeodes miurus*, *Catastomus commersonii* and the crayfish *Cambarus propinquus*. In this stream it provides one of the chief foods of the grass pickerel. In the ponds it is most frequently associated with *Ameiurus melas*. No water seems too foul or too stagnant for these fish and no ordinary amount of drying up of ponds during a hot dry summer seems to exterminate them. They seek refuge in the soft muck of the bottoms, often completely burying themselves in the ooze. Their tenacity of life is unique among our fishes, in spite of which they are never used locally as bait, presumably because of their dark color. The food is very largely aquatic plant material, duckweed (Lemna), particles of Elodea, Ceratophyllum, etc., together with any minute animal life that may be attached to this growth. Thus I have found particles of *Hydra* sp. in the intestine, probably off of Elodea. They spawn very early, probably as soon as the ice goes off the ponds, as I have no gravid females later than April 12. In the Fox river I have never seen a mud-minnow more than 3 inches long, while in the ponds near Okauchee lake I have taken them 5½ inches in length. Generally known as "young dogfish" locally.

Family ESOCIDAE

54. *Esox americanus* (Gmelin). Grass Pickerel; Little Pickerel.

Found in only one locality in the county, the headwaters of the Fox river in the vicinity of Lannan. It was quite a surprise to find this little pickerel so far north as this is one of the most northern records, but in the northern waters of the Fox river and until the river becomes about twenty feet wide, this pickerel is the dominant and characteristic species. In this region the water is muddied by carp activity, normally but two feet deep, slow and sluggish, but not stagnant, and the bottom is a mixture of sand and mud. Here the pickerel lives on mud minnows and crayfish, and attains a length of 9 inches, though I have taken few so large. The fish spawn in typical pickerel manner, coming up into the overflowed marsh during the spring flood, to lay their eggs in the shallow water. The young pickerel are about two and a half inches long at the end of the first summer, their food consisting of young crayfish (*Cambarus propinquus*) which are unusually abundant there, and darters and small minnows (*Notropis hudsonius*, *N. cornutus*, *Umbra limi*) with an occasional Physa and Gammarus. The fish are so small as to be of no economic value.

55. *Esox lucius* (Linn). Great Northern Pike; Pickerel.

The common pickerel of the region. Very abundant in all of the lakes and less so in all of the rivers, except during the spawning season. The greater part of the summer is spent just off of the sand bars in water 18 to 25 feet in depth, where the voracious fish lie in the Potamogeton beds and gorge themselves on any passing fish of convenient size. Feeding is almost entirely during the daytime and only very seldom is one caught at night. The food is normally fish, all species of minnows and small Centrarchidae included, with crayfish varying the diet during late summer. They grow to very great size, the largest I have weighed was 27½ pounds; it was caught in the Oconomow river near Fowler lake. I have many records of fish weighing between 15 and 18 pounds, but each year sees fewer of these large specimens caught. Newspapers published during the early summer of 1925 a photograph of 16 pickerel with a total weight of 112 pounds, caught in Muskego Lake, but such catches are unusual, to say the least. Okauchee lake probably has more pickerel than any other lake in the county, and not long ago catches of 15 or more a day were standard. The larger pickerel do some damage by their destruction of game fish. Small bass, sunfish, silverbass, perch, suckers and cisco are preyed upon. I have taken three cisco weighing nearly half a pound each from stomachs of pickerel weighing 8 pounds. The pickerel spawns soon after the ice goes out, passing up into the marsh overflows to deposit their huge quota of eggs. These eggs hatch in about two weeks, the young fish spending the summer in the weed beds along the lake or river shore. By the end of the summer they attain a length of 8 or 9 inches, and have worked out into deeper water near the edge of the bars. A great game fish, that takes any good minnow bait readily and puts up a stubborn fight. Not particularly prized as a food fish because of the many bones.

56. *Esox immaculatus* (Garrard). Muskallunge.

No longer present in the county, there seems little doubt but that this greatest of freshwater game fish formerly occurred in the Fox river, which seems to have been a considerably larger river not very long ago. Dr. P. R. Hoy reports the species from this river, with a specimen weighing 40 pounds, caught in 1877. It is certain that the species has been extinct within the region for at least thirty years, in spite of reports which reach me constantly. Every large pickerel is suspected of being a "musky."

Family POECILIIDAE

57. *Fundulus diaphanus menona* (Jordan & Copeland). Menona Top-minnow.

This is the most abundant of all the Killifishes in the region and is characteristically a lake species. All of the larger lakes, those with gravel and sand shores, such as Keesus, Oconomowoc, La Belle, etc., harbor great numbers of these fish. They are distinctly shallow water forms, seldom entering water more than twenty inches in depth, and are commonly associated with *Notropis blennius*, *Labidesthes sicculus*, and young Centrarchidae. Of the three species of Killifishes in the region this is the least "top-water" of the group. They remain well toward the bottom, feeding on crustacea, entomostraca and some insect larvae, and only occasionally come to the top to get a gnat or fly that has fallen on the surface. They spawn very late, often not until late in July, though they seem ready to burst with eggs by late June. An excellent bait minnow seldom more than $2\frac{1}{2}$ inches long.

58. *Fundulus dispar* (Agassiz). Top-minnow.

This interesting killifish has been taken by me only in the Mukwonago Millpond, at the town Mukwonago. Here the species seems to be abundant. The water of the millpond is dark due to much sediment in suspension, and has very soft mucky banks and reedy shores. Among these reeds this species is seen swimming just under the surface, or even sometimes with the dorsal fin out of water, feeding largely on tiny insects that chance to fall in the water. They are rather slow in their ordinary movements, but zig-zag away rapidly if disturbed, usually to return very shortly to the spot they left.

59. *Fundulus notatus* (Raf.). Top-minnow.

Next to *F. diaphanus menona*, the commonest of the killifishes. They frequent rivers and streams in preference to lakes, and I have taken them in Battle creek, and in all of the river systems except the Menomonee. They prefer slowly flowing water, and do not seem worried by sediment in suspension. Like the preceding species, this top-minnow remains constantly just under the surface, and when disturbed it zig-zags wildly, but it does not descend. Yet their food habits are in striking contrast to the preceding: about 75% of the food is vegetable matter, almost wholly filamentous algae, Spyrogyra, and Zygnema predominating. The remainder of the food is mostly insects picked from the surface. They spawn late, seemingly carrying nearly mature eggs for several weeks. I have taken gravid females from June 10 to July 8. One of the stable foods of the small-mouth bass (*Micropterus dolomieu*) that inhabit the rivers.

Order ACANTHOPTERI

Family GASTEROSTEIDAE

60. *Eucalia inconstans* (Kirtland). Brook Stickleback.

The characteristic inhabitant of small, weed-choked creeks, so heavily overgrown with brush, usually willows, as to be almost invisible. In such little streams, tributaries to the Scuppernong river and creek of the same name particularly, this pugnacious little fish builds its nest, rears its young, and lives its life. This is the only fish here that actually builds a nest, in the usual sense of the word. This nest, made of tiny twigs and branches of water plants, is almost round in shape, and is well hidden in the dense aquatic vegetation. The fish guards the nest vigorously, and will strike at anything that intrudes on the premises, including the finger if it is advanced slowly. The food is largely insect life, over 50% being small non-aquatic insects that fall into the water. An interesting variation in the number of dorsal spines exists among the sticklebacks of Scuppernong creek particularly. While 5 is the typical number, both 4 and 6 occur. Out of 100 fish examined, 13 had 4 spines, 69 had 5 spines, and 18 had 6 spines.

Family ATHERINIDAE

61. *Labidesthes sicculus* (Cope). Brook Silversides; Top-water.

In southern Wisconsin this is characteristically a clear-water lake species, seldom found in streams. Especially abundant in Oconomowoc lake but common also in Fowler, La Belle, Pine, the Nashotahs and Nemahbins, North, etc. Occasionally taken in the Oconomowoc and Bark rivers. Together with *Fundulus notatus* and *F. dispar* the most persistently "top-water" minnow. They inhabit the upper foot of water normally, varying in their distribution with day and night and with the seasons as to whether they are littoral or pelagic. Very gregarious, they travel in large schools, and may be seen leaping out of the water after insects on the surface. The fish breed in May, spawning in the shallow water along the lake shore, and the eggs hatch in from 8 to 9 days. The young fish travel out to assume a position over deep water, and here many fall prey to small-mouth bass (*M. dolomieu*) cisco (*L. artedi*) and gar (*Lepisosteus osseus*). The food is very largely animal matter—entomostraca, rotifera (Anuraea), *Mysis relicta*, and occasionally a considerable amount of insect material (dipterous larvae). An interesting point to be noted is that the fish live for only fifteen to seventeen months: they die during the summer following their one and only spawning. Of no use as a bait minnow, and usually carefully replaced by fishermen who uniformly believe them to be young ciscos.

Family CENTRARCHIDAE

62. *Pomoxis annularis* (Raf). White Crappie; Silver Bass; Strawberry Bass; Calico Bass.

Less common than the following species, the white crappie is never distinguished from the darker species by local fishermen, who believe it a color phase of the latter. It is found in nearly all of the larger lakes, and in some of the smaller, such as Laura, showing no particular aversion to muddy water or soft bottoms, though it is more common in lakes with sand and gravel beds. It is a deep water species, living off the bars in 15 to 30 feet of water, and frequenting the Potamogeton beds. The young of the year are found in the shallow water weeds along the lake shores, and to some extent up the streams. They bite readily on small minnows (*N. blennius*) and are a high grade pan fish. I have taken this species in Neosha Millpond, Dodge County, just over the Waukesha county line, weighing $3\frac{1}{2}$ pounds.

63. *Pomoxis sparoides* (Ladepede). Silver Bass; Crappie; Strawberry Bass; Calico Bass.

By far the most common of the silverbass in Waukesha county, inhabiting nearly all the lakes, whatever the size, though absent from the small ponds. Like the preceding, an inhabitant of the deeper water and the submerged vegetation. Here they feed voraciously on small minnows of many species, and young of perch, sunfish, pumpkinseed and occasionally of bass. The fish spawn during April, rarely carrying their eggs as late as May 5, and, like the preceding, the young are found along the lake shores where they attain a length of just under two inches by the end of the summer. During the winter the fish bite in water 6 to 10 feet deep, and thousands are caught in Oconomow, Pewaukee, Okauchee and other lakes where ice fishing is practiced. The best bait is any of the shore minnows of small size, and rarely are they caught on angle-worms. An excellent pan fish, not as large, however, as the white crappie. These fish seldom attain a weight of over a pound, half a pound being normal size.

64. *Ambloplites rupestris* (Raf.). Rockbass.

An abundant species in every lake and in all of the rivers, less frequently taken in the smaller creeks. The rockbass seems to prefer the shallow water, though occasionally taken from the weed beds off the edges of the bars. They prefer weeds as their environment, and are commonly caught in the midst of heavy masses of Potamogeton. They spawn in the shallow water along the shore, often among rushes, where a slight depression is made in the sand or gravel, the adults keeping guard until the young hatch. The young rockbass is found in the shallow water weeds all summer, attaining a length normally of hardly more than an inch by fall. These are handsome little fish, with a coloration entirely different from that of the adult, being heavily mottled with very large pattern. The food is composed of about equal parts of insects, fish and crayfish, the young of the latter being the dominant food during the late summer and fall. They bite on almost any bait, worms, minnows, chub, or spoonhook, but are not game fighters. While they are really a very good pan fish, they are looked upon with distaste by local fishermen because of an entirely mythical infection of "grubs." They are, however, often parasitized rather heavily with the cysts of (?) *Diplostomulum cuticola*, as are the perch, which, notwithstanding, are regarded as an excellent table fish.

65. *Chaenobryttus gulosus* (Cuv. & Valen.). Warmouth Bass.

A rather uncommon sunfish, which is not ordinarily separated by local fishermen from the rockbass, which it somewhat resembles. A fish of the smaller lakes—Laura, Skidmore ponds, Genesee—it prefers soft, muddy bottoms to sand or gravel, and is tolerant of dirty water. It inhabits the dense weed beds of these lakes, feeding upon insects and small fish, and to a much less extent upon crayfish. It bites readily upon worms or minnows (*N. blennius*), and puts up about the same sort of fight as the rockbass. It reaches a length of about 8 inches, 6 inches, however, being nearer the average size. Not highly ranked as a pan fish because of its small size and resemblance to the ill-favored rockbass.

66. *Lepomis cyanellus* (Raf). Logfish; Green Sunfish; Blue-spotted Sunfish.

An abundant inhabitant of rivers, and to a less extent of lakes, though quite common in lakes of muddy rather than clear water. Weeds are essential to their habitat, and Potamogeton and Ceratophyllum afford protection in most of the river systems. I have taken the species, which is common, in all the rivers except the Menomonee, where it is absent. Of the lakes, the smaller bodies of water like Skidmore ponds, Laura lake and similar ponds, have their logfish in large numbers, and they also occur to a lesser extent in clear lakes, Oconomowoc, Lower Nashotah, as well. In these latter, however, the fish seem not to attain so large a size. In Oconomowoc lake, I get a great many very small logfish in the shore weeds, yet large ones are rare. They attain a weight of a quarter of a pound or a bit more in the Oconomowoc and Fox rivers, but are not prized as a pan fish—for no particular reason it would seem. The food consists of any animal life that happens to be at hand—fish, crayfish, insects, larvae, mollusca. They bite readily on worms, but rarely on minnows, and put up a fight about equal to that of a goodsized rockbass. The fish spawn in June and July, making shallow depressions in the shallow water near the shore—often in rushes. Here the old fish bravely defends its nest against intruders. So strong is the defense reaction that I frequently have caught the fish on the nest with no other equipment than my hands. The eggs are whitish, and very sticky, lying in the nest in a mass. They hatch in 7 to 9 days.

67. *Lepomis euryorus* (McKay). McKay's Sunfish.

The rarest of the sunfish, known to me only from three specimens taken in Oconomowoc lake, on three different occasions, and always at night. Whether this is significant or not I can not say, as the habits of the species are but little known. These fish came from the north shore of the lake, in water less than a foot deep, over gravel bottom, and were taken in a minnow seine along with *Microperca punctulata* and *Labidesthes sicculus*. The largest specimen measures $2\frac{1}{4}$ inches long.

68. *Lepomis humilis* (Girard). Orange-spotted Sunfish.

This tiny little sunfish is also rare in Waukesha county, and has been taken by me only from the headwaters of the Fox river at Lannon where it is associated with *Esox americanus* and *Umbra limi*. My largest specimen, $2\frac{3}{4}$ inches long, was a male in full nuptial coloration, taken July 7, 1920, and is one of the most beautiful of our local fishes. I have not taken the species since this date, and a total of only five specimens has come to hand. The food consists of about equal parts of vegetable and animal matter, being composed of bits of Ceratophyllum, Potamogeton and Elodea, with some algae, together with entomostraca, insect larvae, a few tiny mollusca, and some very small crayfish (*Crambarus propinquus*). I know nothing of its breeding habits. The fish is so small as to be of no economic importance.

69. *Lepomis incisor* (Cuv. & Valen.). Bluegill; Sunfish.

Abundant in all the lakes and streams in the county, and by far the commonest of the true sunfish. In the lakes they are found in deep and shallow water, the former being the large adults, the latter young individuals ordinarily not sexually mature. The fish are gregarious, inhabiting the heavy off-bar weed beds in association with *Micropterus salmoides* the silverbass (*Pomoxis sparoides*) and pickerel (*Esox lucius*). They vary greatly in coloration, depending upon the character of the water they inhabit, those coming from muddy water being very dark. Bluegills weighing a pound are frequently caught, and the species is highly prized as a pan fish. They are very game fighters, utilizing their width to the utmost to resist the efforts of the fisherman. The food is largely animal matter. The young fish live mostly on entomostraca and bits of leaves of Potamogeton and other aquatic plants, while the adults eat fish, crayfish, small mollusca, insect larvae and often insects which fall upon the surface of the water.

70. *Lepomis gibbosus* (Linn.). Pumpkinseed.

This is distinctly a fish of the rivers and streams, and only to a slight extent of the lakes. In the latter they are most frequently found near the mouths of the rivers, from which they probably came. They are also found in the smaller ponds, Skidmore and Okauchee ponds. The fish show a decided preference for weed beds in soft bottom, usually muck, and are consequently very tolerant of dirty water. They are only to a slight extent gregarious, and have a more general distribution through the streams than do the preceding species. They prefer deeper water, and seek refuge in holes in the stream bed. Vegetation is also a requisite of their environment and much of their time is spent in the shade of aquatic plants or overhanging banks. They breed in June, nesting in the shallows along the shore where a nest is excavated in the bottom, always amid vegetation, and here the male valiantly guards the eggs. The young leave the nest almost at once, and no further parental care is displayed. The food is essentially like that of the preceding. Their size is a bit too small to make them a choice food fish, as they seldom exceed 5 or 6 inches in length.

71. *Micropterus dolomieu* (Lacepede). Small-mouth Black Bass; Red-eye.

This is the gamest of all the local fishes, the best fighter known. It is abundantly distributed throughout the county, but is decidedly a fish of clear lakes though it is also found in muddy streams. The factor which determines the persistence (if not the existence) of the red-eye in a lake is gravel bars. While food may be abundant and water conditions ideal in a lake, if gravel bars are not present neither is the red-eye. These bars are essential to their breeding habits, and the breeding habits of a fish, far more than the food habits, determine whether a species can survive in a given body of water. The red-eye occurs in most of the larger lakes, and is conspicuously absent from the following: Golden, Ashippun, Genesee, Pewaukee, Henrietta, Dutchmans, Otis and other small ponds. The fish inhabit the deeper water off the bars after the breeding season, but are not as dependent upon weed beds as is the next species. On still, hot days in mid-summer one often sees these fish at the surface, breaking water in quest of insects of all sorts that have fallen upon the surface. Thus I once took 8 honey bees from the stomach of a red-eye caught on a dry fly in the middle of Oconomowoc lake when the fish were very evidently "up." The species is very voracious and largely piscivorous during most of the summer, but toward fall the food changes to crayfish of which they are inordinately fond. During September and October the stomachs are packed with crayfish, often as many as 6 or 8 in a single alimentary canal. They bite well on chubs (*H. kentuckiensis* and *S. atromaculatus*), shore minnows (any species of *Notropis*) and frogs (*Rana pipiens*), but the best bait undoubtedly is "nightcrawlers" (*Lumbricus terrestris*). They spawn on gravel bars, clearing out a depression 2 or 3 inches deep in which the eggs are laid and over which the fish lies, gently fanning the water to keep it in circulation. Any intruder is met by a furious rush and either driven off or devoured. The young bass frequent the shallow water along the edges of the lake, and are not at all confined to the presence of weeds. In fact, in La Belle lake they are most abundant in water a foot deep without a sign of vegetation. The young grow rapidly and reach a length of about 3 inches by fall. Spawning occurs in May, but is hurried or delayed by the temperature of the water, 65° to 68°F being the critical temperatures in Waukesha county. The average size is $2\frac{1}{2}$ pounds, but I have taken specimens 5 to $5\frac{1}{2}$ pounds, these being about the maximum size attained. An excellent table fish, second to none.

72. *Micropterus salmoides* (Lacepede). Large-mouth Black Bass; Green Bass; Oswego Bass.

By far the most abundant of the bass, inhabiting all of the lakes and rivers. While the species is dependent upon bars for breeding purposes, they are not particular, and any ledge two feet wide will do for the purpose. This at once extends the possible distribution of the species over that of the preceding. The green bass is also a fish of the deep water just off of the bars, but those bars must be bordered by weed beds, usually Potamogeton. In these weeds the fish lie, and into these weeds goes the fish with any bait as quickly as possible. The average size is between 2 and $2\frac{1}{2}$ pounds, though bass weighing 5 pounds and over are on rare occasions caught. The largest of which I personally have a record which I know to be authentic is $8\frac{1}{4}$ pounds, caught in Eagle lake. Between this enormous fish and bass weighing 6 pounds I have no record. The fish breed in May and if the season be backward are often still upon the beds by June 20 when the fishing season opens. These beds are shallow depressions well up on the bars and, if the spawning space be limited, the nests are often as close together as it is possible to put them. Over these beds the male lies, keeping the water in circulation and sediment in motion until the eggs hatch. Thereafter the male accompanies the swarm of tiny bass for a period of about two to three weeks, protecting them against the ravages of larger fish. The food of the young fish is almost exclusively entomostraca, but they begin their piscivorous habits when about an inch long, eating young shore minnows, darters, etc. The adults are almost exclusively fish-eaters, crayfish playing only a very minor rôle in their diet. Unlike the red-eye, the green bass is active all winter and hundreds are caught through the ice on most of the larger lakes. At this time of the year they inhabit water 10 feet or less in depth and are associated with the silverbass (*Pomoxis sparoides*) which are caught in the same holes. The greenbass bites best on chubs (*H. kentuckiensis* and *S. atromaculatus*) but will also take frogs, crayfish or angleworms. An excellent table fish, prized next to the red-eye.

73. *Scardinius erythropthalmus* (Linn.). European Rudd; Pearl Roach.

In 1916, Mr. B. O. Webster, at that time superintendent of hatcheries, now a member of the Wisconsin state conservation commission, went to New York at the request of Mr. Fred Pabst of Oconomowoc, and obtained from the New York Aquarium "several pails" of this species. These fish were successfully brought back to Waukesha county and were planted in Oconomowoc lake, where they are doing very well. At present there are three sizes of fish in this lake, indicating two successful spawnings at least. The fish have never traveled more than half a mile from the site of the original planting, at the southeast end of the lake. Knowing the location of the school in a general way, I have caught three specimens since 1918, always on worms as bait. The food of these has been entomostraca, aogether with insect larvae and small minnows, with a few snails (Physa) tnd small clams (Pisidium).

Family PERCIDAE

74. *Stizostedion vitreum* (Mitchill). Wall-eyed Pike.

An introduced species which has been abundantly planted in Golden, Oconomowoc, La Belle, Forest, both Nashotahs and Nemahbins, Laura, Pine, Pewaukee and Nagawicka lakes. Except during the spawning season when they ascend the rivers, the pike is distinctly a lake fish within the limits of the county, but in Rock river just over the boundary it is very abundant. It inhabits the deep water off the bars, ordinarily in the vicinity of weed beds. The fish are of a wandering disposition, here today and there tomorrow, so that their capture is often rather difficult. They spawn early in the spring, ascending the rivers for the purpose soon after the ice goes out. In this respect they resemble the pickerel (*E. lucius*) which they follow and are themselves followed by the various species of suckers. The young wall-eyes return to the lakes rapidly after hatching and go into deep water where many must fall prey to larger fish. However, young pike are extremely pugnacious and begin their piscivorous diet when 5 or 6 days old. In my collection I have a string of seven wall-eyes of this age, each member of the string with the posterior half of the preceding pike well down his throat. Thus the whole string died. The fish attain a good size; I have records of many weighing between 7 and 10 pounds, and I have no doubt that 15 pounders are not unknown to Golden, Oconomowoc and the Nashotahs. They are frequently the host to the peculiar ecto-parasite *Argulus stizostethi* which crawl over them much in the manner of lice.

75. *Stizostedion canadense griseum* (DeKay). Gray-Pike; Sand Pike; Wall-eye.

This species, like the preceding, has been widely introduced throughout the county, and is never distinguished by local fishermen who take it for small fish of the preceding species. They differ from the preceding markedly both in coloration and in size. This fish is distinctly of a gray tinge while the other is very golden. Furthermore, this species is much smaller, seldom exceeding a pound or a pound and a half. They are very abundant in Forest and La Belle lakes, much less so in all the other lakes. Their general habits and food are so nearly like those of the preceding species that they need not be discussed. Decidedly a less desirable table fish because of its smaller size.

76. *Perca flavescens* (Mitchill). Perch.

Abundant in all of the lakes and rivers in the county. The large perch are distinctly a deep water fish, inhabiting the Potamogeton beds in the deep water off the edge of the bars. If one were to make a survey of the water between here and the shore, one would find a gradual decrease in size of the perch correlated with a decrease in the depth of the water, with the young-of-the-year in the very shallow water along the shore associated with *Notropis blennius* and *N. hudsonius*. The nest is a shallow depression in the sand along the shore and here a string of very beautiful eggs is laid. The young remain in the shallows and attain a length of about three inches by fall. The food of the young is largely entomostraca and insect larvae while that of the big adults is largely crayfish and minnows. Like the green bass (*M. salmoides*) and silverbass (*P. sparoides*) the perch is active and feeding all winter and thousands of them are caught through the ice when they are so heavy with spawn that they can barely flop. Such fish often weigh a pound or a pound and a half. A very excellent table fish, readily caught on either worm or small minnows.

Subfamily ETHEOSTOMINAE

77. *Percina caprodes* (Raf.). Log-perch.

A common species of darter in the deeper portions of the larger rivers, particularly in the Fox and Oconomowoc. It is an inhabitant of water of moderate current and reasonable clearness, avoiding foul or muddy water. The fish prefer a rocky or heavy gravel bottom to sandy bottom, and avoid entirely mud or silt. Very fast in action, they are easily approached but disappear under rocks or stumps as if by magic if disturbed. In this characteristic only do they resemble the other darters. They feed on bottom animal matter almost exclusively, Chironomus, Simulium, Allorchestes and other small crustacea, with occasionally a minute mollusk. They have no particular economic value and are never used as bait because of their small and tender mouth. I have found them as food in *Micropterus salmoides*, *Esox lucius* and *Stizostedion vitreum*.

78. *Hadropterus aspro* (Cope & Jordan). Black-sided Darter.

