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By Ira T. Wilson and David F. Opdyke.

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Bloomington, Indiana

18. Natural History of the Northern Mimic Shiner
Notropis volucellus volucellus Cope[1]

by

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INTRODUCTION

As a part of the research program in aquatic biology carried on jointly by the Division of Fish and Game, Department of Conservation, State of Indiana, and the Department of Zoology, Indiana University, a study of the natural history of the northern mimic shiner, *Notropis volucellus volucellus* Cope, was undertaken in June, 1935, and continued through August, 1937.

The study centered around the population of this species in Shriner Lake, of the Tri-Lakes group, situated at the head of the Eel River system, 7 miles north-northeast of Columbia City, Whitley County, Indiana. The data here presented deal entirely with that population, although supplementary studies on the fishes of various other Indiana lakes were made during the investigation.

ACKNOWLEDGMENTS

The identification of the "shore minnow" at Shriner Lake as *Notropis volucellus volucellus* Cope has been verified by Dr. CARL L. HUBBS, Curator of Fishes, Museum of Zoology, University of Michigan. Dr. HUBBS has also read the manuscript of this paper and made valuable suggestions regarding the presentation of the data. The study was supervised by the late Dr. WILL SCOTT, Director of the Indiana University Biological Station, and Professor of Zoology at Indiana University, and in part by A. E. ANDREWS and KENNETH KUNKLE, both of the Indiana Department of Conservation. My wife, RUBY YERTON BLACK, rendered valuable field assistance, as did JAMES BODLEY, Custodian of the Tri-Lakes State Fish Hatchery. Dr. A. I. ORTENBURGER, Chairman of the Department of Animal Biology, University of Oklahoma, and formerly of the Indiana University Biological Station faculty, has made some important suggestions furthering the study. I am sincerely grateful to all.

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[1] Contribution No. 327 from the Department of Zoology, Indiana University. Submitted in partial fulfillment of the requirements for the Master of Arts degree in Zoology, Indiana University, August, 1937. The present paper contains data not included in the original thesis.

MATERIAL

Total lengths were measured on 14,226 adults and 50 immature specimens, and 200 sets of scales were prepared and studied.

The contents of the stomach and intestine of 520 adults were studied. Dissections of 481 females were made to determine the development of the ovaries, and egg counts were made on 103 breeding females.

All specimens dissected were examined for parasites, and close watch was at all times maintained to discover indications of parasitism on specimens that were not dissected.

Field obsersations were recorded on the movements of countless thousands of individuals in their natural habitat, and at different times several hundred were studied in aquaria, tanks and pens of the Indiana University Biological Station, Tri-Lakes Hatchery and the Indiana University Zoological Laboratory.

All of the specimens preserved during the investigation are now in the University of Michigan Museum of Zoology fish collection. This material has recently been re-examined by Dr. HUBBS and myself to make certain that only the one species is represented. The characters distinguishing this species from *Notropis deliciosus* Cope, the only northern Indiana minnow with which it is likely to be confused, have been discussed by HUBBS and GREENE (1928: 375-379) and HUBBS and LAGLER (1941: 52, 59). *Notropis volucellus* and *Notropis deliciosus* are both common in northern Indiana, but the latter species apparently does not live in Shriner Lake.

SHRINER LAKE AND ITS FISH FAUNA

Shriner Lake is a typical northern Indiana lake (for physical data see SCOTT, 1931) and there is nothing other than its wealth of "weeds" and extreme clarity to mark it off from other lakes of the section. It is probably the clearest lake in Indiana and has an abundant and varied rooted flora. The sandy areas are limited and the lake is therefore ideally suited for *Notropis volucellus volucellus*, a typical species of moderately weedy water.

The northern mimic shiner is by far the predominant forage fish, but several other species are present, including the bluntnose minnow, *Hyborhynchus notatus*, and the northern brook silversides, *Labidesthes sicculus sicculus*. Among the smaller fishes these two rank next to the northern mimic shiner in abundance and in importance as forage fishes, but are vastly outnumbered by it. Other small species present but relatively uncommon include the blackchin shiner, *Notropis heterodon;* the western banded killifish, *Fundulus diaphanus menona;* and the central common shiner, *Notropis cornutus chrysocephalus*. Both the largemouth bass, *Huro salmoides*, and the northern smallmouth bass, *Micropterus dolomieu dolomieu*, are very common, as are several of the sunfishes (*Lepomis*), and the warmouth, *Chaenobryttus coronarius*. The black crappie, *Pomoxis* *nigro-maculatus*, the yellow perch, *Perca flavescens*, the mud pickerel, *Esox vermiculatus*, and the northern pike, *Esox lucius*, are less common members of the