A darter of the river systems only, taken in all but the Menomonee river, particularly common in the Mukwonago and Fox rivers. A fish of medium current, but preferring water a bit faster than the preceding. Usually found where some vegetation is present into which the fish retreat. Fine gravel is the preferred type of bottom but they are occasionally found over muck, in which case the fish are decidedly darker in coloration. In the Fox river they are associated with *Esox americanus*, *Umbra limi* and *Cottus* sp.; in the Mukwonago especially with *Semotilus atromaculatus*. The food is largely entomostraca and crustacea (copepods) with large numbers of insect larvae and nymphs. Spawning occurs early in June, in shallow water, often under overhanging banks or amid vegetation, in water of some current.

79. *Diplesion blennioides* (Raf.). Green-sided Darter.

Distinctly a stream species, though I have taken the species a number of times in both Oconomowoc and La Belle lakes. Common wherever found, this beautiful little darter prefers a sandy bottom and medium current, being absent from rock and mud environments. On this sand they lie supported by their very ample pectoral fins, as if they were resting on their elbows, ready for instant departure. When they start off, the quick flip of the tail stirs up the soft bottom in a whirl of sand and by the time this settles, the darter is nowhere to be seen, having made good its escape behind the "smoke screen." While I have never seen the nest in a river habitat, I have found several in Oconomowoc lake. These have invariably been under small pieces of water-logged wood, from beneath which protrudes the peculiarly shaped head of the watching fish. This is the male; and if an intruder of considerable size appears, he retreats under his shelter without delay. If the enemy be a small minnow, the male makes a furious dart out of his hole, flies at the intruder, and returns again so quickly that about all one sees is a cloud of sand which conceals for a moment the opening to the nest into which the male has dived. By the time the sand settles again, the head of the male is once more poking out of the nest entrance. Food is entirely bottom fauna of small size, as entomostraca, small crustacea like Hyalella and Gammarus, and small mayfly and damsel-fly nymphs.

80. *Boleosoma nigrum* (Raf.). Johnny Darter.

The characteristic and most abundant darter of the region, found in every lake and in every river and stream. It is equally at home in the swift current of the Bark river and the still waters of the large lakes, its one demand being gravel bottom or coarse sand. Mud it strictly avoids. It is distinctly a shallow water darter, found resting upon the bottom supported by the pectoral fins in true darter attitude. It is not particularly timid, often joining *Notropis blennius* in investigating one's toes when one goes swimming. However, when frightened, Johnny is off amid a swirl of sand and is found in a rigid, expectant attitude when the cloud settles. The eggs are laid on clear sand, no nest being constructed that is worthy of the name, during May and very early June. The food of the species is composed of Chironomus and Simulium larvae to about 50%; with crustacea (Hyalella) and entomostraca (Cyclops, Daphnia, etc.) composing the other half.

81. *Ammocrypta pellucida* (Baird). Sand Darter.

This peculiar darter is recorded from a single specimen taken by me in the Ashippun river. The region from which it came is one of clear sand over a stretch of perhaps 300 yards, with not a sign of aquatic vegetation of any sort, or of a pebble larger than a sand grain. In looking over this barren stretch I found this darter buried in the sand, with nothing visible but the eyes and mouth. Such is the normal habit of the species: avoiding vegetation they protect themselves by imbedding the body in the soft sand. I know nothing about its breeding habits or its food, as careful search here and in other similar localities has revealed no further specimens.

82. *Etheostoma iowae* (Jordan & Meek). Iowa Darter.

A common species in certain lakes, Oconomowoc, Pine, and La Belle, where it inhabits the shore waters above a sand or fine gravel bottom with some low, submerged vegetation present. Here it is associated with *Boleosoma nigrum*, *Etheostoma coeruleum*, and *Notropis blennius*. While the pectoral fins are well developed, the species has rather less of the darter habit of resting upon them, the fish being more constantly in motion than the Johnny darter. While capable of very rapid motion, the Iowa darter tends to be more deliberate than many other species of darters, though the fish is, of course, a member of the bottom fauna. The food is largely copepods, with some insect larvae and many small mayfly and stonefly nymphs. I have taken gravid females during May and early June.

83. *Etheostoma jessiae* (Jordan & Brayton).

Not an uncommon species in lakes of certain kinds. I took the species first in Oconomowoc lake, but it is much rarer in the large, gravel bottom lakes than in the smaller, soft bottomed lakes and ponds. I have the species from Laura lake, the larger of the Skidmore ponds, Okauchee ponds, Forest lake, and the Genesee lakes. It is a small, inconspicuous darter, rapid in movements, and using the darter trick of stirring up the bottom by a violent flick of the tail in order to hide or escape enemies. It is distinctly a solitary fish, being much less gregarious than any of the preceding species, and seldom more than a single specimen in taken in the net at one sweep. The fish breed in May, but I have taken gravid females in Oconomowoc lake as late as June 12. They spawn in the shallow water along the shore, usually in a clump of submerged vegetation. The food is typical of the darters, being largely entomostraca and insect larvae, mostly Chironomus, but with some nymphs or small crustacea (Hyalella) as well. The species is often rather heavily infected with the cysts of the parasite (?) *Diplostomulum cuticola.*

84. *Etheostoma coeruleum* Storer. Rainbow Darter.

While this species somewhat resembles the preceding, it is a fish of the larger gravel lakes, Oconomowoc, Pine, La Belle, Okauchee, North, Keesus, Pewaukee, Silver, Golden and Beaver. It is in all respects a very typical darter, and one of the most common species of the group. It inhabits the shore water along with *Boleosoma nigrum* and *Notropis blennius*, and few collections along the lake shores fail to yield two or three of this species. It is very fast in its actions, and resembles *Diplesion blennioides* in its habit of seeking refuge under stones or sticks though it does not remain under objects for any length of time. The fish spawn in May, usually the latter half, laying in shallow depressions well up toward the shore, within the zone of wave action. The food is mostly cladocera and copepods, while crustacea (Hyalella and Gammarus) form about 25% of the total bulk. Often used as bait for silverbass and perch, though not desirable because of the dark color and not very great vitality.

85. *Etheostoma flabellare lineolatum* (Agassiz). Fan-tailed darter.

In delicacy of markings, if not in color, this is one of the most attractive of our darters. It is an inhabitant of very rapid water, being associated most frequently with *Cottus bairdii bairdii* and *Noturus flavus.* It is very local in its distribution, being confined to those parts of the various rivers in which the current is great and the bottom hard. The Little Oconomowoc, Oconomowoc, Scuppernong and Bark rivers contain large numbers of fan-tails where these conditions prevail, and it is a rare fish in the Mukwonago river. They attain a length of 3 inches in the Scuppernong, though the average size is 2½ inches. The fan-tail is very rapid in its movements, probably the fastest of all the darters, and this speed stands it in good stead in its habitat. The food is largely insect larvae, Simulium predominating when the form is in season. These, together with mayfly and small dragon fly nymphs, Planaria, and occasionally young leeches make up the bulk of the food, while entomostraca and tiny gastropods are also items. During the breeding season the cheeks of the male swell up, each spine of the first dorsal fin develops a tiny white mushroom-shaped tip, the color deepens, and the fish becomes really an exquisite example of the darter group. They spawn just below the rapids, usually behind a stone, clearing out a shallow depression in the immediate vicinity of which the now very pugnacious male patrols. Infection with cysts of (?) *Diplostomulum cuticola* is not infrequent, but never heavy. They spawn in June.

86. *Boleichthys fusiformis* (Girard). Spindle-shaped Darter.

This is one of the rarer species of darters in the county, and has been taken by me in Oconomowoc, Pine, and La Belle lakes, and in the Bark river. It is a fish of quiet water and hard bottom, avoiding dirty conditions entirely. A depth of about 18 inches of water is preferred, and the fish show little of the typical darter characters of behavior, rather resembling *Etheostoma iowae* in this respect. I have, however, taken them in tributaries of the Bark river in much shallower water, amid heavy vegetation. Gravid females have been taken in May and only once as late as May 30.

87. *Microperca punctulata* (Putnam). Least Darter.

This tiny darter, by far the smallest of the group, is quite rare in Waukesha county, having been taken by me only in the Bark river north of Rome, on the very western edge of the county. Here, however, it is locally common, inhabiting water of 2 feet or more in depth, heavily loaded with Potamogeton and Elodea. It avoids any considerable current, preferring the quiet, deep pockets along the muddy shores, associated with young *Pomoxis sparoides* and *Micropterus salmoides*, which in turn feed to some extent on it. Giants of the species measure $1\frac{3}{4}$ inches, but the average size is under one inch. Their food is entirely animal matter, being about equally divided between insect larvae, nymphs and entomostraca. It is an exquisite little fish whose reticulate markings remind one of the fan-tailed darter (*Etheostoma flabellare lineolatum*) while the lateral markings resemble those of the Johnny darter (*B. nigrum*).

Family SERRANIDAE

88. *Roccus chrysops* (Raf.). White Bass; Striped Bass.

Another introduced species which has taken firm hold in a large number of lakes. In La Belle and Pewaukee the fish are very abundant, while the species is present in somewhat lesser numbers in Oconomowoc and Nagawicka. The most gregarious of our fresh water fishes, the adult white bass seem at all times to travel in large schools of several hundred individuals while the young are apparently solitary. During most of the year the fish inhabit the deep water off the sand bars where they can be caught on small shore minnows by deep trolling. However, on quiet hot days in July and August the great schools often come to the surface, frittering along half out of water as they travel rapidly in a zig-zag course. At such times they offer great sport to the dry fly fishermen, as the fish often strike furiously and follow it up with a very game fight in the deep water. They attain a size of over three pounds, with 2 pounds as a good average. Spawning occurs about the middle or end of May, and the fish ascend the rivers if possible, to lay their eggs among the rocks and under the falls or amid the riffles. The ascent of the rivers is usually at night and the spawning occurs at night, as I have often witnessed in the Oconomowoc river below the falls marking the outlet of Fowler lake into Lac La Belle. Here the water is literally alive with white bass for three or four days and nights. As soon as the eggs are laid the fish return to the deep water of the lake. The young remain in the shallows along the banks of the river or return to the lake and follow the shallows of the shoreline where they are taken in association with *Notropis blennius* and young-of-year of *Ambloplites rupestris* and *Lepomis pallidus*. The food is almost entirely small minnows, with occasional insect larvae or nymphs. This food is taken while the fish are in deep water, as stomachs of fish caught frittering along the surface are invariably empty. An excellent game and food fish, the continued planting of which is earnestly urged.

Family SCIAENIDAE

89. *Aplodinotus grunniens* (Raf). Sheepshead; Drum.

This species is included in the list solely upon the authority of Dr. I. A. Lapham, who lists it as an inhabitant of Oconomowoc lake in the only published list of fishes of the region (1882). The sheepshead is no longer a native fish in the county, though occasionally young individuals are planted along with shipments of bass, whitebass, perch and catfish from the Mississippi river overflows. Several fingerlings went into Oconomowoc lake in August, 1925. The prevalent idea of the undesirability of the sheepshead as a food fish is not concurred in by the writer, who considers it equal to the white bass and the croppies, and better than the sunfish, pickerel and buffalo.

Family COTTIDAE

90. *Cottus bairdii bairdii* (Girard). Sculpin; Miller's thumb.

This peculiar looking fish is a common inhabitant of rapid water regions of the Oconomowoc, Little Oconomowoc, Bark and Fox rivers. It lives only in regions of the greatest current, frequenting the rocks below falls and the riffles of the many small rapids. Here the sculpin is associated with *Noturus flavus* and *Schilbeodes* sps. The great pectoral fins are used in darter fashion to support the body against the current, head upstream.

The movements are likewise darter-like in their rapidity. The fish lie on the bed of the stream or under the edges of rocks, the belly pressed in close contact with the bottom. The food is composed of entomostraca and small crustacea, with occasional insects, stonefly larvae and small dragonfly and mayfly nymphs, Chironomus and Simulium larvae, and rarely a small mollusk.

TABLE 4

A LIST OF THE FISHES OF WAUKESHA COUNTY, SHOWING THE NUMBER OF LAKES IN WHICH EACH SPECIES IS FOUND, AND THE NUMBER OF COLLECTIONS IN THE RIVER SYSTEMS IN WHICH EACH SPECIES HAS APPEARED

		Rivers					
	Lakes	Ashippun	Oconomowoc	Bark	Fox	Menomonee	Scuppernong
Lepidosteus osseus	26	9	46	27	14	12	—
Amiatus calvus	31	12	31	28	11	13	16
Leucichthys artedi	13	—	—	—	—	—	—
Salmo irideus	3	1	—	—	—	—	37
Salvelinus fontinalis	1	6	—	9	—	—	82
Salmo fario	3	—	—	—	—	—	47
Anguilla rostrata	2	—	1	—	—	—	—
Ictiobus cyprinella	2	9	12	14	8	—	22
Ictiobus urus	—	7	20	11	9	—	16
Ictiobus bubalus	4	14	17	9	12	1	18
Catastomus commersonii	11	91	37	29	52	31	88
Catastomus nigricans	—	33	16	87	35	16	26
Moxostoma aureolum	10	12	31	62	27	3	11
Moxostoma breviceps	—	1	14	15	6	8	12
Cyprinus carpio	11	34	43	46	72	—	62
Campostoma anomalum	14	63	66	34	41	62	84
Chrosomus erythrogaster	—	a	13	23	—	—	7
Pimephales notatus	38	a	a	a	18	a	a
Semotilus atromaculatus	2	a	a	a	a	8	a
Notemigonus crysoleucas	3	2	—	—	—	—	—
Notropis blennius	41	37	46	39	13	—	35
Notropis whipplii	2	19	27	22	26	—	7
Notropis cornutus	4	a	a	a	a	13	a
Ameiurus natalis	9	22	13	27	17	3	19
Ameiurus melas	21	42	19	36	32	9	25
Leptops olivaris	—	—	—	—	1	—	—
Umbra limi	18	9	2	4	10	—	5
Esox lucius	38	11	52	24	19	—	18
Fundulus diaphanus menona	41	10	13	9	22	16	19
Fundulus notatus	7	1	—	3	—	4	8
Eucalia inconstans	—	—	—	—	—	1	6
Labidesthes sicculus	28	19	26	20	11	2	9

(Continued)

Species	Lakes	Rivers: Ashippun	Oconomowoc	Bark	Fox	Menomonee	Scuppernong
Pomoxis sparoides	13	1	6	—	—	—	—
Amploplites rupestris	36	a	a	a	a	4	a
Lepomis cyanellus	27	25	49	23	31	8	21
Lepomis incisor	41	68	71	44	37	14	68
Eupomotis gibbosus	40	19	63	31	25	3	22
Micropterus salmoides	37	45	87	72	a	17	31
Micropterus dolomieu	17	9	2	33	17	—	—
Stizostedion vitreum	19	—	3	—	8	—	—
Perca flavescens	41	52	a	47	63	10	26
Percina caprodes	9	14	8	3	11	1	—
Boleosoma nigrum	35	57	a	a	29	33	18
Etheostoma iowae	21	5	19	5	1	3	8
Etheostoma coeruleum	8	12	17	9	16	3	11
Etheostoma flabellare	3	19	22	10	8	31	18
Roccus chrysops	9	—	—	—	—	—	—
Cottus ictalops	—	2	21	13	—	—	—
Ictalurus furcatus	2	—	—	—	—	—	—
Cristovomer namycush*	3	—	—	—	—	—	—
Coregonus albus**	2	—	—	—	—	—	—
Salmo sebago***	2	—	—	—	—	—	—
Oncorhynchus tschawytcha[0]	1	—	—	—	—	—	—
Esox masquinongy[00]	—	—	—	—	2	—	—
Etheostoma jessiae	7	2	4	1	1	—	2
Hybopsis kentuckiensis	1	a	a	a	44	23	36
Cliola vigilax	—	19	7	—	12	2	7
Esox vermiculatus	—	—	—	—	10	—	—
Hadropterus aspero	4	5	2	18	3	11	4
Lepomis euryorus	—	1	—	—	—	1	—
Lepomis humilis	—	1	1	—	1	—	—
Opsopoeodus emiliae	2	3	3	—	—	—	2
Ameiurus nebulosus	10	4	19	13	3	1	14
Pomoxis annularis	5	—	—	—	1	—	—
Aplodinotus grunniens	—	—	1	1	—	—	—
Fundulus dispar	3	—	—	2	4	1	—
Notropis atherinoides	—	3	1	1	4	—	—
Stizostedion canad. griseum	8	—	—	—	—	—	—
Schilbeodes exilis	—	12	8	2	6	1	3
Hybognathus nubila	—	—	1	—	—	—	—
Diplession blennioides	2	1	5	1	4	2	—
Notropis hudsonius	21	42	18	14	10	19	23
Microperca punctulata	4	—	—	—	—	—	—
Etheostoma zonale	5	1	9	13	1	—	8
Number of species:	48	55	53	49	51	37	46

* 690,000 planted 1877, 1878, Oconomowoc and Nagawicka lakes; no sign of the species now.
** 350,000 planted 1887 in Oconomowoc lake; probably gone.
*** 12,000 planted 1879 in Oconomowoc and Nagawicka lakes; gone.
0 6,300 planted in Oconomowoc lake in 1879; gone.
00 Formerly in several of the rivers; now exterminated.

TABLE 5

Total Planting of Fish in Waukesha County, From 1877 to 1918*
(Compiled from records of the State Game Commission)

Year	Brook Trout	Rainbow Trout	Wall-eyed Pike	Carp	Black Bass Fry	Black Bass Finger-ling	White Bass	Perch	White-fish	Lake Trout	California Salmon	Land-Locked Salmon
1877	10000									360000	(1) 4800	
										330000	—	
1878	—										(2) 1500	12000
1879	—											(2)
1880	—											
1881	20000											
1882	20000											
1883	10000											
1884	20000	20000	1300000									
1885	15000	—	2650000									
1886	55000	—	850000	135								
1887	50000	30000	1100000	250					350000			
1888	85000	—	800000	975					(1)			
1889	90000	85000	1200000	75			2500					
1890	80000	165000	2080000	200			—					
1891	80000	80000	1800000	800			—					
1892	50000	80000	300000	750			—					
1893	25000	10000	800000	100	14000		—					
1894	40000	—	1500000	50	9000		1700					
1895	16000	—	3400000		27500		—					
1896	25000	40000	1500000		35600		5050					
1897	14000	6000	1800000		—		3525					
1898	33000	40000	2850000		15200		7800					
1899	20000	—	2660000		15900		2500					
1900	33000	40000	8960000		—		—					
1901	18000	25000	1800000		—		—					
1902	40000	22000	2000000		3600		—					
1903	24000	30000	1740000		45000		—					
1904	—	—	100000		44000	10300	—					
1905	15000	6000	6850000		30000	1800	5950					
1906	17500	7500	5480000		127000	—						
1907	20000	15000	2400000		50000	—						
1908	42000	27000	9100000		4000	44300						
1909	28500	20400	11800000		27700	46000						
1900	30000	46500	3720000		96000	12300						
1911	40000	32000	22020000		47500	14275						
1912	103000	22000	16900000		6000	—						
1913	76000	27000	11670000		12000	111925						
1914	93000	51000	8795000		—	102000						
1915	95400	39200	6672000		—	91000		3840				
1916	56000	26400	7192000		—	4847		4440				
1917	48000	44200	5690000		115500	—		4200				
1918	42000	57800	8950000		122500	—		—				
Total:	1579400	1095000	165429000	3335	848000	438747	29025	12480	350000	690000	6300	12000

(1) Oconomowoc Lake. (2) Nagawicka Lake.
* No accurate data are available since 1918.

TABLE 6

Plantings of Pike, Black Bass and White Bass in Certain Lakes, Between 1895 and 1908 inclusive*

Lake	Wall-eyed Pike	Black Bass	White Bass
Oconomowoc	2,900,000	43,600	3,850
Pewaukee	5,140,000	68,950	1,000
Okauchee	5,065,000	59,200	4,900
La Belle	3,200,000	30,100	4,050
Pine	2,175,000	11,500	2,625
Nemahbin	2,720,000	26,400	1,500
Nagawicka	4,735,000	26,100	2,250
Silver	1,850,000	4,600	200
Nashotah	3,650,000	8,500	1,600
Keesus	920,000	9,000	—
Beaver	1,900,000	28,100	700
Moose	1,550,000	35,100	—
North	60,000	—	—
Ashippun	1,050,000	3,000	—
Lake Five	1,430,000	—	—
Eagle	2,210,000	7,750	—
Forest	200,000	4,500	900
Crooked	150,000	7,000	500
Fowler	2,250,000	4,500	500
Hunter	180,000	27,000	—
Golden	—	20,000	500

* No tabulated data available since 1908.

THE BROOK SILVERSIDES *LABIDESTHES SICCULUS* (COPE)

INTRODUCTION AND DESCRIPTION

The brook silversides, *Labidesthes sicculus* (Cope), which in southern Wisconsin is characteristically not a brook species at all, being found most commonly in clear water lakes, is one of the most abundant and typical species of lake minnows found in Waukesha county. While its abundance varies considerably in the different lakes, yet it has been found in all of the lakes of considerable size (28 in number, table 4) and is conspicuously absent from the small, muddy-bottomed ponds, and from all lakes and rivers whatsoever their size in which the water is not clear.

This little species is the only Wisconsin representative of the family Atherinidae of Linnaeus (1758). These fish, known generally as the "friars" or "silversides" compose a family whose members are typically salt water forms. The family is composed of sixteen genera and about seventy species, none of which attains a large size. Among the more familiar genera can be listed Atherina, the friars; Chirostoma Swainson; Menidia (Bonaparte) Jordan and Gilbert; Atherinopsis Girard; Atherinopus Steindachner; and Labidesthes Cope. Of these genera, Menidia is the closest to Labidesthes both in morphological characters and in general habits, as Menidia, typically a marine genus, often ascends streams and rivers, passing from the brackish water environment to the fresh water conditions beyond the tidal zone. Structurally Labidesthes differs from Menidia in the prolongation and depression of both jaws to form a "beak" which characteristic gives the name to the genus—"a pair of forceps." The name is well chosen, and gives a clear picture of the daintiness of the mouth structure. The Atherinidae are all carnivorous in their habits and in common all the species have a straight gut lacking entirely pyloric ceca. The small size of the individuals makes them of little economic importance as food fishes but those which reach a size sufficiently large to warrant attention are highly valued as food, hence the common name of some of the marine species: "Pez del Rey"—fishes of the king! This applies particularly to the genus Menidia, and more especially to *Menidia sardina*.

The genus Labidesthes was created by Cope in 1870 to hold the type species, *sicculum*, originally described by himself as *Chirostoma sicculum* in 1865, the type specimen coming from the region of Grosse Isle in the Detroit river. This places the type locality as the inlet of the Detroit river into Lake Erie, some twelve miles south of Detroit, Michigan. The genus comprises a single species, of which the following description is given by

Jordan and Evermann (1896: 805): "Head 4½; depth 6; eye 3½; D. IV-1, 11; A. 1,23; scales 75. Body elongate, very slender, compressed. Head long, flattened above, narrow below. Snout slender, conic. Premaxillaries broad posteriorly, very protractile, produced forward, the snout longer than the eye. Edge of upper jaw strongly concaved. Teeth very slender, mostly in one series, forming a narrow band in front. Scales small, thin, with edges entire (cycloid). Spinus dorsal very small; soft dorsal short. Anal fin long, caudal forked; pectorals moderate. First dorsal inserted somewhat behind the vent. Pale olive green, translucent; lateral silvery band very distinct, scarcely broader than pupil, bounded above by a dark line; back dotted with black. In the black waters of the lowland swamps the silvery is underlaid by black. Length 3½ inches. Ponds and sluggish streams; Lake Ontario and southern Michigan to Iowa, Florida and Texas; locally abundant; a very graceful little fish, widely distributed, confined to fresh waters." The present writer can offer no improvement on the above description beyond pointing out the fact that the tendency of the black pigment to underlie the silvery band is evident in a vast majority of the specimens from southern Wisconsin where the water is anything but like the "black waters of the lowland swamps."

In spite of the familiarity of all ichthyologists with this attractive species, and despite the fact that it is listed as common or abundant in practically every list of fishes of the Mississippi valley, no comprehensive study of the species has been published, nor are observations of the habits or general behavior of the species to be found in other than the most general terms. "Beyond observations that Labidesthes remains near and feeds at the surface and that it frequently skips through the air, nothing has been published concerning the habits of this fish" (Hubbs 1921). Notes on its food have been presented by Forbes (1878, 1883, 1888), Forbes and Richardson (1908), Baker (1916, 1918), Evermann and Clark (1920), Pearse (1915) and Hubbs (1921). This represents the status of our knowledge at the time of publication by Hubbs (1921) of his ecological study of the life-history of the species in 1921. This report contributed considerable to our knowledge of the species and pointed out several problems which enter into the life-cycle of the fish from a behavioristic standpoint. Explanations of these problems are offered, but they are essentially theoretical in nature, and the present writer, as a result of five years of observations and as a result of experimental procedure, finds it necessary to disagree with Hubbs in some of his conclusions. Several important points in the behavior of the species have been entirely overlooked by the previous author, and several errors appear as a result no doubt of having failed to find these facts. Thus he says: "In striking contrast to their intense activity by day, the adults at night were observed to lie quiescent as though asleep." This statement points to entirely erroneous conclusions, for under certain conditions, and at certain times of the year the "intense activity" of the species during the day is as naught compared to the frenzied activity of the species *at night*. A small point, perhaps, but the key to many of the problems requiring solution in a study of the life history of the silversides.

BREEDING HABITS

The adult of *Labidesthes sicculus* is primarily a shallow water inhabitant. After the fish has attained approximately two thirds of its mature size, the species takes up permanently a shallow water habitat which is in direct variance with the habits of the immature fish. Both young and adults are surface species, living normally within less than a meter of the surface of the water, and spending most of their time within ten or twelve centimeters of the surface. Indeed, the species is the most consistently "top-water" fish in these fresh water lakes, distinctly more so even than the gar, *Lepisosteus osseus*. The gar often seeks very deep water when it feeds, grasping a minnow sidewise the fish descends at an angle of about 45° to a depth of from ten to thirty feet, where the juggling which accompanies the adjustment of the food into a position permitting its entrance into the small mouth takes place. After feeding the gar may remain in the deep water for some time, upward of fifteen minutes, before ascending slowly to the surface. The silversides never under any conditions descends below the upper meter of water, this being the maximum depth sought by the adults, while nothing can drive the immature individuals more than a few centimeters below the surface. Hence the statement that the silversides is the most characteristic of our surface fishes. It is as typical of the upper stratum of water as the Johnny darter (*Boleosoma nigrum*) or Miller's Thumb (*Cottus bairdii bairdii*) is of the very bottom of the lakes and rivers.

The breeding habits occur during May and June under normal, seasonable conditions, the exact time being closely correlated with the temperature of the water. As the surface waters warm up under the influence of the May sun, the silversides are to be seen swimming near the shores often in pairs. As there is no sexual dimorphism it is impossible to distinguish the sexes while the fish are in their element, but repeated captures and laboratory examinations show that the two individuals associated at this time are male and female. The fishes often swim in perfect alignment, one *above* the other, a distance of approximately ten inches to a foot intervening. This alignment is under the control of the upper fish which, because of the position of the eyes, can keep the lower individual under observation. This was repeatedly borne out by observations which showed the fact that when the path of progression deviated from a straight line, the first sign of the turning was made by the lower fish. The upper fish is the male, the lower the female. Frequently two, three or more males may be associated with a single female during the height of the spawning season, but this poly-association usually terminates by one of the males driving away the others. During the early part of the breeding season the progress of the fish is leisurely, a foot being traversed in from three to four seconds. As the breeding season advances and the water warms up still more, the speed of progression increases until the fish travel in spurts, covering a foot in a fraction of a second and often breaking water. At the same time the interval of alignment has been decreased to about two inches, and finally, as the breeding season reached its peak, the position is shifted to a *horizontal* one, the male following the female which travels at a furious pace. A school of silversides reveals a wild sight when the spawning activities are in full sway. In and out dart the females, pursued by one or more males, darting this way and that, shooting an inch or more out of the water and landing again three or four inches from the spot of their emergence amid a spatter of spray, followed immediately by the attending male retinue. Suddenly the female slows down her pace and comes to what amounts to *comparative* rest. The first male to reach her approaches from the rear and draws up along side. This apparently is the signal for the departure of any other males that may be pursuing that particular female, for never have I seen any disturbance once a male is associated along side of a female. Other males simply disperse and join in the chase of other females. The paired fish now begin a downward glide, approaching the bottom at an angle of approximately 30°. During the descent, the fish bring the edges of their abdomens into repeated momentary contacts—from eight to twenty-one times being the extreme numbers observed, with fourteen as an average of forty-six observations. During the descent the eggs are extruded from the body of the female and may be seen slowly settling toward the bottom in the wake of the descending pair. Fertilization takes place in the water immediately after the eggs leave the female, the spermatozoa being extruded by the male coincident with the momentary contact with the abdomen of the female. By the time the pair reach the bottom the egg complement has been deposited. Observations on twenty-six females captured immediately after the completion of the descent, show the ovaries empty, with only occasionally (three cases) some half dozen eggs still retained. Normally the female is entirely spent on the completion of a single breeding performance, and hereafter she is completely ignored by the still active males. The males, on the other hand, hesitate not at all on the completion of the breeding descent, but ascend at once to the surface and are off in pursuit of other females.

A series of observations over four breeding seasons in which a series of temperature readings of the water was taken during the period of breeding activity, shows that the vertical pairing of the fish begins when the water has reached a temperature of 18°C (64.4°F), that the spawning begins at a temperature of 20°C (68°F), and reaches its climax with the water at a temperature of 22.4°C (72.9°F), the place of observation being the north shore of Oconomowoc lake, where the silversides breed abundantly over the sand and gravel bottom. These facts are brought out in table 7.

TABLE 7

TEMPERATURE OF WATER OF OCONOMOWOC LAKE ASSOCIATED WITH BREEDING PHENOMENA OF *LABIDESTHES SICCULUS*

	Degrees Centrigrade				
	1920	1921	1922	1923	Av.
Vertical pairing first noted	18.3	17.8	17.7	18.2	18.0
First spawning noted	20.3	20.0	20.0	19.7	20.0
Climax of spawning	23.2	22.1	22.3	22.1	22.4

After extrusion the egg settles slowly to the bottom. It is armed with an "organ of fixation," consisting of a single gelatinous filament of a length equal approximately to six times the diameter of the egg. This is called by Hubbs an organ of *flotation*, but its primary function seems, rather, to be that of *fixation*. It adheres to the first thing with which it comes in contact, either vegetation or bottom material, and the egg is firmly attached. Where spawning occurs in rivers, the secondary function of flotation may well be of some importance in relation to distribution by current, but as the species is so active and this activity carries it such long distances, this slight distributional value must be regarded as subordinate to the fixation function. As the egg itself is not at all viscous, it would become buried in the debris and sand at the bottom, did it not become fixed before reaching it.

DEVELOPMENT

Nothing whatever is known regarding the embryological development of the species, and the present writer has not considered this phase of the life of the species as within the scope of his problem. That development is quite rapid is indicated by the fact that eggs hatched in eight days in the writer's laboratory in water kept at approximately 25°C (77°F). This temperature is two degrees above that of the lake from which the specimens were taken. Observations on eggs located in the lake and observed daily indicate that the hatching period is very close to 8 days (between 8 and 9) with the water at 23°C. That temperature affects the rate of development is very probable from what is known concerning other species, in which the rate of development increases with an increase in the temperature of the water; therefore one would expect a variation in the normal hatching periods of the eggs in a lake depending upon the fortuitous chances of the eggs becoming fixed in water of varying depths. For it must be remembered that since the eggs are laid in shallow water, a considerable range of temperature variation will be encountered, the range being greater the shallower the water is. One would therefore expect the eggs that drift into shallow water to hatch earlier than those that settle in deeper water, as they receive more degree-hours of heat per day. Such conclusions are borne out by the facts as shown in table 8.

TABLE 8

EFFECT OF DEPTH OF WATER UPON THE HATCHING PERIOD OF EGGS OF *LABIDESTHES SICCULUS*

Depth of water: inches	Eggs laid	Eggs hatched	Average noon temp.	Time required
16	6/14/23	6/22/23	24	8
22	6/14/23	6/23/23	23	9
29	6/14/23	6/23/23	23.2	9
37	6/15/24	6/24/24	.22.8	9

THE YOUNG

Immediately after hatching the young silversides wiggle themselves to the surface. The term "wiggle" is used advisedly as best describing the action of the young fish: the activity consists of much lateral movement with relatively little forward progression. The activity of the fish begins before it leaves the egg, and is responsible for the rupture of the egg membranes and the subsequent liberation of the fish. Once the young reach the surface it is a long time before they see the bottom of the lake again, for they remain permanently just under the surface of the water for the following weeks, and never forsake the upper few centimeters under any circumstances. Their relation to the surface may be stated in these terms: the younger the fish the closer to the surface film of the water do they remain. Newly hatched Labidesthes frequent the upper three centimeters or less of their habitat.

As they hatch, then, the young work to the surface, where they congregate in rapidly increasing numbers. Inasmuch as the eggs laid by a single female in the course of her breeding activities do not scatter very far—there is no current in the lake sufficient to cause a wide dispersal—all hatch at very nearly the same time. Thus are built up at the surface schools of young silversides varying in component numbers from thirty to perhaps two hundred. The individual fish are constantly active, swimming around in a course conspicuous for its irregularities. Yet there is a certain coordination within the school: if the school is going ahead, all the members are going in a course almost exactly parallel to each other; if the school veers to the right, all the members shift in the same direction and almost at the same instant. While the course of the school is therefore very irregular and the progress in any one direction slow and uncertain because of the many turnings and twistings of the path of progression, the school is very evidently heading for the deep water, or rather, for the surface water over a pelagic habitat. For be it remembered that of the deep water itself and its contents, *Labidesthes sicculus* knows nothing, nor in its entire existence does it ever learn by exploration what the depths contain.

By the end of the first day the young are well out of the shallows, but unless the deep water be close to the shores—that is, unless the sand bar is narrow—they will still be over relatively shallow water. The one outstanding feature of the behavior of the young during the day is their activity; during three years of intensive observation on the species the writer has *never* seen a living, healthy silversides that was not in action. While I have seen hundreds of thousands of these little fish in dozens of different lakes and streams of every size, I have never during the hours of daylight, seen one at rest for a period of time measurable with a stop-watch. It is by all odds the most active minnow of our fresh waters, and were it not for the fact that this activity is, during most of the year, confined to the hours of daylight, I would venture the statement that it is the most active of all our fresh water species. As it is, this honor must go to the cisco (*Leucichthys artedi*) later to be discussed, which is active day and night the years around. Yet, during the hours when it is active, no fish is more active or vigorous. Certainly no fish covers more distance in the course of the hours of daylight than does this, in relation to its size. Some idea of this activity is brought out in the following experiment: Six young silversides were brought into my laboratory and placed in a large boiler, where they were permitted to swim around and get over any shock their transfer from the lake might have caused. Two hours later, when their activities were perfectly normal, a tracing was made on a large sheet of wrapping paper of their individual movement for a period of two minutes. While watching the movements of an individual fish I traced as nearly as possible its every movement. At the end of the experiment the distance traveled was measured. The results follow.

TABLE 9

DISTANCE TRAVELLED IN TWO MINUTES BY YOUNG *LABIDESTHES SICCULUS*

Fish No.	Length cm.	Distance cm.
1	2.2	176
2	2.4	234
3	2.0	211
4	2.2	220
5	2.1	209
6	2.3	216
Average:	2.2	211

On this basis one can figure as follows: 211 cm in 2 minutes; that is 6,330 cm per hour; and since this is early summer, one can figure at least fourteen hours of activity, which gives 88,622 cm traveled in the course of a day, by a fish that is 2.2 cm long. That is 40,283 times its length!

Throughout the day these tiny, semi-transparent fish work their way incessantly back and forth just under the surface of the water. Their small size, together with their inconspicuous coloring and nearly transparent bodies affords them a protection against wandering enemies, both in the water and in the air. At the approach of a boat the school breaks up immediately, the individuals darting like lightning in every direction except down. When the school is broken up the tiny individual fish is extremely difficult to see, while its zig-zag course makes it difficult to capture even after it is discovered. The approach of a tern (*Clidonias nigra surinamensis* or *Sterna hirundo*) sends the fish scattering wildly, and a similar reaction follows the approach of a larger fish either from below or from their own level. This indicates a keen alacrity on the part of the silversides, which no doubt saves many of them from destruction, for they have many enemies.

With the coming of darkness, however, all this changes. The incessant activity dies down with the failing light until darkness finds the fish entirely inactive, floating motionless just under the surface. Thus they remain throughout the night, drifting back and forth with the waves, or hanging suspended under a glassy surface. Little co-ordination exists within the school at night, for a spotlight flashed upon the school shows the fish pointing in all directions: there is no marked orientation. This is particularly true on quiet nights. When the surface is agitated by wind, however, there is a vague indication of orientation with a tendency on the part of the individuals to head into the waves. The following table (10) shows the results of a series of observations on orientation in relation to the prevailing night wind.

TABLE 10

ORIENTATION AT NIGHT OF *LABIDESTHES SICCULUS* IN RELATION TO WIND

Date	No. fish in school	Direction wind	Number of fish heading S	SE	SW	W	E	N	NE	NW
8/6/23	31	S	*8*	4	5	3	5	0	2	4
8/12/23	49	SE	6	*12*	9	5	2	5	3	7
8/13/23	26	None	3	5	2	4	3	2	4	3
8/20/23	44	S	*12*	6	8	4	5	3	2	4
8/25/23	58	S	*16*	10	4	8	7	4	5	4
8/27/23	36	E	5	5	4	0	*11*	3	5	3
8/30/23	41	None	3	2	7	6	4	9	6	4
9/12/23	22	N	0	1	0	0	1	*12*	2	4

It will be noted that in every case the tendency is to orientate to face the waves, but in only one case is even one-half of the school oriented.

As the writer had no instrument for measuring the light intensity, the Eastman Kodak Company's exposure-meter was used as the basis for the determination of the amount of light present when activity ceased in the evening and began again in the morning, and this method proved satisfactory in as far as it goes. The principle involved in this instrument is the exposure of a piece of photographic paper until it darkens to match a color shade on the dial of the instrument. Since one piece of paper may be used twenty times or more by exposing only a small surface of it at a time, the method of comparing light intensities is fairly accurate after one has had a little experience matching colors. As a result of a series of experiments dealing with the intensity of light at which activity ceases at night and begins again in the morning, the writer finds that the light is slightly less intense when activity begins than when it ends. This conclusion is reached from the following data:

TABLE 11

TIME REQUIRED FOR PHOTOGRAPHIC PAPER TO MATCH DIAL SAMPLE COLOR, IN THE MORNING AND EVENING AT THE TIME ACTIVITY CEASES AND BEGINS AGAIN

	Time in Seconds	
	Morning	Evening
	64	53
	72	70
	56	58
	53	44
	65	50
	62	61
	59	46
	61	54
	55	43
	70	62
	62	60
	88	52
	74	48
	64	46
	67	52
	64	50
	68	44
Average:	65.32	52.59

Since the length of time required to darken the paper is a measure of the light intensity, and since the more light present the shorter will be the time required, one may say that the time required is inversely proportional to the amount of light present. In the case of *Labidesthes sicculus* it appears, then, that the fish are 23.44% more sensitive to light in the morning than they were in the evening. From this one must conclude that the sensitivity of the fish to light increases in the absence of light, which is perhaps not surprising when one recalls that the fish lives at the very surface of the water where it receives at all times the maximum amount of light. This sensitivity to light following a period of darkness was checked in the laboratory by confining a number of fish in the total darkness of a photographic dark room for varying periods of time. Each fish was kept in a separate dish, and the following data were taken (table 12):

TABLE 12

LIGHT INTENSITY IN TERMS OF SECONDS OF EXPOSURE OF THE EXPOSURE METER, AT WHICH FISH REACT AFTER CONFINEMENT IN DARKNESS FOR VARYING PERIODS OF TIME

Fish number	Number of hours kept in dark			
	34	48	72	96
1	54	47	42	48
2	63	44	39	42
3	58	46	38	40
4	60	48	42	42
5	52	30	33	28
6	50	34	30	32
7	46	30	25	25
8	41	42	40	38
9	49	44	36	36
10	55	46	38	36
Average:	51.8	46.1	36.2	36.7 seconds

In this experiment the light from a 100 watt Mazda light was permitted to fall upon the fish, and the length of time required for their reaction was noted. Thus one finds that up to a certain point, namely 72 hours, the sensitivity to light increases, and that beyond this point there is practically no change. Confinement in total darkness for 48 hours has increased their sensitivity 11% over what it was when confined for 24 hours; that this sensitivity is increased 21.25% when the fish are confined in darkness for 72 hours over that recorded for the 48 hour period, and that the total increase in sensitivity is 30.11% when kept in the dark for 72 hours over that recorded for the 24 hour period. This bears out one of the fundamental principles of physiological ecology: that a factor becomes of increasing importance to an organism when there is the least of it.

GROWTH OF THE YOUNG

During the period immediately following the hatching, the young silversides grow rapidly. This growth approximates very closely the surprising total of a millimeter a day for a period of nearly two weeks, this period being the first two weeks of the life of the minnow. This period of rapid growth gradually passes into one of slower increase, which lasts from about the second week in July through August. A second rapid growth period starts about the first week of September and continues for about three weeks, ending with the cooling of the water late in that month (see figures 11 and 12, which should be considered together). By the end of September the fish have reached a length of 6.5 cm, and this length is not increased during the winter period, as specimens caught in December, February and April show no appreciable increase in length. As the water warms up toward the end of April, however, a new growth stage is inaugurated with the increased activities of the fish, so that the mature size of 7.62 cm is reached at about the spawning season, though data indicate that there is often a slight growth even after the deposition of the eggs. In obtaining data from which these conclusions could be drawn regarding the growth rate of the species two hundred and fifty individuals were measured and the average of the lot was taken as the mean size on the date of capture. Figure 13 shows the number of individual fish of different lengths as taken on August 1, 15, 29, September 12 and 26. Two precautions were taken to unify the results: all adults captured were excluded from the tabulation, and the individuals used for measurements were obtained from as many schools of fish as practicable without too much waste of time in hunting for them, as the schools of very young Labidesthes are at times provokingly difficult to locate in a large lake. During the months of ice, the species is rather difficult to capture, as the number of individuals is greatly reduced (the reason for which I shall discuss shortly) the schools are very much broken up and the fish somewhat sluggish in movement. The following table shows the number of fish measured on different dates, together with the average size of the individuals involved. In all cases the measurements were taken from the tip of the snout to the base of the caudal fin.

In this table correction must be made for those variations which have been starred because of the small number of individuals involved. The small numbers are due to the difficulties encountered in securing the fish during the period when the lake is covered with ice. The figures, however, tend to indicate that there is no appreciable increase in size during these months.

It is interesting and important to note that the change in growth rate which occurs toward the end of July, as shown in figure 22, is intimately correlated with two important changes in the habits of the fish: 1) the assumption of a shallow water habitat in place of the deep water situation; and 2) the change from an entomostracan diet to a mixed ration of entomostraca and insects, which is merely a transition stage leading to a culmination in an almost entirely insectivorous diet which is characteristic of the

TABLE 13

MEASUREMENTS OF *LABIDESTHES SICCULUS* FROM LAKE OCONOMOWOC FROM JUNE, 1922, TO JULY, 1923

Date	No. Fish	Average length in mm	Growth in mm
6/22/22	254	11.2	—
6/29/23	250	20.0	9.8
7/6/22	252	28.6	8.6
7/13/22	255	35.8	7.2
7/20/22	255	39.1	3.3
7/27/22	253	40.2	1.1
8/2/22	250	41.9	1.7
8/17/22	252	46.2	4.3
8/31/22	253	48.8	2.6
9/7/22	250	53.3	4.5
9/14/22	250	58.0	4.7
9/28/22	251	63.9	5.9
10/5/22	250	65.1	1.2
10/12/22	255	65.5	0.4
10/26/22	250	65.6	0.1
1/3/23	10	65.6*	—
2/5/23	8	65.2*	—
3/2/23	21	65.5*	—
4/6/23	35	65.4*	—
4/27/23	15	64.9*	—
5/4/23	112	65.6	—
5/18/23	170	68.6	3.0
6/1/23	185	72.2	3.6
6/8/23	116	73.0	2.2
6/22/23	80	75.2	2.2
7/6/23	110	76.0	0.8
8/1–9/1/23	370	76.2	0.2

* Numbers too small to be significant.

adult. This point will be discussed in detail under the heading of food habits. The change from the position over deep water to the shallow water habitat will be considered at once.

MIGRATION OF THE IMMATURE FISH

I have repeatedly stated that after hatching the young leave the shallow water and travel toward the deep. During the first month or six weeks after hatching the silversides is to be found *only* over the deep waters of Oconomowoc lake and other bodies of water investigated (La Belle, Fowler, Golden, Silver, Upper and Lower Nashotahs and Nemahbins, Okauchee and Pine lakes). Occasionally a school will be located well over the edge of the sand bars in water from three to five meters deep, but far outnumbering these are the schools found over the water of a depth of from 10 to 20 meters. During July, 1923, the writer located 460 schools of silversides in Oconomowoc lake, and measured the depth of the water at the point where the schools were found. Every effort was made to equalize the search over both shallow and deep water, and an equal length of time was spent hunting for schools in water of the different depths. The results are shown in table 14. Since the edge of the bar occurs in water between 5 and 6 meters deep, a total of 14.77% of the schools occurred upon the bars as against 85.23% over the deep water. The difference is sufficient to show a decided preference on the part of the fish for a pelagic habitat over deep water.

TABLE 14

THE DISTRIBUTION OF SCHOOLS OF YOUNG LABIDESTHES OVER WATER OF DIFFERENT DEPTHS (OCONOMOWOC LAKE) IN JULY, 1923

Depth in meters	Number of schools	Percent of total
0–1	0	0.00
1–2	2	0.43
2–3	14	3.04
3–4	18	3.91
4–5	12	2.61
5–6	22	4.78
6–7	16	3.48
7–8	14	3.04
8–9	31	6.75
9–10	20	4.35
10–11	16	3.48
11–12	44	9.57
12–13	31	6.75
13–14	36	7.83
14–15	32	6.97
15–16	29	6.30
16–17	40	8.70
17–18	16	3.48
18–19	36	7.83
19–10	31	6.75
	460	100.00

However, this distribution of immature fish undergoes a radical change toward the end of July. This fact was discovered quite by accident while investigating a very different problem—the distribution of the shore fish at night as compared to daylight dispersal. Beginning late in June, 1923, the writer collected the fish present along a given strip of shore line on Oconomowoc lake after dark and again at noon over the same area and listed the species found. This area was seventy-five feet in length and was dragged with a twenty foot fine meshed minnow seine. Silversides were found in almost every collection, but more commonly at night than in the day time, and all the specimens were fully grown. It was decidedly interesting, therefore, to find, on the night of July 10, five young silversides in the collection, these young averaging 1.4 cms in length—evidently early-hatched young of the year. Not one was found in the day seinings. Hereafter, with occasional exceptions, young Labidesthes were found every night in the shallow water, and were conspicuously absent during the day from the same region. The one factor which kept the fish from the shallows at night was the condition following occasional heavy rains when the shallow water was in a state of great turbidity. Attention was therefore centered on this migration phenomenon and its progress investigated from various angles. Beginning with July 21, an increase in the number of silversides found each night was noted, and this increase reached its climax on August 6, when the astonishing total of 621 young silversides was collected in a single drawing of the net. Investigation was immediately started at other points along the shore to determine if this was merely a local condition, with the following results:

TABLE 15

DISTRIBUTION OF YOUNG *LABIDESTHES SICCULUS* IN OCONOMOWOC LAKE ON THE NIGHT OF AUGUST 6 IN RELATION TO TYPE OF BOTTOM SELECTED

Type of bottom	Location	No. fish found
Gravel	North shore	621
Sand	South shore	316
Gravel	South shore	508
Rushes on gravel	North shore	141
Potamogeton on gravel	Northeast shore	12

From this table two conclusions can be drawn: 1) that the condition noted was not a local exception but a general rule, that throughout the lake there was a great inshore migration of young silversides; and 2) that these young fish showed a preference to a gravel bottom relatively free from plant growth, that the increasing abundance of vegetation reduced markedly the number of young inhabiting the location. A mechanical error may creep into these figures because of the increasing difficulty of drawing a seine through heavy weeds, but as the silversides is strictly a surface inhabitant, this error is reduced to a minimum as the surface water is covered with reasonable efficiency even in the presence of heavy bottom vegetation. The next morning the same areas were re-seined, with the result that only 38 young were found. Of this number 21 were evidently injured, and probably were cripples left over from the night seining—for it must be said that every effort was made to replace the fish as quickly as possible after they were caught, and with the least possible injury. Since, therefore, the fish have returned to the deep water again in the daytime, a third conclusion can be drawn from the facts: 3) that this migration is a nocturnal-diurnal phenomenon. Figure 14 shows the abundance of the silversides along seventy-five feet of the north shore of Oconomowoc lake at night, from July 10 to September 24, 1923.

Once the fact of this nocturnal-diurnal migration was established, the next step was to accumulate the facts concerning it: the time at which it occurred both in the morning and at night; the conditions existing when the migration did not occur as well as when it did occur; a correlation between light conditions and migration; chemical conditions of the water in possible relation to the movement, and various other phases of the problem. These will now be discussed.

The fact that young *Labidesthes sicculus* proceed after hatching to a pelagic habitat over deep water, while the adults select a shoal environment was noted by Hubbs (1921), who dismisses the subject with the single sentence: "As these young fishes rapidly grew during the summer, they showed less aversion to shoal waters." It is evident, therefore, that Hubbs has missed entirely the tremendously interesting fact of the nocturnal migration.

In an effort to analyze the change in preference from a suprapelagic habitat to a shoal environment as the fish ages, Hubbs offers a series of possible causes, and rejects them all in turn. It is well to summarize his conclusions briefly, 1) Temperature: this is cast out as a deciding factor as the difference in temperature of the water inhabited by the young over deep water and the adult over shallow water is too small to be effective and is wholly inconclusive. 2) Light: since both adults and immature live very near the surface the light intensity for each would be essentially the same. 3) Oxygen: the amount of oxygen is so nearly the same in both habitats and the range overlaps to such an extent that this is eliminated as the causing factor. 4) Food: is eliminated on the grounds that food is abundant where the species is not found. 5) Protection: is eliminated on the ground that the young were found to "avoid shoals even when other fish were not in evidence" nor "can the seclusion from enemies explain the invasion of the shoals by these young silversides in the *late summer*, nor the exclusive presence there of the adults." 6) Reaction: Hubbs reaches the conclusion that the young have a negative reaction to large objects, hence seek the uniform environment over deep water, and bases his conclusions partially on the fact that the fish "swam away from the boat" as it approached. Had Hubbs hit upon the night movements of the fish, this conclusion would have had to be given up.

The discovery by the writer of this nocturnal diurnal migration puts an entirely different aspect on the problem, which becomes not what causes the young to assume a different habitat from the adult during the early summer and causes them to come back again to the shallow *late in the summer*? but: what are the factors at work that result in the production of this daily migratory phenomenon?

1. Temperature: The writer agrees with Hubbs that there is relatively little difference between the surface temperature over deep water and over the shallows if he specifies *during the day* (which he does not) but with the new turn the problem has taken, a more careful study of temperature relations and conditions must be considered before any conclusions are drawn.

The following table (16) shows a series of temperature readings made over shallow and deep water at 10 o'clock in the morning and again in the same place at 3 o'clock in the afternoon. These readings were made over

TABLE 16

SURFACE TEMPERATURE OF OCONOMOWOC LAKE OVER SHALLOW AND DEEP WATER

Date	Surface temperature over water 1 m deep		Surface temperature over water 16 m deep	
	10 A. M.	3 P. M.	10 A. M.	3 P. M.
6/10/23	18.4	19.5	18.1	18.7
6/20/23	25.3	27.4	25.1	26.7
6/30/23	28.4	29.6	28.2	28.3
7/18/23	27.7	27.9	27.5	27.6
8/1/23	30.8	31.4	29.6	29.8
8/16/23	25.6	25.8	25.4	25.2
9/1/23	30.0	30.9	29.7	29.9
9/24/23	28.4	28.6	28.3	27.8
10/12/23	14.4	14.5	13.6	13.9

locations in which silversides were found, and represent the relative environmental temperatures selected by the adults (1 meter deep) and the immature (over water 16 meters deep). It must be admitted that the absolute differences are slight, but it must also be remembered that fish are very sensitive to change in temperature: Shelford and Powers (1915) report a reaction to a change of 0.2°. The table shows conclusively that the adults are located in water that is *uniformly warmer* than the immature; hence the young, on establishing themselves permanently in the shallow water are coming into a region of water that is uniformly a little *warmer*. It does not, however, explain why the young seek the deeper water to begin with.

Turning now to an examination of the temperature conditions over shallow and deep water during the day and night, I find a situation a little more definite, and results a little more decisive. In compiling the following table, two sets of temperature readings were taken, one just under the surface of water 1 meter deep, the other just under the surface of water 16 meters deep. With the aid of an assistant anchored in a row boat over 16 meters of water, I was able to obtain thermal readings of the two localities taken at exactly the same time. These records are tabulated in Table 17.

TABLE 17

TEMPERATURE READINGS OF WATER TAKEN AT FIFTEEN MINUTE INTERVALS DURING THE EVENING OVER SHALLOW AND DEEP WATER: OCONOMOWOC LAKE, 1923

	Over water 1 meter deep								Over water 16 meters deep				
Date	3:00	6:30	6:45	7:00	7:15	7:30	7:45	8:00	3:00	6:30	7:00	7:30	8:00
8/8	24.5	24.3	24.3	24.2	24.1	23.9	23.9	23.8	24.0	23.7	23.4	23.1	23.6
8/10	25.7	25.5	25.3	25.1	25.0	24.8	24.6	24.3	25.1	24.7	24.4	24.1	23.7
8/11	27.2	27.0	27.0	26.8	26.6	26.6	26.5	26.4	26.4	26.1	25.8	25.5	25.1
8/13	30.5	29.9	29.7	29.5	29.2	29.0	29.0	28.8	28.2	27.4	26.8	26.2	25.8
8/14	31.2	31.7	31.4	31.2	30.9	30.7	30.5	30.3	29.4	29.0	28.6	26.2	25.8
8/17	25.9	25.5	25.3	25.3	25.2	25.0	25.0	24.9	24.6	23.7	23.5	23.1	22.7
8/18	29.2	29.0	28.8	28.5	28.4	28.1	27.9	27.7	28.1	27.7	27.3	26.8	26.3
8/22	30.3	30.5	30.4	30.1	30.0	30.0	29.8	29.6	29.8	29.4	29.1	29.0	28.6
8/23	32.1	32.4	32.2	32.0	31.9	31.8	31.6	31.6	31.7	29.9	29.6	29.2	28.8
8/24	30.5	31.0	30.8	30.7	30.4	30.2	30.3	30.1	30.0	29.2	28.7	28.4	28.1
8/26	28.4	28.2	28.0	28.1	27.9	27.7	27.6	27.6	27.5	27.2	26.8	26.4	26.2
9/5	26.3	26.6	26.4	26.3	26.0	26.0	25.8	25.7	25.5	25.0	24.7	24.5	24.2
9/7	23.7	23.6	23.3	23.2	23.0	22.9	22.7	22.4	22.2	21.9	21.6	21.2	20.8

A study of this table will show a number of interesting and important facts. To begin with, it will be noted that there is consistently a slight difference in temperature over the shallow and deep water, and that the shallow water is consistently warmer than is the deep. In the second place it should be noted that the shallow water retains its heat better than does the deep water—that is, the surface water in the shallows tends to cool off less rapidly than does the surface water over the deep. Thus a greater drop in temperature is noted, in a short time over the deep water than over the shallows, and this occurs where the water is already cooler. This is due very largely to the fact that much heat is retained by the sand and bottom material, and tends to replace the heat given off by surface radiation. Therefore, while the difference in actual temperatures is, as has been said, not great, there is a decidedly greater drop over the deep water, and this is the habitat which the young forsake *as the temperature begins to drop*. Correlated with the preceding table, the following tabulation gives further information: the time at which the young silversides arrive in the shallow water. Standing at the end of a pier in 70 cm of water the young were plainly seen coming in from the deep water. The hour of their arrival at this point was noted on the same dates as the datain Table 18 were taken. Characteristic of the shoreward journey is the speed with which the minnows travel: they swim at top speed straight for the shore. Thus, knowing something about the rate of speed with which the fish travel one can figure back and find that the shoreward migration begins at the time the temperature starts to drop over the deep water. Furthermore, be it noted that the minnows arrive *together*, which fact is significant. In from ten to twenty-

TABLE 18.

TIME OF ARRIVAL OF *LABIDESTHES SICCULUS* IN THE SHALLOW WATER DURING THE EVENING MIGRATIONS

(To be considered in connection with Table 26)

Date	Time of arrival	Weather
8/8	7:40	
8/10	7:42	
8/11	7:35	
8/13	7:35	
8/14	7:41	
8/17	7:25	cloudy
8/18	6:55	very cloudy
8/22	7:20	
8/23	7:35	
8/24	7:15	
8/26	7:08	
9/5	6:55	
9/7	6:50	

five minutes the entire silversides population of the lake is inshore. Since there is a lessening gradient in radiation as one approaches the shallower water, it is evident that the fish over the deeper water start their migration first, and move shoreward, picking up the fish nearer the shore as they advance with the drop in temperature, this bringing all the fish into the shallows within a very short interval of time.

With the coming of fall and the cooling of the water, the shallows warm up increasingly more than does the deep during the day, and relatively more heat is stored up in the bottom for radiation during the hours of darkness. Hence the immature fish, on coming into the shallow water to assume the same habitat as the adults, are seeking an environment of *warmer water*. Data indicate that, while the diurnal range of variation may be greater in the shallows than over the deep, the average condition is upward of 3° warmer. Since a factor is of increasing importance as its abundance decreases, this excess of warmth in the shallows must be considered as being important.

One other point needs emphasis in connection with the temperature problem. Observations show that cold water acts as a depressor on the silversides, for the fish are very much less active in winter than in summer. In fact, the fish are so sluggish and slow moving that, when seen under the ice in winter, one hardly recognized the dashing, darting minnow of the summer. The following figures bear out this point:

August 8, 1923. By means of a stop watch the number of vibrations of the pectoral fin were counted. The average of ten counts of 100 vibrations shows the rate of movement per 100 vibrations at a water temperature of 26.2°C as 100 vibrations in 34 seconds.

February 3, 1924. A similar experiment. The average of ten counts of 50 vibrations at a temperature of 4.5°C shows 100 vibrations in 2 minutes and 24 seconds.

This must be taken as an indication of the reduced activity of the fish due to a low temperature, as control conditions were the same in both cases. Hence it can be assumed that a drop in temperature has an effect upon the fish.

In order to ascertain whether or not the fish react to a drop in temperature, ten *Labidesthes sicculus* were placed in a galvanized iron tank four feet long by eighteen inches wide by twelve inches deep. Water taken from their own environment was placed in it, stirred up to give it a uniform temperature, and temperature readings were taken (as well as hydrogen ion concentration readings). The fish were placed in the tank and their movements noted and traced. At the beginning of the experiment the fish traveled consistently the length of the tank, turning back when they hit the ends. As soon as the normal behavior was noted, a piece of ice was suspended in the upper three inches of water at one extreme end and a subsequent tracing of the movement of each of the fish was taken (the experiment being performed separately for each fish). It was found that as the fish approached the ever increasing zone of cooler water they turned back sharply toward the warmer water, and the temperature was taken at the point at which the fish turned back. The results of one of these experiments, which has been selected as typical, is presented (Fig. 15). It will be noted that the fish reversed itself at the first 0.4°C drop in temperature, and that a drop of 0.7°C was sufficient to confine it to one end of the tank. Since the fish used in the experiment were immature individuals measuring 4.5 cm, the conclusion is warranted that the young at least are very sensitive to slight temperature changes. Their sensitivity is not quite as marked as the case of Shelford and Powers (1915) where the reaction occurred at a change of 0.2°C.

The writer can not agree with Hubbs in his statement that the light intensity is the same over deep and shallow water. In fact, when the bottom is clear sand or fine gravel of a light color, the writer believes that there can be no question but that the intensity of the light is *much greater over the shallow water*, due to the reflection from this bottom. Since the bars of Wisconsin lakes are largely light sand, plainly visible because of the clearness of the water to a depth of twenty feet or more, the writer would emphasize the fact that as the fish approach the shore over water becoming increasingly shallower, the light intensity increases in direct proportion to the closeness with which the shore is approached. Hence with the failing light of evening, *if* the fish be positively phototropic, one would expect a shoreward migration in correlation with the decreasing daylight. Does such a correlation exist? I have already mentioned the time at which the fish come from the deep. By referring once more to table 18, one will find that there is a slow but *very definite* time gradient, from 7:45 on August 8 to 6:50 on September 7. One notes, further, that on cloudy days, when the light intensity is lessened, the hour of inshore migration is notably earlier, as on August 18. These facts, coupled with the known fact that *Labidesthes sicculus* is a surface inhabitant, point to a conclusion that the species is positively phototropic. Is there any further evidence on the question? This brings us again to Hubbs' statement that at night the fish lie motionless as if asleep. Had he happened to visit the lake on a clear moonlight night, he would have seen a sight that would have caused him to alter his conclusions.

During the permanently deep water stage of the life history of the fish the young *do* lie motionless at night—motionless, that is, except for the fin movement necessary to sustain their position. But with the change in habits which propels them shoreward at dusk, certain other changes occur. If the night be dark and calm, with no moon—or at best a new or old moon—the fish come in and behave essentially as they do in the earlier stage of their history over deep water: they lie suspended, motionless. But let the moon be two thirds or more full, and the shallows becomes the scene of one of the most startling activity in the fish world. The silversides seem to go crazy, as if they were moon-struck. They dart about at a most startling speed, dashing here and there, leaping out of the water again and again, bumping into each other, splashing, circling, behaving in a most exaggerated manner. If the water be calm, the surface becomes entirely agitated by their activity so that a myriad of tiny waves dance upon its surface, and the gentle splashing of the "breaks" is the characteristic night sound of the lake. Such activity goes on during the entire night if the light holds. But let the sky become clouded and the moon be hidden, and the activity immediately dies down. That this is a phototropic reaction can not be doubted. If the moon is not sufficiently bright, no activity results; if the moon be full, but so low that the light is refracted from the surface instead of penetrating into the water, no reaction occurs. But let the point of refraction be passed and the activity begins at once. Again, late at night, let the point of refraction be again reached by the setting moon, and activity ceases. It is a phototropic reaction in response to a certain minimum amount of light. Thus one can explain not only their activity on bright moonlight nights, but their incessant activity during the daytime.

A series of simple experiments was designed to see if this activity is a phototropic reaction. On the night of August 10, with no moon present, the fish were up in the shallows, lying quiescent. A bright, focused beam from a pocket flash-light was thrown upon the water. To begin with, there were no fish in the circle of light (two feet in diameter); however, the following results were obtained:

15 seconds	after	light	was	thrown,	2 fish	were	within	the	circle.
30 "	"	"	"	"	8 "	"	"	"	"
45 "	"	"	"	"	14 "	"	"	"	"
60 "	"	"	"	"	23 "	"	"	"	"
75 "	"	"	"	"	38 "	"	"	"	"
90 "	"	"	"	"	42 "	"	"	"	"

Thus, within the short period of a minute and a half 42 fish were attracted into the circle of illumination. This experiment was performed on 32 nights under varying conditions, always with the same general results—the fish *always* came to the light. How strong was the attraction of the light on the fish? By walking out on the pier, a distance of 100 feet, shining the light in the water as I walked, I was able to lead the fish entirely around the pier again and again: they would follow as long as the light was there, with an increasing number of individuals in the procession as new fish found the illuminated area. By sitting in the back end of a row boat with an assistant at the oars, I found that I could lead the fish for quite a distance out into the lake, and once, on a very hot, quiet night, I was able to lead a little school of five silversides entirely across Oconomowoc lake, a distance of seven-eighths of a mile, in three hours and ten minutes. Seventeen fish started the trip; five arrived, the others getting lost en route. On all other occasions the school abandoned the light as deep water was reached, and here it was found that a difference in temperature of 4.3°C existed between the point where they started and the point where they turned back. How far inshore would they follow the light? With the fish normally over 30 cm of water I have repeatedly lead them inshore into water 1 cm or less in depth—up among the stones where there was scarcely enough water to float their slender bodies. Further: I have often had them leap clear out of the shallow water, up onto the dry land, when they were unable to follow the light any farther because of insufficient depth. The conclusion must be drawn that the fish are very strongly positively phototropic and that light intensity plays an important part in their migrations. The writer has been unable to demonstrate any measurable difference in the oxygen content of the upper water and over the deep water which might account for the diurnal-nocturnal movement. Repeated analysis has failed to yield any clue that oxygen is a determining factor in the migration. This conclusion is further borne out by Mr. Juday, who tells me that a demonstratable change in the oxygen content of the water during the day as compared with the night is almost unknown in his experience.

As has been already stated, a change of food habits occurs at the time the shoreward migration begins. Up to this time the food of the young has been almost entirely entomostraca, and entirely plankton organisms. An examination of the stomachs of 250 young Labidesthes taken prior to the beginning of the inshore migrations by night, shows the following results:

Entomostraca:	
Cyclops	14.5%
Daphnia	16.8%
Bosmina	35.7%
Other species	5.0%
Rotifera:	
Anuraea	16.6%
Diatomes, Algae etc	8.4%
Unidentified	3.0%
	100.0%

An examination of 250 stomachs of immature individuals taken August 12, at night, while inshore, gives the following results:

Entomostraca:	
Copepoda	5.5%
Cladocera	10.8%
Ostracoda	1.2%
Mysis relicta	10.3%
Plant remains	9.5%
Insecta:	
Diptera	35.2%
Coleoptera	9.0%
Larvae	22.4%
Unidentified	3.2%
Arachnida	1.9%
	100.0%

A comparison between these two tables will show very clearly that a great change accompanies the initiation of the migratory habits of the species, resulting in a much more varied diet when the fish enter the shallow waters. A third series of stomach examinations, consisting of 45 stomachs of adults taken on the night of August 14, gives the following tabulation:

Entomostraca:	
Ostracoda	0.5%
Copepoda	4.7%
Cladocera	12.5%
Plant remains	1.4%
Insecta:	
Chironomus larvae	58.5%
Diptera, adult	21.5%
Miscellaneous	3.6%
	100.0%

Thus there appears a transition from the micro-organism diet to a predominantly insectivorous diet, and this change in the food habits accompanies the change in environment selection. However, since entomostraca are still eaten commonly by the adults, and since insect food is notably absent over the deep water of the lake, it must be assumed that the change in food habits is a secondary one, a *result* of the changing of the environment, rather than a *cause* of it. It is a well known fact that the food habits of a species undergo radical changes as the fish grow; this has been pointed out by Forbes, Turner, Pearse, and others, but in no case has it been shown that this change causes migration or in any way disturbs the distribution of the species. However, the consideration of the cisco later furnishes an example of just this type of phenomenon. The case of Labidesthes is different, and it is necessary to consider the change in diet as characteristically an accompanying phenomenon, not a causing one.

There can be no doubt but that the habit of the young silversides in assuming a pelagic environment over deep water is a very great protection to the species. As they are for the most part the only inhabitants of these waters, they escape the very keen competition existing in the shallow water. Their very small size would make them ideal food for the dozens of species of larger fish which feed in the shallows along the shore. As it is their enemies are reduced to a minimum as long as they remain over the deep water. In this habitat they are preyed upon by the following species: *Clidonias nigra surindmensis; Sterna hirundo; Lepisosteous osseus; Leucichthys artedi* which occasionally comes to the surface and captures them; *Micropterus dolomieu; Micropterus salmoides.* The last two named make occasional raids into the region and capture a good many silver sides.

However, once the species begins its shoreward movement, the number of enemies increases tremendously. I have found remains of silversides in the stomachs of the following animals which captured the fish while in the shallow water:

Micropterus dolomieu; Micropterus salmoides; Amiatus calvus; Esox lucius; Amploplites rupestris; Lepomis cyanellus; Lepomis incisor; Eupomotis gibbosus; Roccus chrysops; Perca flavescens; Esox vermiculatus (Fox river only); *Leucichthys artedi* (during spawning season only); *Botaurus lentiginosus; Ixobrychus exilis; Ceryle alcyon; Mergus serrator; Necturus maculatus; Chelydra serpentina; Natrix sipidon; Cambarus* spp.; and *Mustela vison.*

Thus it becomes evident that the species is tempting fate when it comes inshore, and that this temptation results in wholesale destruction of the species is evidenced by the curve showing the abundance at night along the shore (Fig. 14). Here is shown the tremendous decrease in numbers that occurs between August 6 and September 6, when the silversides are reduced to such an extent that they no longer offer the wholesale food supply to their competitors. From these facts two conclusions can be drawn: 1) that the pelagic habitat is a great protection for the young as long as they remain in it; and 2) that the change from the deep to the shallow water environment is not due to enemies in the deep. Hence protection can not account for the migration toward the shore.

The suggestion of Hubbs that the species seek the deep water as an avoiding reaction against large objects falls down when the species is found returning to the shallows under cover of twilight and associating itself more closely with large objects than any fish with the exception of those characteristically bottom thigmotactic forms such as many of the species of Boleosoma, Cottus, Etheostoma, etc. Since the fish return to their deep water station again during the day, it would be hard to account for this reversal of their reaction if the behavior were merely a negative response to large objects.

In order to determine in the laboratory whether the young fish tend to avoid large bottom objects, the same tank used in the work on changing temperature was used. This time three large stones were placed near one end, and the fish permitted to swim around in the tank. The results as shown in figure 16 indicate that the fish pay no attention to the presence of large objects on the bottom. In the case of a piece of floating wood, however, the fish show a marked aversion to its vicinity. This however, is not surprising, and can be considered as nothing more than a normal reaction to an object in the path of progress. It could hardly be expected that a fish or any other animal would do anything other than avoid such an object.

This brings us to the last of the factors investigated by the writer as a possible cause of the migrations which Labidesthes performs, the change in hydrogen-ion concentration of the water. It was previously noted that there is a slight change in the H-ion concentration of the lake water from top to bottom, the pH readings (colorimetric) being higher at the surface than at the bottom (see table 3) indicating a lesser (more alkaline) condition near the surface. Inasmuch as the silversides is confined to the surface waters, it is these surface conditions that are important. The question under consideration becomes: is there any change in the H-ion concentration over the deep water that could cause or initiate the shoreward movement as evening approaches.

With the aid of the assistant, a series of readings of H-ion concentrations were made over the shallow and deep waters, a duplicate, checked series of phenol red indicators being used. Two samples of water were taken in each case, and if there occurred a material difference between the two readings, a third was immediately taken. In order that the light conditions remain constant throughout the work both day and night, a small black box was fixed to the end of a pocket flashlight, and the light sent into the box through a pale blue glass, to give as nearly a white light as possible. Both batteries were checked at the beginning and end of the work each day. A hole in the top of the box permitted the insertion of the tube containing the sample to be examined and a vertical slit made possible a clear reading under constant illumination. This precaution regarding the light was made necessary as it was found that very deceiving results were obtained as the light intensity diminished, the weakening light giving higher readings than normal light, thus leading to conclusions wholly erroneous and misleading. The results obtained over a period of a month are given in table 19.

TABLE 19

CHANGES IN HYDROGEN ION CONCENTRATION IN THE EVENING OVER SHALLOW AND DEEP WATER: OCONOMOWOC LAKE, 1923

	Over shallow water								Over deep water					
Date	3:00	6:30	6:45	7:00	7:15	7:30	7:45	8:00	3:00	6:30	7:00	7:30	8:00	
8/8	8.0	8.0	7.9	7.8	7.8	7.65	7.6	7.6	7.8	7.8	7.6	7.6	7.5	
8/10	8.1	8.0	7.95	7.9	7.8	7.7	7.7	7.65	7.8	7.75	7.7	7.6	7.55	
8/11	8.0	8.1	7.96	7.95	7.85	7.7	7.65	7.6	7.7	7.7	7.65	7.6	7.5	
8/13	8.2	8.0	7.9	7.9	7.85	7.75	7.6	7.6	7.9	7.8	7.6	7.6	7.5	
8/14	8.2	8.1	7.95	7.95	7.85	7.8	7.8	7.7	7.8	7.75	7.7	7.6	7.6	
8/17	7.9	7.8	7.8	7.7	7.65	7.65	7.6	7.7	7.7	7.65	7.55	7.5	7.45	cloudy
8/18	7.8	7.8	7.8	7.75	7.65	7.6	7.6	7.6	7.7	7.65	7.6	7.55	7.5	cloudy
8/22	8.0	7.95	7.9	7.9	7.85	7.8	7.75	7.7	7.8	7.7	7.6	7.55	7.5	
8/23	8.2	8.1	7.9	7.85	7.8	7.7	7.7	7.6	7.9	7.85	7.75	7.6	7.55	
8/24	8.0	8.0	7.9	7.85	7.8	7.7	7.65	7.6	7.8	7.7	7.6	7.5	7.45	
8/26	7.9	7.8	7.8	7.7	7.7	7.65	7.6	7.6	7.7	7.65	7.55	7.5	7.5	
9/5	7.8	7.7	7.65	7.65	7.6	7.6	7.6	7.55	7.6	7.65	7.6	7.5	7.5	
9/7	7.8	7.8	7.75	7.7	7.7	7.6	7.6	7.55	7.65	7.6	7.5	7.45	7.45	

From this table certain facts become clear: 1) that the H-ion concentration over the shallow water is lower (pH higher) during the day than over the deep water. This is undoubtedly due to the great activity of the shallow water vegetation, which during the day is giving off oxygen and taking on carbon dioxide. 2) It is to be noted that with the coming of darkeness the H-ion concentration increases, as indicated by the decreasing amplitude of the figures. 3) The change in H-ion concentration is greater along the shore than over the deep water. This again is due to the plant activity and the reversal of the photosynthetic process; oxygen is now being taken up and carbon dioxide given off, thus increasing the acidity and increasing the H-ion concentration. 4) Both the shallow and deep water reach a stage of more or less stable equilibrium with the pH of the shallow water higher than that over the deep. 5) Finally, *Labidesthes sicculus* moves toward the higher pH value as the change begins to occur over the deep water. That the species is sensitive to changes in the H-ion concentration of the water is further made clear by a series of laboratory experiments to be discussed.

So far I have considered only the shoreward migration of the evening, and have said little as to the outward migration of the morning. This morning movement is very much harder to study, as it is less definite, less of a mass movement, than is the evening migration, and this in itself indicates what might be termed "reluctance" on the part of the fish to leave the shallows, and also because the departure of a few fish from a great school is less easily noted than the first arrivals in an area theretofore free of the species. The region into which the evening movement comes is relatively limited; that into which the morning migration goes is relatively unlimited. Yet a study of the H-ion concentration changes during the early hours of dawn gives a very good clue as to the cause of this second phase of the daily shifting. The results of the changes in H-ion concentration along the shore and over the deep water, made in the same way as the night readings, are given in Table 20.

TABLE 20

CHANGES IN HYDROGEN ION CONCENTRATION IN THE MORNING OVER SHALLOW AND DEEP WATER OCONOMOWOC LAKE, 1923

	Over shallow water:							Over deep water:					
Date	3:00	3:30	4:00	4:30	5:00	5:30	9:00	3:00	3:30	4:00	4:30	5:00	5:30
8/9	7.6	7.65	7.65	7.7	7.8	7.85	7.9	7.5	7.5	7.6	7.65	7.7	7.7
8/10	7.6	7.65	7.7	7.8	7.85	7.85	8.0	7.5	7.5	7.6	7.65	7.7	7.8
8/11	7.55	7.65	7.7	7.75	7.85	7.9	8.1	7.5	7.5	7.5	7.6	7.7	7.75
8/14	7.6	7.7	7.75	7.8	7.85	7.85	8.0	7.55	7.6	7.6	7.7	7.75	7.8
8/17	7.65	7.65	7.7	7.7	7.7	7.75	7.9	7.5	7.5	7.55	7.6	7.65	7.7
8/18	7.6	7.6	7.6	7.65	7.65	7.7	7.9	7.5	7.5	7.5	7.55	7.6	7.65 (cloudy)
8/22	7.65	7.65	7.75	7.8	7.85	7.9	8.1	7.55	7.6	7.6	7.65	7.7	7.8
8/24	7.6	7.65	7.7	7.75	7.85	7.95	8.0	7.5	7.5	7.55	7.6	7.6	7.7
8/26	7.55	7.6	7.65	7.75	7.75	7.85	7.95	7.45	7.5	7.5	7.55	7.65	7.75
9/5	7.55	7.55	7.55	7.60	7.65	7.7	7.8	7.45	7.5	7.5	7.55	7.6	7.7
9/15	7.55	7.55	7.55	7.55	7.6	7.65	7.8	7.45	7.5	7.5	7.5	7.65	7.7

As compared with Table 19 showing the evening changes, certain marked and important differences are to be noted. Conspicuous among these is the fact that the H-ion concentration along the shore begins to change considerably earlier than over the deep water, as indicated by the rise in the pH values as early as 3:30 on August 8. The fact that the pH values for September do not change as early as those in August must be explained as being due to the light conditions as affecting the respiratory activity of the aquatic vegetation. It is a well known fact that photosynthesis takes place in the presence of very little light; hence the night intake of oxygen and output of carbon dioxide are reversed in the early morning hours long before the sun gets up, resulting in the output of oxygen and intake of carbon dioxide. With the intake of CO_2 the change in the H-ion concentration of the water begins and this is indicated by the slowly rising amplitudes of the pH values, showing an increase in alkalinity. Since the surface water over the deep is less abundant in photosynthesizing organisms, the larger aquatic plants being entirely absent, the change in pH values is measurably slower. It is to be noted further that on cloudy days (August 18) the pH values change more slowly and at a later hour, due to the absence of sufficient light to start the photosynthetic processes of the water plants.

The morning off-shore migration of the silversides starts with a definite change in the H-ion concentration of the shoal water. This becomes evident if one compares the different pH values with the hour at which the fish start out.

TABLE 21

HOUR OFFSHORE MIGRATION BEGINS AND pH OF WATER AT THAT TIME

Date	Time of start of outgoing	pH of the water at that time
8/9	4:20	7.65
8/10	4:05	7.7
8/11	4:08	7.7
8/14	3:48	7.65
8/17	3:58	7.7
8/18	5:20	7.65
8/22	4:10	7.75
8/26	4:22	7.7
9/5	3:55	7.65
9/15	5:10	7.6
Average:		7.68

Thus it is seen that the fish leave the shore as the pH reading reaches 7.65 to 7.7, the average being 7.68, which can not be read by the colorimetric method. This gives a clue to the cause of the morning movement: it is an avoiding reaction to a higher pH reading, that is, to water of increasing alkalinity. Since the water in the shaol environment shows a higher pH reading during the day than does the water over the deep, and since the water over the deep shows a lower pH value at night than does the shallow water, it must be assumed that the fish are reacting negatively to a high pH value and negatively to a low pH value, indicating a marked sensitivity to H-ion change and a limited range of tolerance. This conclusion is borne out in a series of laboratory experiments. It is impossible to account for the morning migration by light, temperature, food, oxygen or protection, but one can account for it as a reaction to changes in the hydrogen-ion concentration of the water.

In order to ascertain the pH preferences of the fish the galvanized iron tank was again used. This was filled with water and well mixed so as to give a uniform pH value throughout the tank. The fish were placed in the tank and their normal movements noted. Then the pH readings were taken at different points in the tank to make sure that the environment was uniform. At one end of the tank a small amount of acetic acid was added, this lowering the pH readings as the H-ion concentration increased with the increased acidity of the water. The behavior of the fish was noted and the pH of the water was taken at the point where the fish turned back in its avoidance reaction. The results of this procedure are given in figure 17. The fact that the fish react against a slight increase in the acidity of the water is shown by their returning to the less acid end of the tank as soon as they come in contact with the increasing zone of water of a higher acidity. The change from the pH of 7.9 is noted by the fish at once, and the pH value of 7.7 and 7.65 are evidently the critical points. The fish does the best it can to avoid the increasing acidity by retreating before the advancing zone of pH 7.65, and the experiment ends with the fish flat up against the end of the tank farthest away from the acid, with further retreat impossible.

Essentially similar results were obtained by the use of carbonate instead of acid, thus increasing the alkalinity of the water. These results are given in figure 18. It is evident from a glance at this figure that the fish avoid water of a higher pH than 8.2 if possible. It is further evident that their avoidance to increasing alkalinity is less decided than to an increasing acidity as evidenced by their frequent lingering along the advancing pH 8.2 line. As in the case of acidity, the fish are evidently doing their best to avoid the radical change in pH until retreat is impossible longer. In this connection it is well to note that the critical point is very close to pH 8.2, which is also the pH value of normal sea water. This may be significant when one recalls again that this is a fresh water representative of an otherwise strictly *marine* family, and becomes more marked when one compares the reactions against higher alkalinity and higher acidity; it is to be noted that the reaction against higher acidity is less decisive.

In order to see how the fish would react in a tank with high alkalinity at one end and high acidity at the other, a third series of experiments was run under combined conditions. The results are very similar to those of the two preceding experiments combined. The fish retreat before increasing acidity and tolerate greater alkalinity in preference to greater acidity, as shown in figure 19. It will be seen that as long as any real choice was possible, the fish chose a pH value very close to 7.7.

From these experiments it must be concluded that: (1) the fish are very sensitive to pH changes in the water; (2) their range is from pH 8.3 to pH 7.5, with the optimum approximately 7.65 to 7.7; (3) the experimental results check very closely with the behavior of the fish in nature; (4) there is a greater tolerance for increased alkalinity than for low alkalinity or acidity; and (5) the experimental data bear out the assumption that the early morning change in the hydrogen-ion concentration of the shore water is sufficient to cause the offshore migration of the species at that time.

This sensitivity on the part of the silversides suggested an experimental study of the pH of the blood of the species in an effort to ascertain whether or not there is a correlation between the pH preference of the fish and the pH of the body fluid. The procedure followed was that of Levy, Rowntree and Marriott. Celloidin sacs (or dialyzing tubes) were made according to their method, and stored until used in normal salt solution. The idea of the experiment was to obtain an amount of blood of the fish and dialize this blood through the celloidin sac suspended in normal salt solution. The dialysis excludes from the liquid outside of the sac both proteins and coloring matter, but permits the free outflow of hydrogen ions. As the amount of blood obtainable from a single silversides is small—even in the case of the adults—it became necessary to use a number of fish in each experiment. A thin hypodermic needle was inserted directly into the heart of the fish, this being rendered a simple operation by the transparency of the fish. The blood drawn out was placed in a small test tube, the mouth of which was covered with a rubber membrane to exclude the air. In an effort to exclude the maximum amount of air, the test tube was filled with normal salt solution before the rubber membrane was put on, and the liquid was then drawn off by means of a hypodermic needle inserted through the membrane. When 3cc of the blood was obtained, the blood was transferred to the celloidin sac and suspended in a slightly larger glass test tube containing 3cc normal sodium chloride solution. After standing for five minutes, the pH of this solution was read. This experiment was performed on both immature and adult fish with the following results:

TABLE 22

TESTS OF BLOOD OF YOUNG AND ADULT *LABIDESTHES SICCULUS*

No. Fish used	Young Av. length	pH	No. fish used	Adults Av. length	pH
14	2.4	7.7	8	7.6	7.8
17	2.0	7.7	7	7.62	7.85
18	2.1	7.75	10	7.61	7.85
Average:		7.71			7.83

These results are interesting and instructive, for they show that the pH value of the blood has undergone a modification as the fish mature. It shows that the pH of the blood of the young fish is lower than that of the adults, and it will be remembered that the young fish on coming into the shallow water, are entering a region of higher pH values: the older they are the more permanently do they select the shallow water with its higher pH values, and the older they are the higher the pH of the blood becomes. Thus the change in habitat selection appears as a reaction to a physiological change in the body which results in a change in the H-ion concentration of the body fluid.

THE ADULT FISH

Once the fish establish themselves inshore toward the end of the summer, their lives assume a much more even and less exciting level. With the coming of the cold weather and the coincident cooling of the water, the activity of the species becomes conspicuously reduced. The species remain inshore all winter, with the exception of a slight tendency to wander about, due probably to the uniform conditions of the water. Occasionally they drift slowly through the openings in the ice where the cisco fishermen are at work over the deep water. Much more frequently, however, they are seen along the shore over water up to two meters deep where the ice cutters have cleared their fields. Movements are slow and sluggish and in marked contrast to the summer activity as already noted. The food habits revert back to those of the immature, principally because of the almost total absence of other food in the upper stratum of water. In fact, it is quite a difficult task at times to obtain sufficient fish during the winter to get a fair idea of what they are feeding upon, so scantily do they appear to feed. This is borne out by the fact that growth ceases entirely and the fish are living on a maintenance ration only. With the coming of spring and the warming of the water, the normal activity slowly returns and the species goes back to its insectivorous diet. With this increase in activity and the excess of rations above the point of mere maintenance, a new growth period is initiated and the fish attain their full size during the early summer (Figs. 11, 12). In June comes again the spawning season, the young of the previous summer go through their breeding performances, and the life cycle begins over again in the new generation.

As to the old generation, their fate is apparently sealed, for they die before the second winter is upon them. The problem of their death and its causes has not been attempted by the writer. It is evident, however, that the adults die sometime during the last half of their second summer, for neither Hubbs nor the writer has ever seen a silversides showing two annuli on the scales. In an examination of 478 adults, no second winter ring has ever been found. Then too, as the summer advances, the adults grow notably less common. On the night of July 18, 1923, I was able to pick up 26 adults along a few hundred feet of shore line in a few minutes;

on September 12 I was able to get only 5 after several hours of search over a considerably more extended area. By adults are meant, of course, those individuals which have passed through one winter and have spawned once. Therefore it must be concluded that the old fish die at the age of about fifteen to seventeen months, breeding but once and leaving it at that to the young to carry on the species.

SUMMARY OF RESULTS ON LABIDESTHES

1. *Labidesthes sicculus* is the only fresh water representative of the marine family Atherinidae found in Wisconsin waters.
2. The fish are found only at the surface of the water, and under no conditions will they descend below a meter from the surface.
3. The spawning habits are described and data are presented which show that the deposition of eggs begins when the water reaches a temperature of 20°C, with the optimum temperature of 23°C.
4. The eggs hatch in approximately eight days at 23°C.
5. The embryological development is unknown.
6. On hatching, the young fish migrate at once away from the shore, and assume a position over the deep water, living at all times within a few centimeters of the surface film while the adults remain permanently inshore.
7. After hatching, the young grow very rapidly, and complete data for the growth of the species are presented.
8. When the young reach an average length of 1.4 cm, they migrate into the shallow water each night and before sun-up they migrate back again to their pelagic habitat over deep water.
9. Data are presented which show that this inshore movement is coincident with a drop in temperature of the surface water over the deep water, as well as with a change in the hydrogen-ion concentration of the water at that stratum.
10. Evidence is presented which shows that the shoreward migration is in the direction of increasing light intensity, indicating a positive phototropism.
11. The fish are constantly active during the day; at night, if it be dark, the fish remain quiescent over the shallows.
12. If the night be light, due to a nearly full moon, the fish show extreme activity, leaping out of the water and displaying unparalleled vivacity.
13. This activity can be induced on a dark night by introducing a spot light on the water, proving the species to be positively phototropic.
14. Further proof of this phototropism is presented by the fact that the young can occasionally be lead entirely across the lake, a distance of nearly a mile, as they follow a light; at all times they can be led to a point

where change in hydrogen-ion concentration and low temperature overcome the phototropic reaction and cause the fish to turn back. The fish will even leap out of the water upon the dry land in an effort to follow the light.

15. This night activity is due to moonlight of a certain intensity and it occurs only when the light penetrates into the water.

16. As the season goes on, a marked decrease in the abundance of Labidesthes along the shore is noted.

17. Data are given which show that the species in coming into the shallows is attempting to maintain a pH equilibrium of approximately 7.7.

18. Further data show that the species migrate to the deep water in the morning with the rising pH value of the water due to the photosynthetic activity of the shallow water vegetation.

19. Experimental data show that the species avoid and react to a drop of 0.4°C in the temperature of the water.

20. Further experimental data show that the fish avoid both increasing acidity and increasing alkalinity, but that the aversion to a higher alkalinity is less marked than to a lower alkalinity; that a pH of 8.2 is tolerated without resistance, and it is noted that this is the normal pH for sea water.

21. Experiments on the blood of the fish show that there is a difference in the pH values of the blood of young and adults; that of the young is pH 7.71; of the adult 7.83.

22. The migrations of the fish are therefore correlated with the hydrogen-ion concentration of the blood: the young fish with the low pH values remain in that portion of the lake having the lowest pH readings, as they begin to mature and the pH of their blood changes, they begin to come into water having a higher pH value.

23. The food habits of 550 individuals of all ages were studied. The young are plankton eaters; as they begin their shoreward migrations a change in food habits occurs and insect food tends to replace the plankton organisms; that the adults are very largely insectivorous during the summer, but tend to revert to the food habits of the immature during the winter.

24. Examination of 478 adults has shown the presence of but a single annulus on the scales, from which, together with the decreasing abundance of the adults in late summer, it must be concluded that the individuals live for but fifteen to seventeen months.

THE CISCO *LEUCICHTHYS ARTEDI* (LE SUEUR)

INTRODUCTION AND DESCRIPTION

Among the most abundant of the food fishes of the great lakes is the Lake Herring or Cisco, *Leucichthys artedi* (Le Sueur). Either this species or a variety of it is an inhabitant of all the great lakes and is particularly abundant in Lake Michigan, the southern end of which marks the southern limit of the fish. It is found also abundantly in most of the larger lakes of Wisconsin, and must be considered as a characteristic fish of the deeper inland bodies of water of that state. In southern Wisconsin, within the limits of Waukesha county, the species has been taken in the following lakes: North, Pine, Nagawicka, Okauchee, Oconomowoc, Fowler, La Belle, Upper and Lower Nashotah, Upper and Lower Nemahbin, Silver and Dutchman's. In the largest lake of the county, Pewaukee, the species does not occur as the lake is too shallow to accommodate it.

The family Salmonidae comprises two great groups of fishes, the white fishes or Coregoninae and the salmon and trout series, the Salmoninae. Three genera make up the Coregoninae: Coregonus, the true whitefish; Stenodus, a peculiar trout-like whitefish from the Mackenzie river, a genus represented by a single species, *mackenzii;* and Leucichthys, the lake herring or cisco, represented by about ten species, which may or may not prove valid. The exact number of species is not known, as the ciscos are extremely variable; hence it is probable that many of the present so-called species will be shown to be synonymous. Variability is, as a matter of fact, characteristic of the whole family. This variability, taken in connection with the fact that no salmoid fish is known in a fossil condition except from very recent deposits, forces the conclusion advanced by Günther that the group is of recent origin. Certain it is that, though the ciscos from the above mentioned lakes are all alike in essential structures, if one is familiar with the fish from the different lakes, it is possible to sort out a mixed collection according to the lakes from which the fish came on the basis of variations in color or body proportions, length and depth of caudal peduncle, and other characters. Yet the writer believes that, until a much more careful study of the genus Leucichthys is made than has appeared to date, all the fish should be considered as merely local environmental variations of the single species *Leucichthys artedi.* (Fig. 3.)

Leucichthys artedi was described by Le Sueur in 1818 from specimens taken in Lake Erie, near Buffalo, under the name of *Coregonus artedi.* In

1850 Agassiz separated the herrings from the white fish, placing them in the genus Argyrosomus. However, it has been found that the name Argyrosomus is preoccupied, having been given to a group of French species by de Fougeres in 1834. In 1874 Dybowski gave the generic name of Leucichthys to a group of Siberian species of the genus Argyrosomus Agassiz, creating *Leucichthys omul* and *L. tugun*. These become the type, therefore, of the genus Leucichthys to which the American species belong. The first to recognize the true situation was Gill, and he is followed by Jordan and Evermann (1911) who apply the name *Leucichthys artedi* for the first time. A similar confusion exists regarding the species which occur in Wisconsin, but until the genus is entirely and thoroughly reviewed little can be done to straighten out the matter. Jordan and Evermann (1896) refer to the cisco of Oconomowoc lake as *Argyrosomus artedi* in their next review of the group (1911) they call it *Leucichthys cisco* the type being from Lake Tippecanoe, near Warsaw, Indiana. However, they state that it is simply a land-locked *artedi*, structurally indistinguishable from it. In view of this confusion, the writer is inclined to follow the original work of Jordan and Evermann, and calls the fish *Leucichthys artedi*, it being understood that the species in question is the common cisco of Oconomowoc lake, Waukesha county, Wisconsin.

Leucichthys artedi is described by Jordan and Evermann as follows: "Head 4½; Depth 4½; eye 4 to 4½; D. 10; A. 12; Scales 8–75 to 90–7; 10 rows under base of dorsal; vertebrae about 60. Body elongate, compressed, not elevated. Head compressed, somewhat pointed, rather long, the distance from occiput to tip of snout usually a little less than half the distance from occiput to dorsal fin. Mouth rather large, the maxillary reaching not quite to the middle of the pupil, 3¼ to 3½ in head; mandible 2½ Preorbital bone long and slender; suborbital broad. Gill rakers very long and sledner, 15–17—28 to 34, the longest 1½ in eye. Dorsal fin high, its rays rapidly shortening. Bluish black or greenish above; sides silvery, scales with dark specks; fins mostly pale, the lower dusky-tinged. Length 12 inches. Great lakes and neighboring waters. An active, voracious fish. Represented in numerous small lakes in Indiana and Wisconsin (Oconomowoc, La Belle) by the slightly modified *Argyrosomus artedi cisco* Jordan." The latter is differentiated from the regular *artedi* by no other fact than that it is a bit smaller and living in deep water. The only lake in southern Wisconsin which contains ciscos as small as 12 inches when mature is Pine lake. Until the last few years, Oconomowoc lake averaged fish 16 inches long or more, and weighing up to 4½ pounds. Beyond the descriptions of various species and subspecies of the genus, the ichthyological literature is entirely silent concerning the cisco of the inland lakes, and other than the fact that they "spawn in shallow water in November," notes on the food habits of other species, notably *L. birgei* Wagner as described by Pearse (1921), and the statement also by Pearse that the cisco is a bottom seeking form (based on the independent work of Pearse and Cahn) nothing has been published regarding the ecology of the fish. Two studies of the Lake Erie cisco (*Leucichthys* sp., but not *artedi*) have recently been published by Clemens (1922). This report is, therefore, the first contribution to a life-history study of the cisco, *Leucichthys artedi*.

The following ecological study was begun in 1915 at the University of Wisconsin on the species inhabiting Lake Mendota, which is the same as that occuring in the other southern Wisconsin lakes. In 1917 the study was begun in Oconomowoc lake and in other lakes in Waukesha county, and has been carried on each summer since then (except 1919, when the writer was in France), and at intervals during each winter. During the summer the fish have been caught in numbers by means of gill nets; during the winter with hook and line. Live fish were kept in the large concrete tank in the vivarium at the University of Wisconsin during the winter of 1916, and their reactions and habits were under constant observation. Thousands of fish have been examined for age, weight, length, food, parasites, and these examinations and observations are the basis of this report.

BREEDING HABITS

The cisco is essentially a deep water fish, spending its life in the deepest part of the lakes during such times of the year as conditions (oxygen content of the water, etc.) permit. This is of interest in view of the statements of Ward, Milner and others to the effect that the fish are surface species in the Great Lakes. This is one of the differences that have been mentioned as separating the small lake forms from the Great Lakes fish. Thus one finds the fish in the deep water of Oconomowoc lake following the fall over turn when the winter conditions of the lake are established. The thermocline has descended and a uniformity of oxygen content exists throughout the water, making the entire lake available to the fish. However, the part selected by the fish is the cold water of the bottom. As the thermocline descends, the temperature of the water also drops slowly. As the water of the lake cools and approaches a mean temperature of 5.0°C (41°F) the fish show the first signs of the breeding migration, and approach the shallower waters near the sand bars. With the continued cooling the fish approach the shore still more closely, surmounting the bars and appearing in water from one to three meters deep. If rivers enter the lake, the fish may ascend them. Thus, the ciscos come up the Oconomowoc river from Fowler lake, only to be stopped by the locks and dam at the outlet of Oconomowoc lake. Much of this trip is made in water not over 1 m in depth and still shallower water is encountered by the Oconomowoc lake ciscos in their ascent of the Oconomowoc river toward Okauchee lake. True, the ascent of the rivers is a rheotropic reaction, but too much weight must not be placed on this because of the fact that in reality only a small part of the fish of the lake actually travel up the streams, the majority of the individuals, all of whom had the same chance to go up-stream, content themselves with approaching the shore and lay their eggs there. This is perhaps well for the species, for it is very doubtful, indeed, if any of the eggs laid in the shallow water of the rivers ever hatch and return young fish to the lake: there are too many voracious small fish seeking to devour the eggs and fry.

The first fish to reach the shallows are the males, and they are functionally ripe when they arrive. These early arrivals strip easily and microscopic examination shows abundant normally active spermatozoa. The first arrivals usually come in at night, but this is not always the case. They swim leisurely about, occasionally wandering toward the deep water, but show a distinct tendency to follow the shoreline. This movement exhibits no co-ordination as to direction, about equal numbers traveling in each direction, which is in marked contrast to the behavior of the fish when they are "schooled up" in the deep water. The arrival of the males precedes that of the females by from two to four or five days. As the controlling factor for the arrival of each sex is the water temperature, no definite statement can be made as to the intervening time; it depends on the weather and the resulting influence on the water temperature. With the arrival of the females the breeding begins. Several males follow behind a single female at a distance of about one foot, the number of males to a female varying considerably. The first females to arrive may have over a dozen males in attendance, while later on two males is more usual. The actions of the fish are at all times slow and deliberate; there is no chasing or darting about, no evidence at all of excitement or pugnacity. The deposition of eggs takes place in water varying from one to two meters in depth, and the region is free from heavy aquatic vegetation. The female descends to within six or eight inches of the bottom as the eggs are deposited, the male following close behind and along side, his head about even with the anal opening of the female. It is not at all infrequent to find two males present during the fertilization process. As the eggs appear, coming from the female in a thin cylindrical band, the males discharge the spermatozoa freely in the water, forming a conspicuous milky cloud as they swim slowly along. The spawning fish does not cease swimming, with the result that the total egg complement is well scattered over a considerable area. The eggs are slightly viscous, the result being that they become fixed to the rocks, vegetation or debris on the bottom, where they remain during their developmental period.

As to the conditions surrounding the nuptial migration, they have been carefully worked out. It was early discovered that the arrival of the fish from the deep water is in a direction perpendicular to the shore, hence it proved a simple matter by means of gill nets, to follow the movements of the incoming ciscos, and to make temperature, oxygen and hydrogen ion readings in connection with the progressive migration stages.

Table 23 gives the results of the temperature readings made during the spawning season of 1916, which is typical of those made in Oconomowoc lake in 1917, 1918, 1921, 1922, and is graphically represented in figure 20.

TABLE 23

THE SPAWNING PERIOD OF THE CISCO IN LAKE MENDOTA AT MADISON, WISCONSIN, IN RELATION TO THE TEMPERATURE OF THE AIR AND WATER

Date	Temperature of Air	Temperature of Water	Number of ciscos caught	Male	Female
Nov. 15	− 4.5	8.8			
16	− 0.5	8.8			
17	2.0	8.6			
18	5.0	8.8			
19	1.0	8.1			
20	1.0	7.7			
21	− 3.0	7.0			
22	− 5.5	6.4			
23	0.0	6.2			
24	2.7	6.7			
25	11.0	6.2			
26	7.0	6.2			
27	2.4	6.2			
28	1.0	5.8			
29	− 4.5	5.5			
30	− 3.0	5.2			
Dec. 1	− 1.0	5.0			
2	− 4.5	4.5			
3	− 1.0	4.3	3	3	0
4	− 1.0	4.3	10	10	0
5	− 0.5	3.8	10	8	2
6	− 1.5	4.0	21	9	12
7	1.0	3.7	38	11	17
8	1.0	3.3	39	10	19
9	−22.0	3.4	14	8	6
11	− 2.5	3.3	5	2	3
10	− 2.0	3.0			
12	− 2.0	2.6			
13	− 7.4	2.5			
14	−11.5	2.3			
15	− 8.3	2.0			
16	− 9.0	1.7			

This gives certain definite information regarding the conditions which precede and accompany the breeding of the cisco. Here it is seen that the males come into the shallows when the water first reaches a temperature of 4.3°C; that the females arrive when the temperature has dropped to 3.8°C and that the spawning season is at its height with the water at from 3.6°C to 3.3°C; and finally, that the season is abruptly over as the water drops below this figure. Table 24 gives the conditions during other years.

TABLE 24.

CONDITIONS UNDER WHICH CISCO SPAWNED FROM 1916 to 1921

	1916 M	1917 M	1918 O	1919 O	1921 O
First ♂ in shallows	Dec. 3	Nov. 29	Nov. 30	Nov. 28	Nov. 26
Temperature water:	4.3	4.4	4.4	4.3	4.3
First ♀ in shallows	Dec. 5	Dec. 2	Dec. 2	Nov. 30	Nov. 29
Temperature water:	3.8	3.9	3.8	3.7	3.65
Maximum spawning:	3.3	3.5	3.5	3.4	3.3
Spawning over:	3.0	3.1	3.0	3.0	3.1

M = Lake Mendota O = Oconomowoc Lake

From these data it must be concluded that the critical temperature at which the male cisco enters the shallows is very close to4.3°C;for the female it is 3.8°C; and that the optimum temperature is between 3.3° and 3.5°C.

As to the ratio between the sexes, it appears that the males outnumber the females to some extent, as shown by the following:

No. ciscos examined	Lake	Males	Females
163	Mendota	101	62
744	Oconomowoc	429	315
907		530	377

This is in the ratio of 100 males to 71.2 females. This difference can be explained by the greater mortality among the females during the late summer, as will be seen later.

The number of eggs laid by the female varies considerably, depending of course upon the size and age of the fish. By the water displacement method the following count of the number of eggs laid by a single female was obtained:

Amount of water displaced by eggs....................	46.5 cc
To displace 1 cc water (av. 5 counts)..................	329 eggs
Total number of eggs..............................	15,238
Weight of female before stripping....................	465 grams
Weight of female after stripping.....................	405 grams
Weight of 15,238 eggs.............................	60 grams

The following data apply to the gonads of the male:

Average weight of 45 right testes	7.5 grams
Average weight of 45 left testes	6.5 grams
Total weight of gonads	14.0 grams

In every case the right testis exceeded the left in weight.

In order to ascertain the effect of temperature upon the fish, twenty-five ciscos were captured by means of a gill net and the ten least injured were brought in alive to the vivarium, where they were placed in a large concrete tank abundantly supplied with a constant supply of fresh running water. The fish lived well throughout the winter, with only an occasional mortality due to the fungus Saprolegnia. The water was kept at a temperature of 4.5°C during a period of four months, covering the breeding season. In spite of the fact that fifteen of the confined fish were females, all heavy with eggs, not a single egg was laid during this time. In a second tank, exactly similar to the first, and with the same water supply, but cooled by means of ice to a temperature of 3.5°C, females from the first tank spawned within ten minutes after transfer.

A second experiment consisted in transferring two females into the second tank while the water was at 4.5°C. After two hours in this tank, a large piece of ice was added and a careful record of the temperature kept. The first female spawned with the temperature at 3.6°C, the second at 3.4°C.

From the fact that the observed temperatures at which the fish spawn in nature coincide exactly with the observed experimental controls in the laboratory, namely 3.3° to 3.6°C, it must be concluded that these figures represent the critical breeding temperature of *Leucichthys artedi*. It must be further concluded that the temperature is the causal factor for egg deposition and that this critical temperature is needed before the eggs will be laid. This conclusion is inescapable as repeated oxygen and hydrogen-ion concentration determinations showed the conditions in the water to be almost constant for these factors, and the carbon dioxide variations were so very slight and in both directions that they must be considered as having no significance.

Nothing is known concerning the embryology of the species, and here again the writer has considered the subject as outside of his problem. However, it is well to point out that this egg is an ideal one for laboratory use and experimental purposes: it is easily obtainable, available for winter work, development is sufficiently slow for convenient study, and the egg is of fair size and remarkable clearness, having only a very few oil globules to obscure the cleavage. The writer has kept them in regulation egg-hatching glass jars until the embryo was well developed, when the set was accidentally destroyed by the breaking of the jar. These eggs were fertilized in a glass dish at 3:30 o'clock in the afternoon of December 2, the fertilization membranes appearing around the eggs very quickly. At 9 P.M. the eggs were all in the 2-celled stage; at 12 midnight the 8-celled stage was nearly completed, while at 8 A.M. on December 3, the 64-celled stage was beautifully marked. The temperature here ran from 4.5°C to 5.5°C. At 3 o'clock that afternoon the cells were too numerous to count, and from then on the eggs were permitted to develop without observation. The exact length of the developmental period has never been worked out.

THE YOUNG

I believe that young ciscos are among the least known of all of the Wisconsin fishes. In fact, there is no evidence that anyone other than myself has ever taken them alive in nature, and it took me nine years of search before I finally got three individuals. These were young of the year, taken in Oconomowoc lake on July 20, 1922, in a trammel net set on the bottom in 52 feet of water. They measured 6.25 cm in length, and are the only young-of-the-year that I have ever handled. Much popular misinformation is in circulation in southern Wisconsin concerning the young cisco, as the brook silversides (*Labidesthes sicculus*) is uniformly considered as the young of *Leucichthys artedi*. This is due largely to a certain similarity of shape and color, and to the well known lack of discriminate observation on the part of people in general. This mistaken identity works for the good of the silversides, for as the cisco is protected by law, many bait gatherers scrupulously return Labidesthes to the water.

As the ice forms over the shallow water very soon after the eggs are laid, difficulties in determining the movement of the young after hatching are greatly increased. Upon hatching the young fish seek the deep water, and this occurs prior to the complete breaking up of the ice in the spring, which takes place usually about the first or second week of April. Repeatedly have I marked the spot where eggs were deposited, only to find them hatched when the breaking of the ice made re-examination possible. That the hatching takes place late in March is suggested by the condition of development of eggs retrieved by chopping through the ice in late February and early March. This would make the developmental period between ten and twelve weeks, probably with considerable variation depending upon the temperature conditions, longer during a long winter, and shorter in the case of an early spring. The young, then, seek the deep water where, because of their small size, they are almost entirely inaccessible for study. There is nothing to indicate that anything of unusual interest takes place during this juvenile condition.

Through the coöperation of the dozens of fishermen who catch the cisco through the ice during the winter, the writer has had the opportunity of examining hundreds of specimens for size measurements and food habits.

The results of these examinations are summarized in table 25 which shows age, length and weight measurements. This table gives the number of fish of different ages examined during the last week of January and the first week of February 1923 and 1924, together with their weight in grams and their length in centimeters. In compiling the table the sexes were not separated as the compilation was made nearly two months after the spawning period and hence the error inevitable in the case of ripe females is not introduced. Furthermore, growth curves for the sexes coincide so exactly that no conclusions can be drawn other than that the sexes develop at essentially the same rate.

TABLE 25

THE WEIGHT AND LENGTH OF CISCOS OF DIFFERENT AGES IN OCONOMOWOC AND PINE LAKES

	OCONOMOWOC LAKE			PINE LAKE		
Age Years	No. Fish Examined	Weight g ams	Length cm	No. Fish Examined	Weight grams	Length cm
5 mos	3	22	6.2	—	—	—
2 yrs.	26	105	13.5	11	45.0	12.5
3	144	166	17.4	41	60.2	16.2
4	168	257	22.3	54	85.2	19.5
5	340	366	28.2	108	119.8	24.6
6	279	445	31.5	172	190.0	28.3
7	138	527	33.6	95	262.4	31.4
8	76	611	36.2	36	342.7	33.0
9	14	623	37.4	17	406.2	33.8
10	11	696	38.6	3	436.1	34.5

The comparison between the cisco of Oconomowoc lake and that from Pine lake is exceedingly interesting, and the relationship is well brought out in figure 21, where the growth in grams has been plotted against the age in years of fish from the two lakes. Oconomowoc lake contains the type of cisco most commonly found in the southern Wisconsin lakes, while the Pine lake fish are on the average much smaller in size and weight than those of any other lake in the county, yet entirely typical of the species from a morphological and ecological point of view. Figure 22 shows the length in centimeters plotted against the age in years for the two lakes. From these figures it is seen that, while the fish do not differ greatly in their relative lengths at the different ages, their weights do not agree at all closely. An explanation of this condition is to be found in the physical factors involved. The cisco is more abundant in Pine lake than in any other lake in the county, probably many times more numerous. I have sat in a fish house on the ice during the winter and watched the fish through a hole in the ice, and have been utterly astonished at their numbers: a thick mass of fish from just below the ice as far down as the eye could see. An examination of the water of Pine lake shows that the plankton organisms are relatively less abundant per liter of water than in Oconomowoc lake. Thus one can explain the weight discrepancy on the basis of inadequate food supply: there are too many fish for the amount of food available. A similar condition is to be found in Otis lake in the case of the large mouthed black bass (*Micropterus salmoides*) this is a small lake to which the public does not have access, and it is full of bass, many times more than the food will suffice for anything over a strict maintenance ration. The result is a large number of bass of light weight and scanty measurements. In a similar way one occasionally catches a cisco in Pine lake that weighs over a pound and still is but five or six years old; but such a one must be looked upon as a particularly fortunate individual in so far as food supply is concerned.

FOOD HABITS

The cisco is one of the most exclusive plankton eaters among our fishes. The food of the immature fish—up to about 16 cm. in length—is 100% plankton organisms, being composed of Cyclops, Daphnia, Diaptomus, Bosmina, Chydorus, rotifers and other animals of a similar nature. Bottom material is freely taken into the alimentary canal and as this contains a considerable amount of vegetable matter, the smaller algae, diatoms etc. form a part of the diet. As the fish reach a larger size the food assumes a wider range, and various mollusks, insect larvae, crustacea and small fish appear in the food list. There is a slight tendency on the part of the fish to feed more upon the micro-crustacea of the Daphnia-Cyclops type during the winter than during the summer, but in Oconomowoc lake, as in all of the lakes in Waukesha county which the writer has investigated, these organisms form normally a large part of the diet the year around. This is at variance with findings of Pearse (1921a) in the case of *Leucichthys birgei* in Green lake in summer, where he found 61.2% of the food to be amphipods. However, his numbers are hardly large enough to base conclusions upon, nor is the seasonal range of his investigations of sufficient duration: he had but 30 fish caught between August 13 and 19. In table 26 the writer presents a summary of 941 stomach examinations grouped according to months in sets of two months to a group. In this table the Cladocera are represented by species of Bosmina, Daphnia and Chydorus; the Copepoda by Dioptomus and Cyclops; the Ostracoda by Cypris. The mollusks include various species of Amnicola, Valvata, Sphaerium, Pisidium and Planorbis. Sayomia (formerly Corethra) has been separated from the other insect food because of its abundance and frequency. The heading "other insects" includes various larvae and pupae picked up from the bottom, largely Ephemerida and Plecoptera, Chironomus and an assortment of adult insects picked up off the surface during the summer when the fish occasionally come to the surface on a quiet evening. The fishes eaten are usually in such a state of digestion that identification was

TABLE 26

THE PERCENTAGE OF VARIOUS ITEMS OF FOOD OF THE CISCO THROUGHOUT THE YEAR IN OCONOMOWOC LAKE

Month	Jan. Feb.	Mar. Apr.	May June	July Aug.	Sept. Oct.	Nov. Dec.
Number	482	26	91	140	128	64
Food						
Ostracoda	1.5	0.5	1.9	2.3	3.5	1.0
Copepoda	26.5	17.6	20.3	13.3	19.8	15.4
Cladocera	30.7	22.8	24.1	20.8	24.6	18.6
Amphipoda	4.5	3.9	1.0	1.2	3.1	5.8
Mollusca	8.1	7.4	2.6	3.2	1.9	2.4
Sayomia	13.5	23.8	18.8	20.1	25.6	19.8
Other Insects	4.3	12.6	9.4	6.8	9.2	8.6
Fishes	2.2	3.4	2.6	7.1	2.1	3.9
Vegetation	2.9	2.6	6.3	3.0	4.5	9.4
Inorganic	3.8	4.2	8.1	3.4	3.4	6.5
Miscellaneous	2.0	1.2	3.6	2.3	2.3	9.6

utterly impossible, but scales found in the stomach has hinted that these are often young of the cisco itself. The vegetable matter includes algae and plant debris from the bottom. The inorganic matter is largely fine silt or sand, taken in as the fishes nose around on the bottom. The miscellaneous item includes forms not found in any great numbers, such as water mites, rotifers (Anuraea) and unidentifiable matter.

Certain facts in connection with the food habits deserve mention. During the winter months it is a common occurrence to find a stomach simply packed with entomostraca. One such stomach, from a fish 31 cm long and weighing 446 grams, was carefully washed out and the contents preserved in alcohol. This mass was then diluted in 250 cc of alcohol and five samples of 2 cc each were carefully counted on a squared plate. The average of the five counts gave the following:

Daphnia........541;	in 250 cc.........	67,625
Cyclops.........263;	in 250 cc.........	32,875
Bosmina........121;	in 250 cc.........	15,125
	Total:	115,625

This gives some idea of the tremendous numbers of organisms these fish consume. A stomach was found in January, 1924, which contained nothing except *Sayomia albipes* larvae. By actual count 376 larvae were obtained, of which 319 were still alive when removed from the stomach after the fish had been out of water over three hours. While Sayomia forms a very stable article of diet, the larvae seem to be more resistent to the digestive juices of the cisco than any food consumed, as in a vast majority of the stomachs examined the larvae have shown great activity after removal, a condition found in no other item of food eaten by the fish.

MIGRATIONS

It has been said that the cisco is a bottom inhabitant and that it must be regarded as a deep water fish. During that part of the year when the oxygen conditions permit, *Leucichthys artedi* remains normally in the deep water, spending most of the time within a meter or two of the bottom. This fact has been demonstrated again and again, year after year by the use of gill nets set at different depths. As I have said, this differs radically from the habitat chosen by the Lake Michigan cisco as reported by Ward (1897). However, with the formation of the thermocline and the accompanying increase in the area of water deficient in oxygen, the cisco is forced to leave the bottom waters of the deeper parts of the lake, and assume a position ever higher in a vertical scale. As the thermocline climbs upward the cisco comes up with it and assumes a position in relation to the thermocline which may be described as directly above it. Therefore, if one takes the temperature of the water at different depths and thus obtains a fairly accurate idea of the location of the thermocline, one can set gill nets just above this depth and catch ciscos all summer. This was discovered in 1916 when the writer wanted the fish for an examination of the summer food. Nets were set in the deep water where the fish were caught in abundance during the previous winter, and caught nothing. After repeated failures a series of eight nets was set, one above the other. The net which was at 10 meters yielded 11 ciscos; the one at 9 yielded none and the one at 11 yielded 2 in the upper foot of mesh; none was caught in any other net. An analysis of the water at that time showed that the thermocline stood at 11 meters. This idea has been followed ever since, and has always yielded fish. I have set 43 nets below the thermocline, in 9 different lakes, and have never in a single instance caught a cisco. From these facts one must conclude that, while the cisco is essentially a deep water fish, it is driven from its chosen habitat by uncongenial gas conditions, so that the species really has a seasonal migratory rhythm in a vertical plane, correlated with and determined by the shifting of the thermocline.

This action of the thermocline in forcing the cisco up from the bottom has an exceedingly important effect upon the fish concerned. Being an inhabitant of the deep water, it is a cold water species. (Fig. 23.) The early summer influence of the thermocline has little effect on the cisco as there is still a great abundance of cold water rich in oxygen, but every meter, every centimeter that the oxygen level creeps upward, the amount of cold, oxygen-abundant water is cut down, and the fish is forced into water of increasing warmth. In the case of very hot summers, when the thermocline ascends unusually high, the cisco is forced into water far warmer than that which it ordinarily selects and to which it is therefore best adapted. The result is often disastrous. Dead fish begin to appear floating on the surface, fish perfect in every detail, unscarred, unparasitized, uninjured. Dozens of the fish I have picked up just as they reached the surface, to find them still alive though barely active. If the wind is blowing the shores of certain lakes, particularly Pine, Okauchee and Oconomowoc, become lined with dead fish. I was called to investigate such an "epidemic" among the cisco of Pine lake in August 1917. On the west (windward) shore I counted 72 dead fish in less than 100 feet of shore line, and this was by no means exceptional. As the result of my survey at that time I estimated that no less than 175,000 ciscos died within a week in that lake alone. This is significant when one considers what I have already said about the abundance of the fish in the lake. Similar catastrophes have occurred in Oconomowoc, La Bella, Okauchee and Silver lakes, though in no other lakes have the numbers run so high. Okauchee lake has come the closest to the record set by Pine and it ranks second in the abundance of the species in its waters. It is significant to note, also, that it is the larger fish which are most affected, suggesting a greater adaptability, resistance and vitality on the part of the young fish. It is further to be noted that the mortality is highest among the females which at this season of the year already have a considerable mass of spawn in the body, and this may explain the excess of males over females to which I have already alluded. There is no remedy for these "epidemics": they are caused by the fish being forced into the warm upper stratum of water by the rise in the thermocline, and the fishes are simply not physiologically adapted to warm water conditions. For the purpose of determining the effect of temperature upon *Leucichthys artedi*, several fish were placed in a large tank on February 3, 1924. The temperature of the water was noted, as were the gas conditions, and then warm water from a boiler was permitted to enter the tank slowly at one end. The results are shown in figure 16. Here it will be seen that the fish avoid water above 17°C if possible, but will stand a temperature of several degrees above this. At 26°C they begin to float at the surface; this is very close to the temperature encountered in nature after a prolonged, quiet, hot spell of a hot summer. The pH readings throughout the experiment showed no indication that the hydrogen-ion concentration was concerned with the reaction of the fishes; the same was true for oxygen. Since the fish require more oxygen with a rise in the temperature of the water, the amount varying directly with the increase in temperature, one can explain the mortality as being due to three factors: 1) the thermocline; 2) warm water; and 3) insufficient oxygen available. The thermocline is responsible for the situation. (Figs. 6, 7.)

A second migratory rhythm was discovered when it was found that the fish in Oconomowoc lake under ordinary conditions were nearer the surface at night than during the day. That this is not a phototropic reaction is indicated by the fact that they can easily be attracted to the surface during the hours of daylight, and that they will remain under the ice during the winter for hours at a time under the brightest of light conditions, if food is available. This suggested the idea that this daily movement might be a feeding rhythm. Since the fish were found to be feeding entirely upon entomostraca at the time (February 2) a series of water samples was taken at different depths at noon and again at the same depths at midnight. The four chief organisms found were Daphnia, Cyclops, Dioptomus and Bosmina. The water was pumped up by means of a garden hose and was strained through the Birge and Juday plankton catcher kindly loaned me by Mr. Juday. The amount of water strained was 15 liters from each depth. Figure 24 shows the distribution of these four organisms at the different depths during the day and at night. It will be noted that in every case the organisms migrate upward at night, the amount of the vertical change being the least in the case of Cyclops and greatest in Daphnia and Dioptomus. Since the cisco is dependent upon these organisms for food, and since it is well known that these minute entomostraca have such a daily rhythm, and, lastly, since the water conditions are uniform in the winter and the fish show no suggestion of negative phototropism, it must be concluded that this daily movement is a feeding rhythm following that of the entomostraca. Repeated observations and examinations have borne out this conclusion.

BEHAVIOR

I have stated in the discussion of *Labidesthes sicculus* that, were it not for the fact that the silversides lie quiescent during the dark nights it would be the most active of all our fishes. But this title belongs to the cisco which is active, apparently, from the time it hatches until it dies. I have had the cisco under observation in the laboratory for nine months; I have spent two weeks each winter for nearly twelve years watching the behavior of the fish through the ice and I have never yet seen one quiet for a period even approaching a second. This constant activity is perhaps due in a large measure to the food habits of the fish; since their chief item of diet is entomostraca and since these are eaten in enormously large numbers as has been shown, it follows that great quantities of water must be passed through the gill rakers in order to obtain this food in quantities such as are found in the stomach. A cisco with an empty stomach is the greatest rarity I recall in the fish life of the region under consideration, rarer even than young of the species, for I have yet to find a single empty stomach in a healthy fish.

That the species is gregarious is borne out by the fact that during the winter when the fish are sometimes seen at the surface, neither I nor any of the hundreds of cisco fishers with whom I have spoken have evern seen a lone cisco. When traveling near the surface at times the schools are seen to number several hundred individuals; the smaller schools are composed of from twenty to sixty fish. While these schools are to a certain extent composed of fish of varying sizes, the large and small fish do not mingle to any great degree, there being a marked uniformity of size in the component individuals in each school. That these facts hold also for the summer months is indicated by the gill net catches. Often I have missed a catch entirely, but the smallest number of fish I ever caught is 5; the largest is 33, in a fifty foot net, four feet deep with one and one half inch mesh. Surely this shows unmistakable gregariousness.

During the summer when the thermocline has driven the fish from the deepest water, the fish travel in schools, parallelling exactly the contours of the sand bars. The interesting fact about this travel is that it has a definite direction: the fish travel west along the north shore of Oconomowoc lake, south along the west shore, east along the south shore and north along the east end of the lake. This has been demonstrated by noting the direction in which the fish are found in the gill nets along the different shores. This is brought out in table 27.

TABLE 27

THE DIRECTION OF TRAVEL OF THE CISCO ALONG THE SHORES OF OCONOMOWOC LAKE IN SUMMER

Shore	Net set	No. caught	Number heading N	S	E	W
North	E–W	286	1	3	—	—
North	N–S	4	—	—	12	276
West	E–W	83	4	79	—	—
West	N–S	0	—	—	—	—
South	E–W	6	4	2	—	—
South	N–S	146	—	—	133	13
East	E–W	74	59	15	—	—
East	N–S	10	4	6	—	—

These figures are the result of a series of catches during the summers of 1921 and 1922 and represent the total catch of 20 nets set in each direction along the shore. The low figures for the east and west shores are explainable by the fact that the bars are much less regular here than along the north and south shores, and the schools go south at the west end and north at the east end over a scattered territory. The figures show conclusively that the line of travel is well laid down. There is at present no explanation for the phenomenon; there is no evidence of oxygen, carbon dioxide, hydrogen-ion concentration, light or temperature changes to account for it, nor can it be a reaction to current, for down the north shore the fish are following the current caused by the incoming Oconomowoc river, while along the west and south shores they are going against the current caused by the outflow of the Oconomowoc river at the northwest corner of the lake. It is difficult to see in what way it could be linked to the food habits, for certainly the entomostraca have no such migratory movement.

However, that the movement of the fish is intimately connected with their food habits is indicated by the fact that a migrating school can be stopped by an abundant food supply. This fact is well known to the winter fishermen who utilize it to their benefit by dropping oatmeal flakes into the water. Upon the descending flakes and the accompanying dust the fish feed ravenously, and a series of schools can be held under the holes in the ice for weeks at a time while hundreds of fish are caught from the schools by means of a small "white bait" or a gold bead. Once the school has been stopped in this way, the stomachs show nothing but oatmeal—the normal food habits are entirely abandoned. Any small object descending slowly through the water is taken into the mouth, but if it be not satisfactory it is ejected again with astonishing rapidity. This oatmeal diet is not injurious to the fish, though the flesh is noticeably softer after the fish have been feeding upon it for some weeks. A few years ago meat scrap was used instead of oatmeal; it was eaten even more ravenously than the meal, but resulted in diarrhea and in the death of many fish, so that its use had to be prevented by law. (Fig. 5.)

One further point should be noted in this connection. In the lakes of the north, where lumbering causes a constant distribution of sawdust over the water, the writer has found dead Leucichthys floating at the surface, with stomachs containing a solid mass of sawdust. These descending particles are no doubt taken in with the water, strained out by the gill rakers, mass in the stomach and eventually kill the fish which is unable to void the debris.

CONSERVATION

It is generally said that the cisco will bite only during the winter, but this is not correct as the writer has often proven. Still no one fishes for them in the summer, which is just as well. Cisco fishing has been a winter sport in the county for forty years and the catches are astonishing. No less, certainly, than 15,000 are taken from Oconomowoc lake each winter, and this is repeated in other cisco inhabited lakes. In former years the catches were much larger, 200 fine fish a day per fisherman being a fair catch. A conservative estimate places the cisco catch in Oconomowoc lake during the last 40 years at least as high as 1,000,000 fish! There has been no restocking, for the cisco is not raised in any hatchery in the state. In spite of the fact that the species is prolific, the fact remains that the rate of growth is slow. The result of the enormous catch each year is that the size of the fish has been reduced about four fifths! I have a record of thirteen fish caught on March 3, 1908, that weighed over $4\frac{1}{2}$ pounds each; a 3 pound cisco is still occasionally caught, but is very, very rare; dead fish are sometimes found during the summer that weigh upward of 4 pounds. But in the winter of 1924 the average weight of 244 fish weighed by the writer was just 116 grams—a little better than four to the pound!

Until the last few years there were no laws relating to the capture of the cisco in the inland waters of Wisconsin. Repeated pressure on the state legislature finally placed a bag limit of 25 per man each day on the species. But this is not sufficient. In view of the situation as it now stands the writer recommends the following conservation methods, these being well worth while as the species is a most excellent table fish.

1. Cisco fishing in all lakes in Waukesha county should be closed for a period of five years.
2. A size limit of 12 inches should be established.
3. The bag limit should be reduced to 15 each day.
4. The cisco should be raised in the bass hatcheries during the winter when these hatcheries are idle, and fry should be planted in suitable lakes.

SUMMARY

1. The cisco, *Leucichthys artedi*, is a member of the family Salmonidae and has a wide range in the deeper glacial lakes of the Mississippi valley, particularly in the northern part. It is known to occur in fourteen lakes in Waukesha county.

2. It is a deep water species, inhabiting the deepest parts of the lake during the winter, spring and fall.

3. Spawning occurs in late November or early December, the determining factor being the temperature of the water.

4. The males precede the females into the shallows, arriving when the water cools to 4.3°C. The females arrive a few days later, with the temperature dropping to 3.8°C, and spawning is at its height at 3.3°C.

5. Males outnumber the females, there being a higher mortality among the females during the warm water period of summer.

6. The eggs develop in from ten to twelve weeks, depending on the temperature of the water.

7. After hatching the young fish seek the deepest parts of the lake where they remain until their first breeding season, at the age of three years, except when driven out by the thermocline.

8. The rate of growth and weight increase is given for fish up to ten years of age.

9. The cisco has a seasonal migration in a vertical plane. This is due to the formation of the thermocline and the accompanying zone of water deficient in oxygen. The result is that the species is slowly driven from the deeper water into water of lesser depth and increasing warmth.

10. Since the cisco is a deep water fish, adapted to cold water, the result of this condition is death to thousands of fish. Death is due to suffocation as the fish require more oxygen in warm water than in cold, and the supply is insufficient to their needs.

11. The result of 941 stomach examinations is given, showing the food habits the year around.

12. Entomostraca form a very important item of the food. Since these organisms are negatively phototropic, being down during the day and up at night, a second migration, or daily rhythm on the part of the fish, also in a vertical plane, coincides with the movement of their food.

13. The fish are active day and night the year around.

14. This activity in summer assumes a definite co-ordinated movement, extending around Oconomowoc lake in a clockwise direction.

15. This movement is connected with the feeding habits as suggested by the fact that the migrating schools can be stopped and held by the presence of an abundant food supply.

16. The decrease in abundance and size of the cisco in Oconomowoc lake call for protective and conservative measures to prevent the destruction of a valuable food fish.

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EXPLANATION OF PLATES

The following photographs are from original negatives made by the writer within the limits of Waukesha county, Wisconsin. The graphs and diagrams are made from original data taken both in Waukesha county and at Madison, Wisconsin, the data being included in the body of the paper.

PLATE I

EXPLANATION OF PLATE I

FIG. 1. Laura Lake. A small body of water showing signs of old age.

FIG. 2. Pretty Lake. A small body of water that is nearly completely filled up. The mound in the middle foreground formerly was an island.

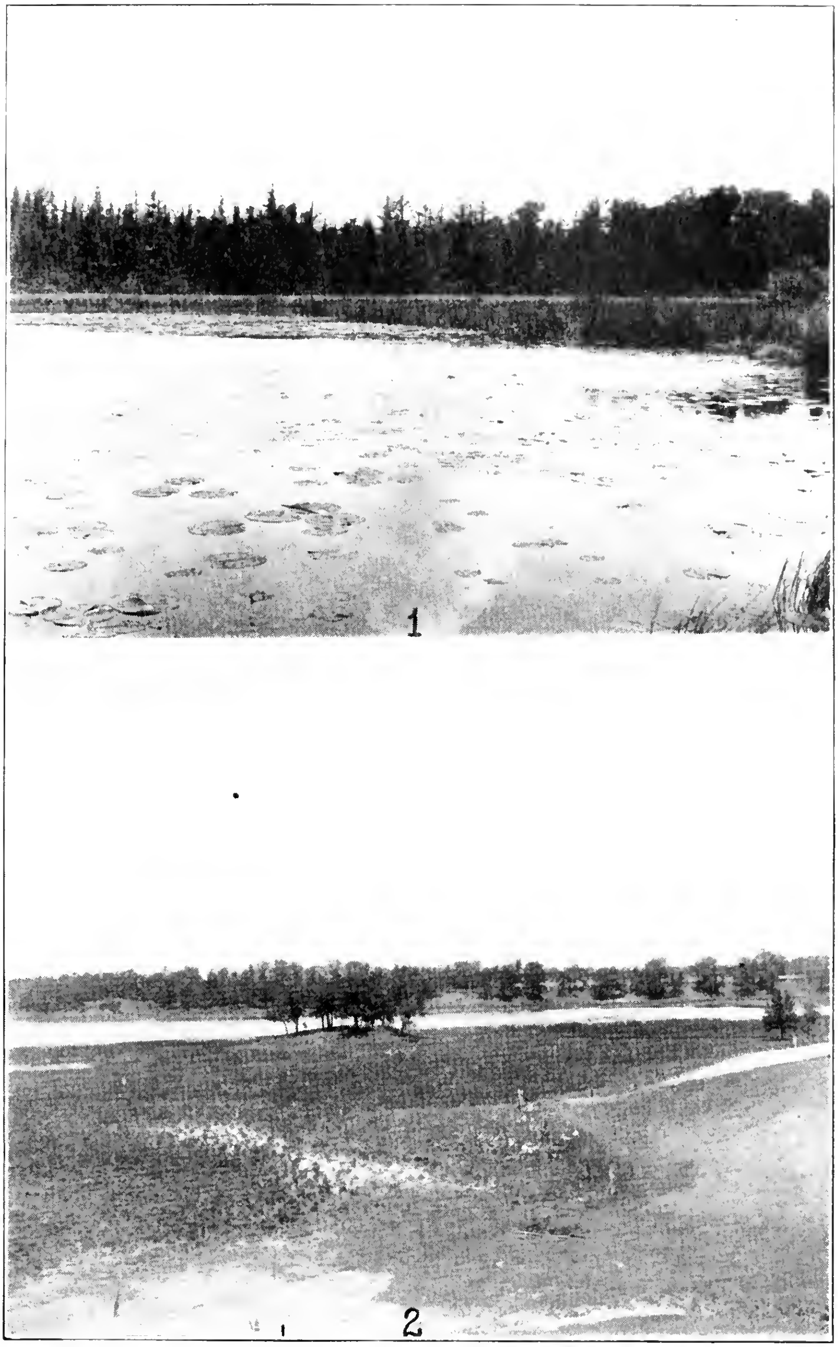
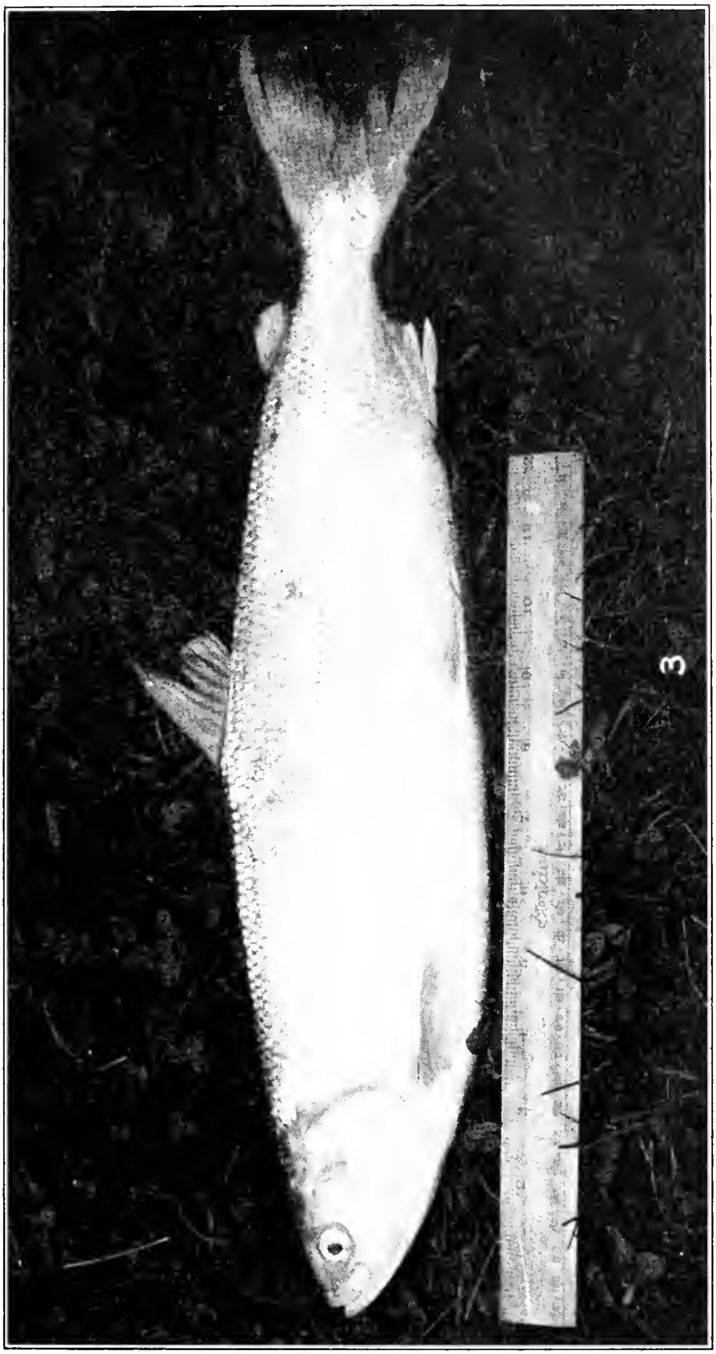

1
2

PLATE II

EXPLANATION OF PLATE II

FIG. 3. The Cisco, *Leucichthys artedi*, from Oconomowoc Lake.



CAHN PLATE II

PLATE III

EXPLANATION OF PLATE III

FIG. 4. The zone of wave action along a steep shore, marked by a paucity of vegetation and fish life.

FIG. 5. Shanties used by cisco fishermen in Waukesha county during the winter fishing season. Oconomowoc Lake.

4

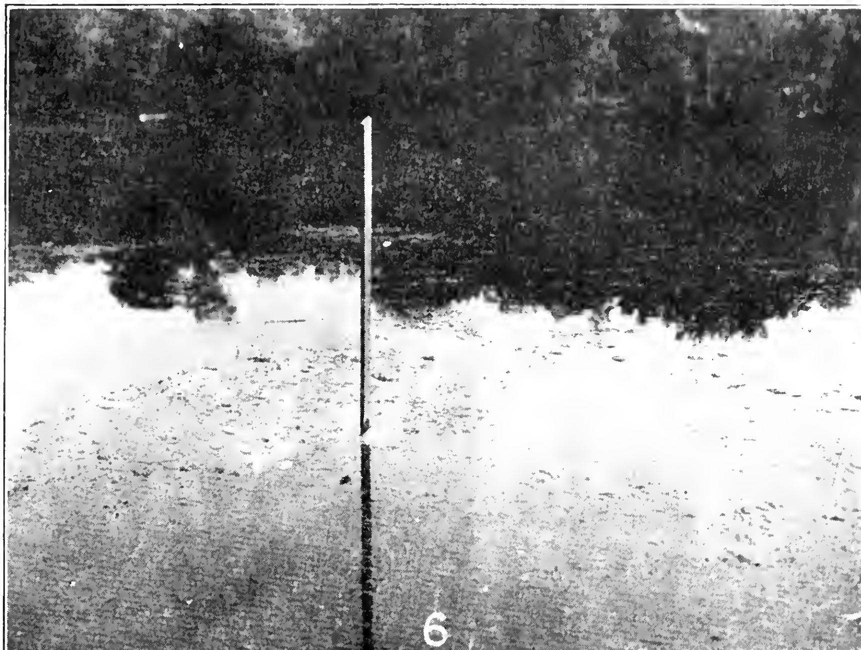
5

PLATE IV

EXPLANATION OF PLATE IV

FIG. 6. Forty-eight dead ciscos along fifteen feet of shore. Okauchee lake epidemic of August, 1925.

FIG. 7. Fifty-six dead ciscos drifting into shore during the Okauchee lake epidemic of August, 1925.


6


7

PLATE V

EXPLANATION OF PLATE V

FIG. 8. Sketch map of Waukesha county, Wisconsin, and the region joining it to the south, showing the distribution of the lakes and river systems.

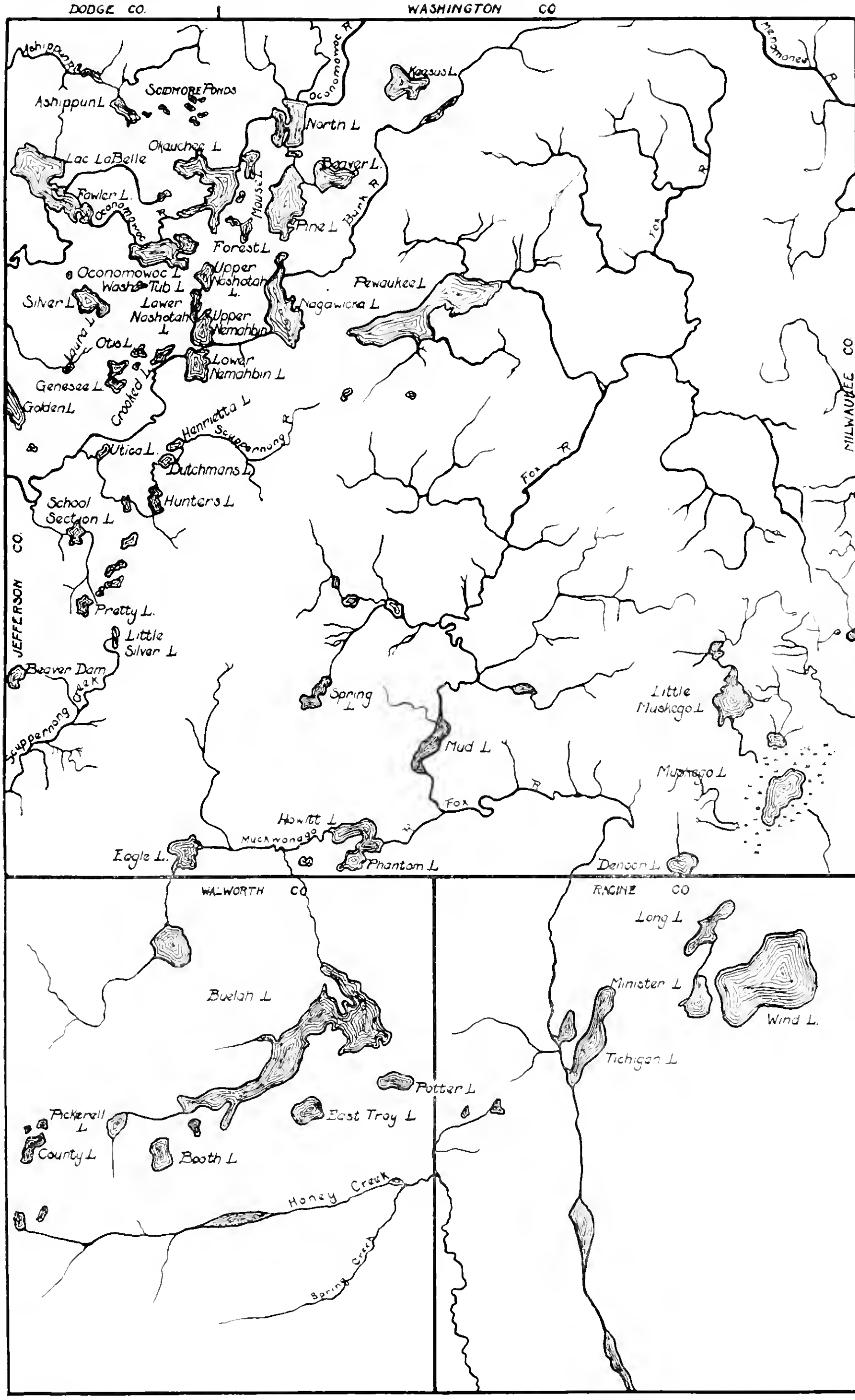

DODGE CO.
WASHINGTON CO
MILWAUKEE CO
JEFFERSON CO.
WALWORTH CO
RACINE CO
Ashippun L.
Scidmore Ponds
Keesus L.
North L.
Oconomowoc R.
Menomonee R.
Okauchee L.
Lac LaBelle
Beaver L.
Fowler L.
Oconomowoc R.
Mouse L.
Pine L.
Bark R.
Forest L.
Fox R.
Oconomowoc L.
Upper Nashotah L.
Pewaukee L.
Wash Tub L.
Silver L.
Lower Nashotah L.
Upper Nemahbin
Nagawicka L.
Laura L.
Otis L.
Lower Nemahbin L.
Genesee L.
Golden L.
Crooked L.
Henrietta L.
Scuppernong R.
Utica L.
Dutchmans L.
Fox R.
Hunters L.
School Section L.
Pretty L.
Little Silver L.
Beaver Dam
Scuppernong
Spring L.
Little Muskego L.
Mud L.
Muskego L.
Fox R.
Howitt L.
Muckwonago
Eagle L.
Phantom L.
Denoon L.
Long L.
Buelah L.
Minister L.
Wind L.
Tichigan L.
Potter L.
Pickerell L.
East Troy L.
County L.
Booth L.
Honey Creek
Spring Creek

PLATE VI

EXPLANATION OF PLATE VI

Fig. 9. The Labrador glacier and its principal lobes. It is this ice sheet which is responsible for the outstanding topographic features of Waukesha county. (Modified after Fenneman)

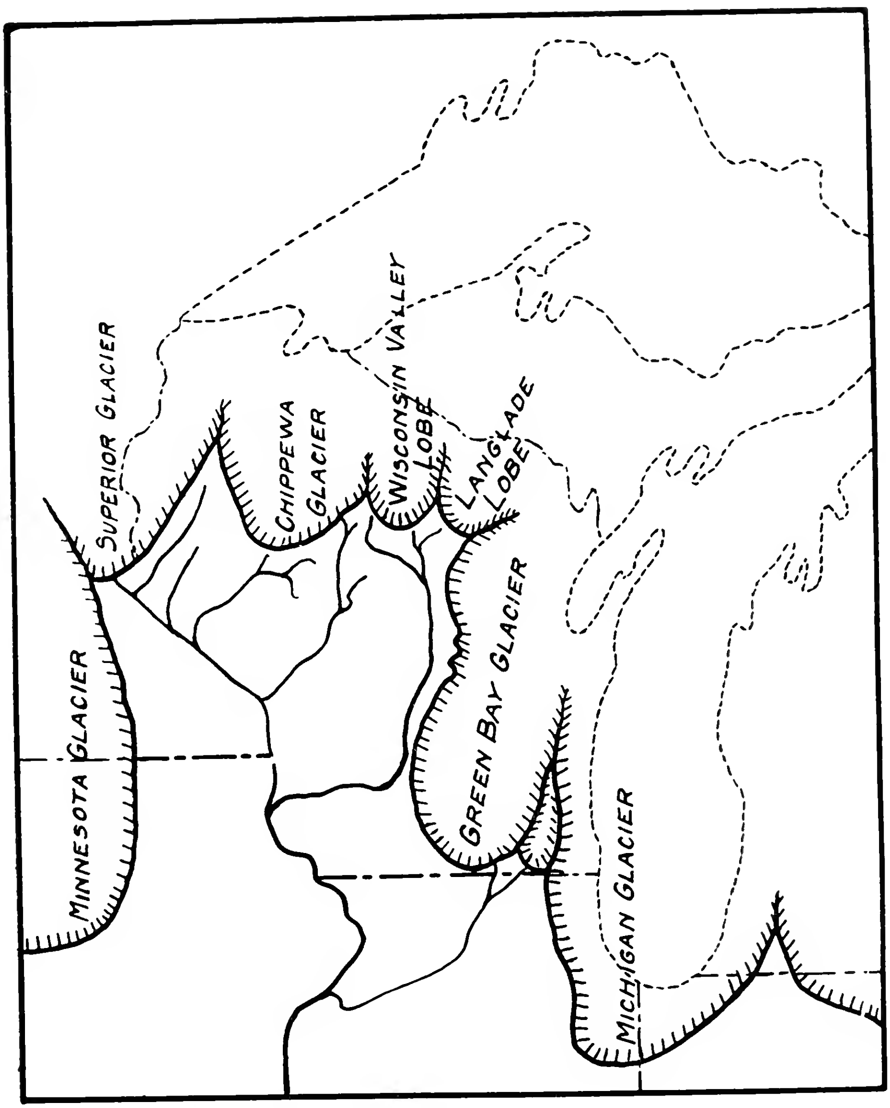

SUPERIOR GLACIER
CHIPPEWA GLACIER
WISCONSIN VALLEY LOBE
LANGLADE LOBE
GREEN BAY GLACIER
MINNESOTA GLACIER
MICHIGAN GLACIER

PLATE VII

EXPLANATION OF PLATE VII

FIG. 10. Graph showing the mean rainfall in inches per month in Waukesha county, Wisconsin from 1871 to 1924 inclusive. Station located in city of Waukesha.

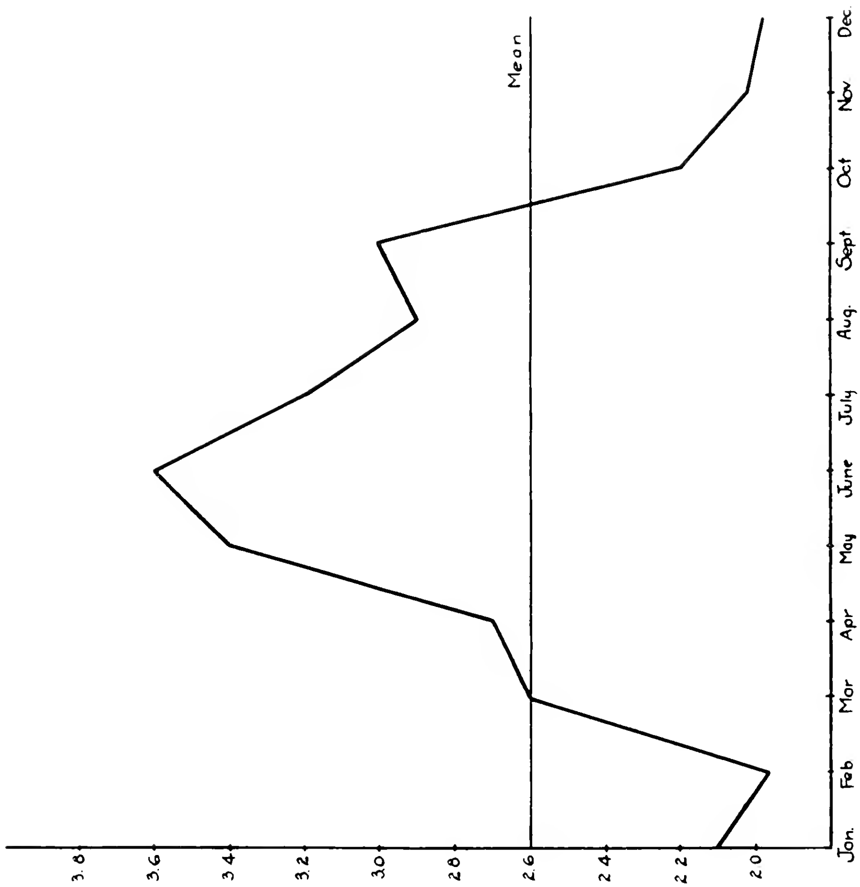
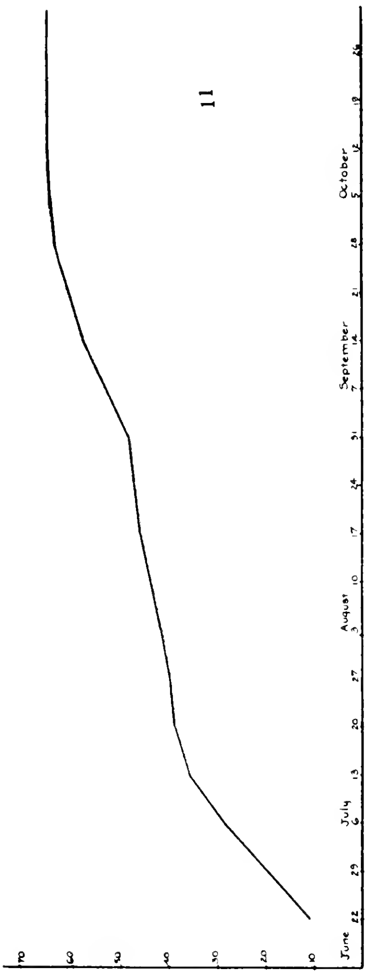

Mean
Jan.
Feb
Mar
Apr
May
June
July
Aug.
Sept
Oct
Nov
Dec
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8

PLATE VIII

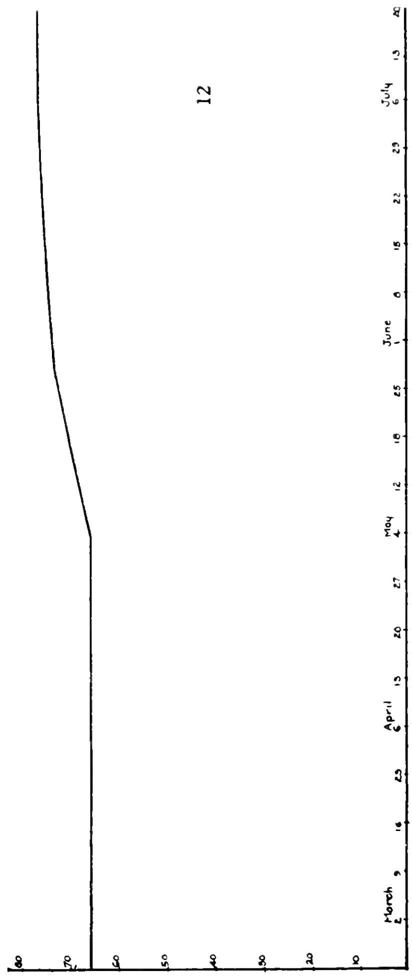
EXPLANATION OF PLATE VIII

FIG. 11. Growth curve for brook silversides, *Labidesthes sicculus:* June to November. Length in millimeters.

FIG. 12. Growth curve for brook silversides, *Labidesthes sicculus:* March to August. Length in millimeters.


June
July
August
September
October

11


March
April
May
June
July

12

PLATE IX

EXPLANATION OF PLATE IX

FIG. 13. Measurements of 250 young-of-the-year of the brook silversides, *Labidesthes sicculus*, on different dates during the summer. Length in millimeters. Data from north shore of Oconomowoc lake.

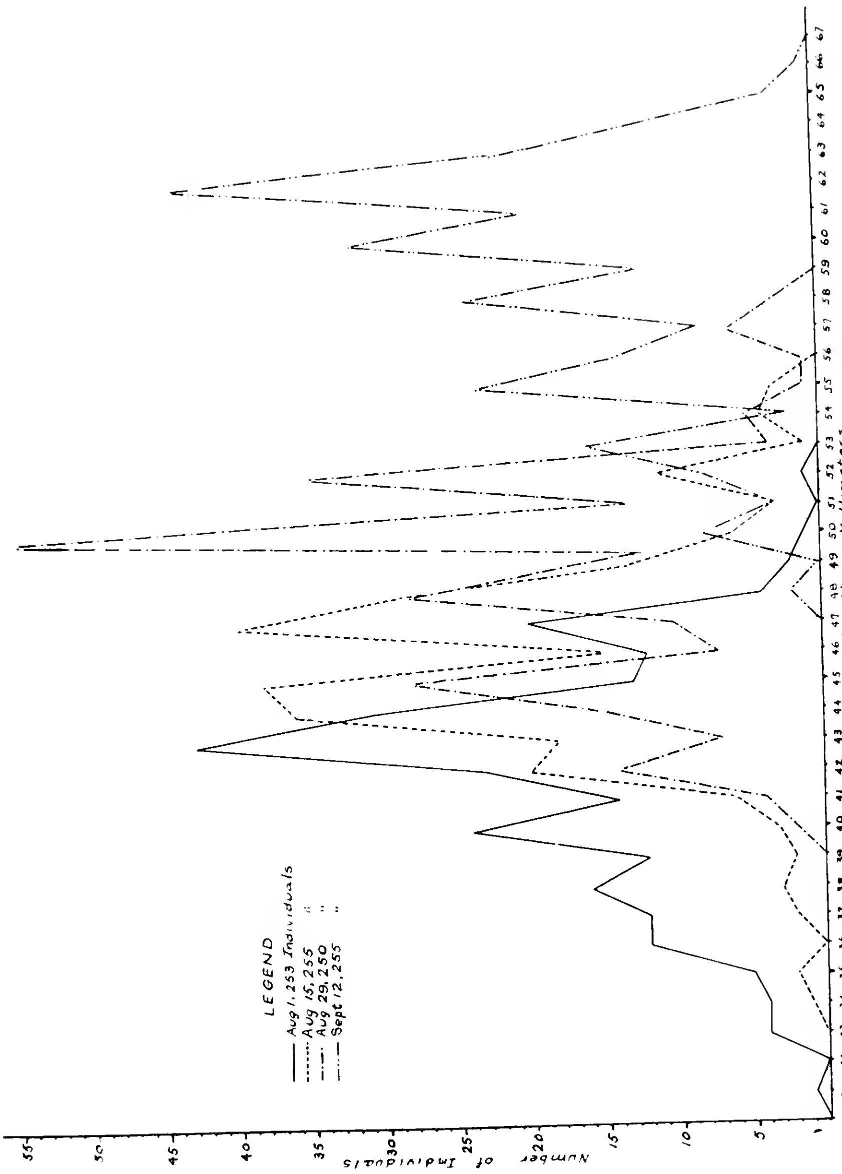
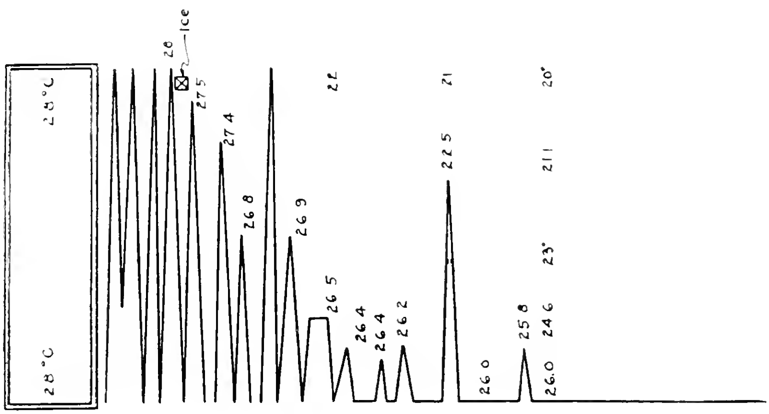

LEGEND
Aug 1, 253 Individuals
Aug 15, 255
Aug 29, 250
Sept 12, 255
Length in Millimeters
Number of Individuals

PLATE X

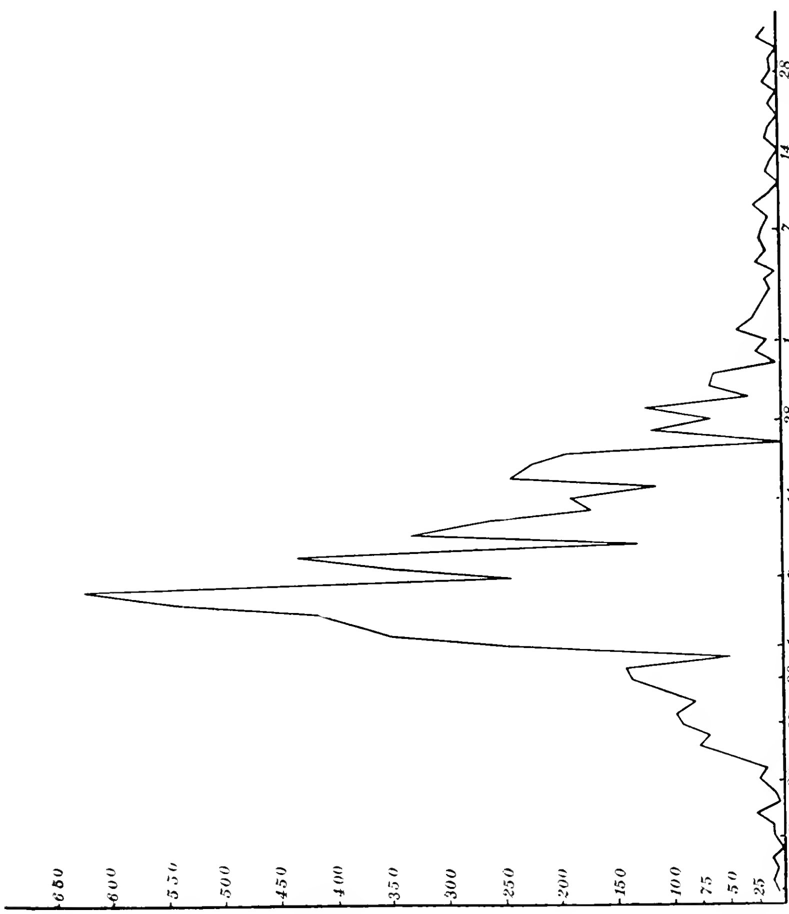
EXPLANATION OF PLATE X

FIG. 14. Showing the abundance of the brook silversides at night along the north shore of Oconomowoc lake, July 10 to Oct. 5, 1923.

FIG. 15. Figure to show the reaction of the brook silversides to water of increasing coldness.


Ice
28°C
28°C
27.5
27.4
26.8
26.9
26.5
26.4
26.4
26.2
22.5
26.0
25.8
24.6
26.0

15


July
Aug
Sept
25
50
75
100
150
200
250
300
350
400
450
500
550
600

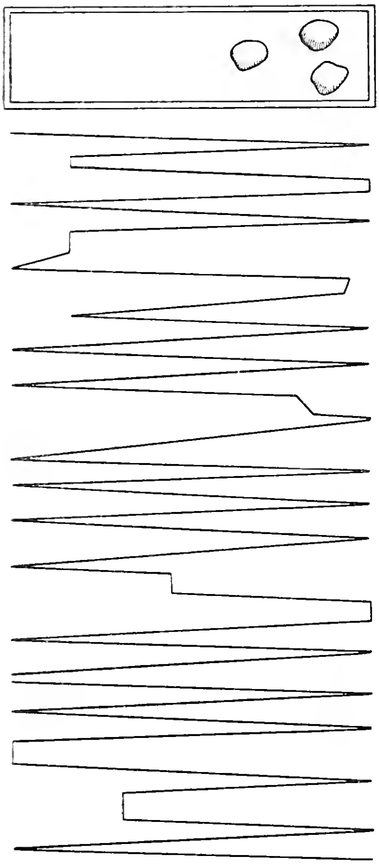
14

PLATE XI

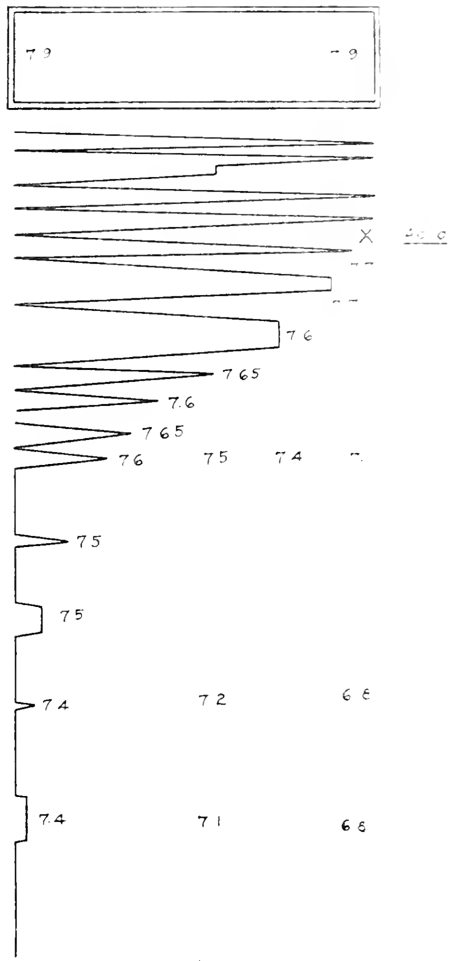
EXPLANATION OF PLATE XI

Fig. 16. Showing the reaction of the brook silversides to objects of large size.

Fig. 17. Showing the reaction of the brook silversides to water of increasing acidity.



16



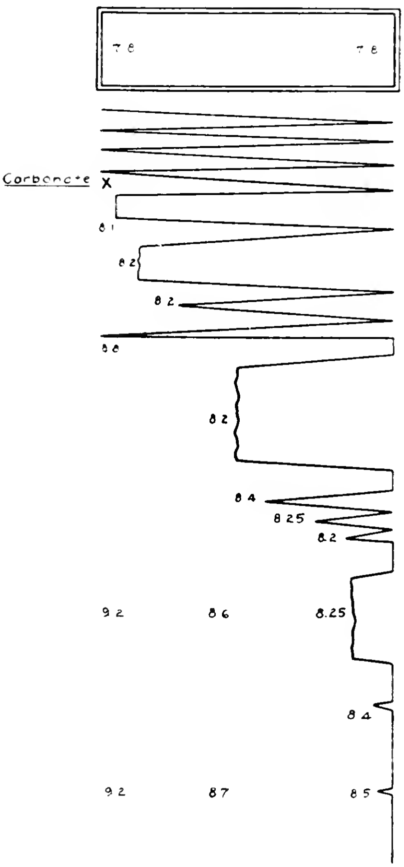
17

PLATE XII

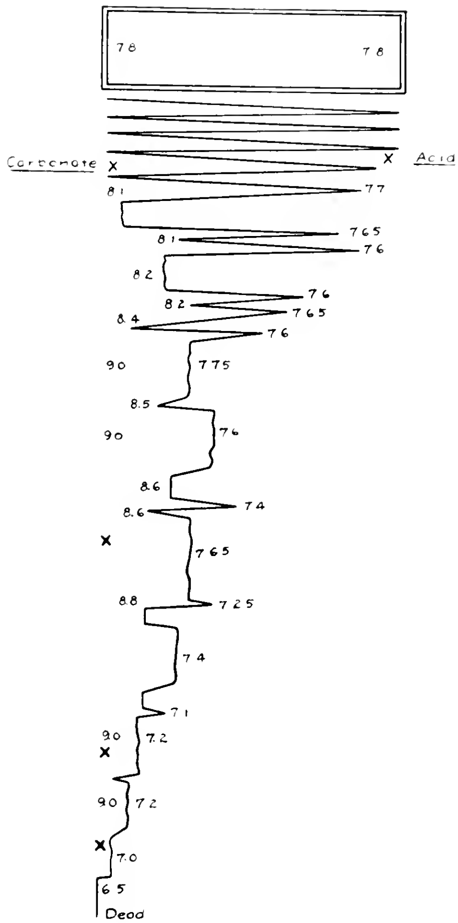
EXPLANATION OF PLATE XII

FIG. 18. Showing the reaction of the brook silversides to water of increasing alkalinity.

FIG. 19. Showing the reaction of the brook silversides to water of increasing acidity and alkalinity.


7 8
7 8
Carbonate
8 1
8 2
8 2
8 8
8 2
8 4
8 25
8.2
9 2
8 6
8.25
8 4
9 2
8 7
8 5

18


7 8
7 8
Carbonate
Acid
8 1
7 7
8 1
7 65
7 6
8 2
8 2
7 6
7 65
8.4
7 6
9 0
7 75
8.5
9 0
7 6
8.6
8.6
7 4
7 65
8.8
7 25
7 4
7 1
9.0
7.2
9 0
7 2
7.0
6 5
Dead

19

PLATE XIII

EXPLANATION OF PLATE XIII

Fig. 20. Showing the spawning period of the cisco in relation to the temperature of the water and of the air. Data from Lake Mendota at Madison, Wisconsin, Nov. 15 to Dec. 16, 1916. This is typical of the conditions existing during the spawning period in the Waukesha county lakes.

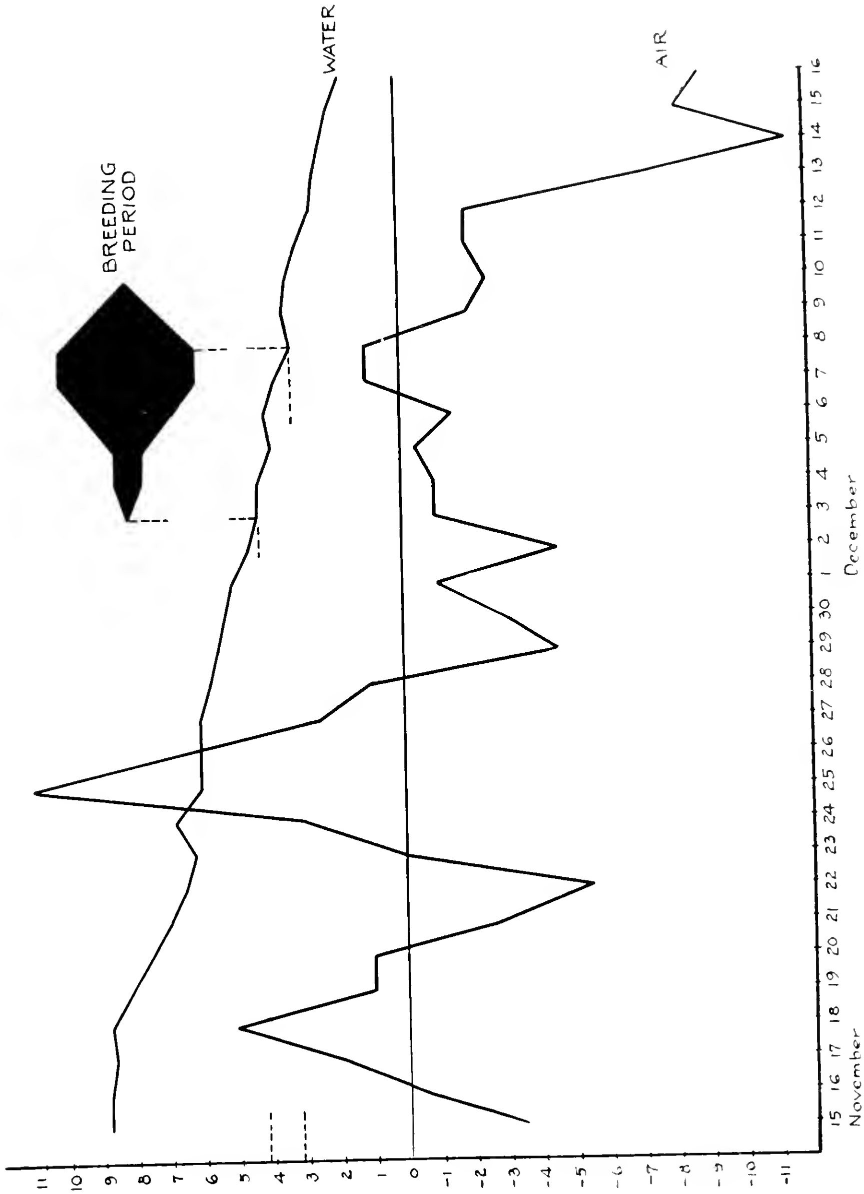
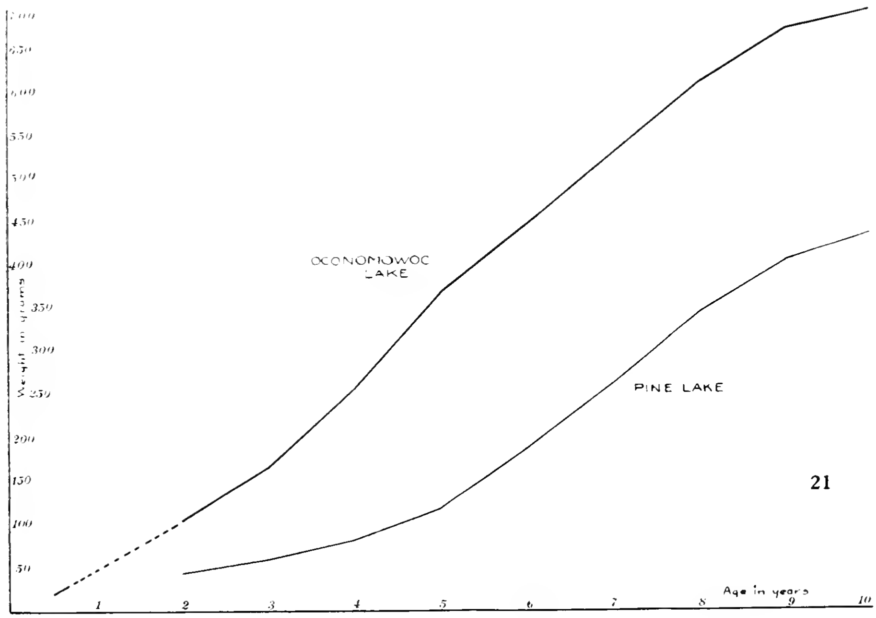

WATER
AIR
BREEDING
PERIOD
December
November
15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
11 10 9 8 7 6 5 4 3 2 1 0 -1 -2 -3 -4 -5 -6 -7 -8 -9 -10 -11

PLATE XIV

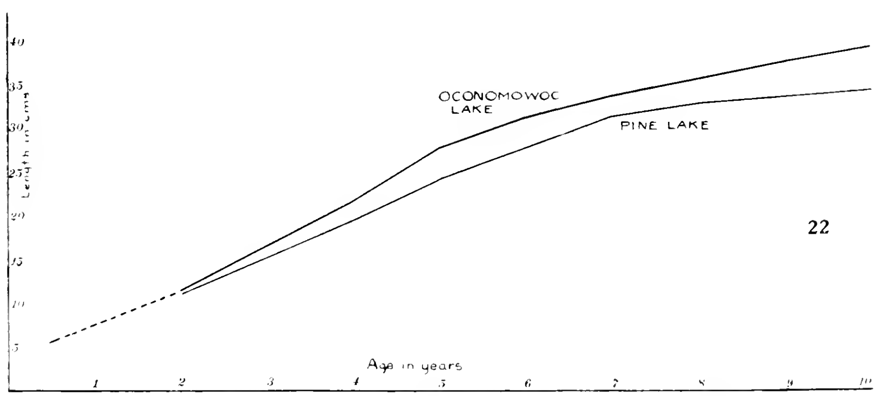
EXPLANATION OF PLATE XIV

FIG. 21. Showing the relationship existing between ciscos from Pine and Oconomowoc lakes. The age in years is plotted against the weight in grams. Pine lake has many times more ciscos per volume than has Oconomowoc lake.

FIG. 22. Showing the relationship existing between ciscos from Pine and Oconomowoc lakes. The age in years is plotted against the length in centimeters.


OCONOMOWOC LAKE
PINE LAKE
Age in years
1 2 3 4 5 6 7 8 9 10
50 100 150 200 250 300 350 400 450 500 550 600 650 700

21

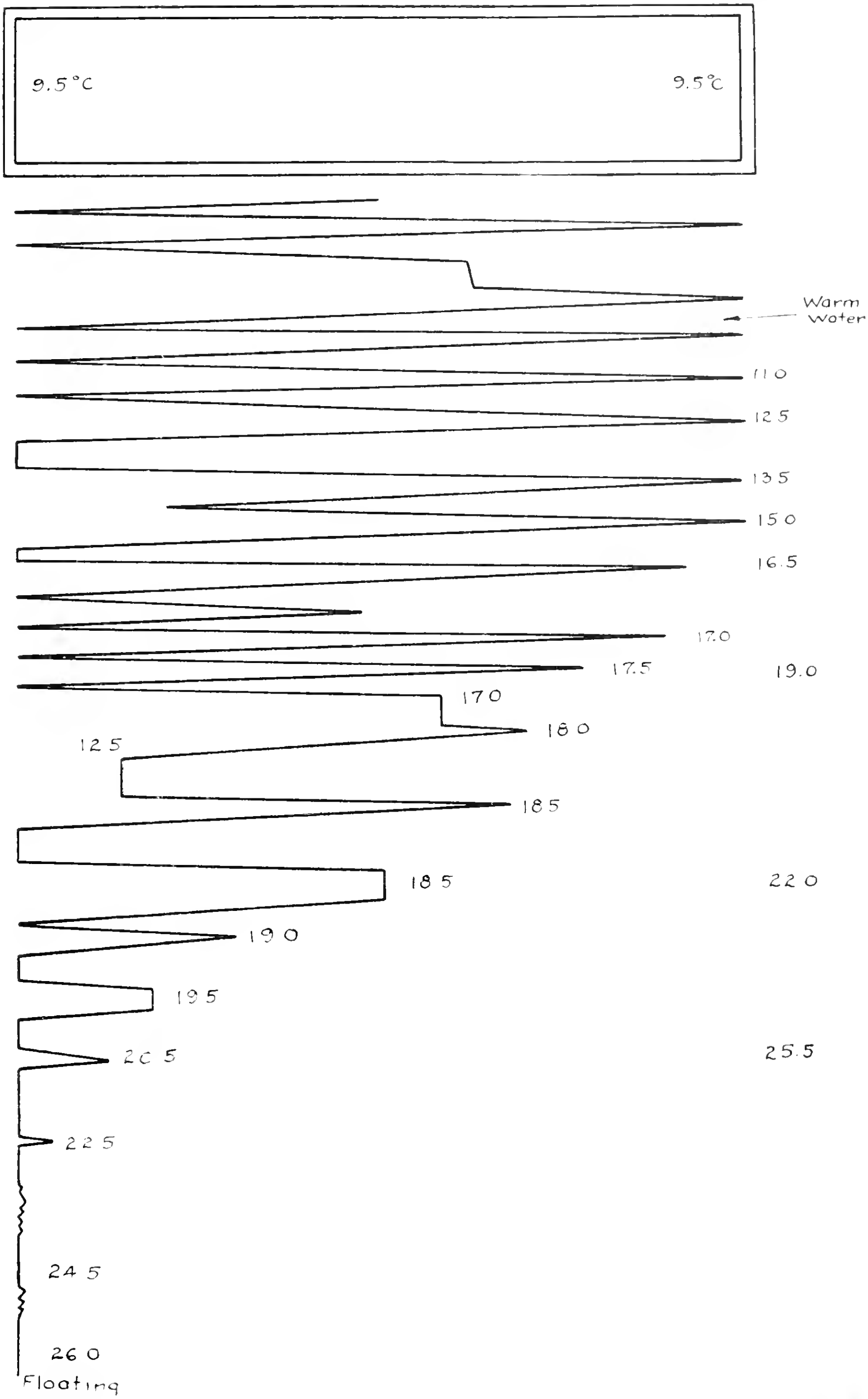

OCONOMOWOC LAKE
PINE LAKE
Age in years
1 2 3 4 5 6 7 8 9 10
5 10 15 20 25 30 35 40

22

PLATE XV

EXPLANATION OF PLATE XV

Fig. 23. Showing the reaction of the cisco to water of increasing temperature.



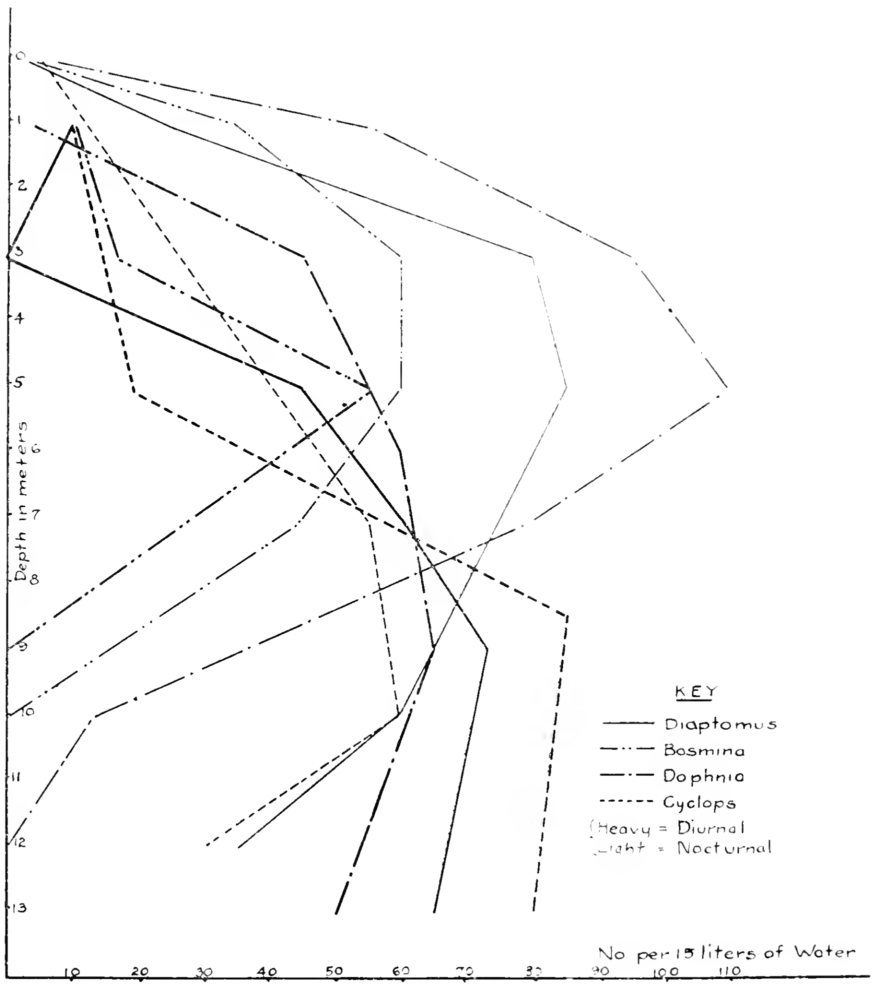
CAHN

PLATE XV

PLATE XVI

EXPLANATION OF PLATE XVI

Fig. 24. Showing the diurnal and nocturnal distribution in a vertical plane of certain entos mostraca in Oconomowoc lake, February 2, 1916. Number of organisms represented as per 15 liters of water pumped from given depths.


Depth in meters
0
1
2
3
4
5
6
7
8
9
10
11
12
13
KEY
Diaptomus
Bosmina
Daphnia
Cyclops
Heavy = Diurnal
Light = Nocturnal
No per 15 liters of Water
10
20
30
40
50
60
70
80
90
100
110

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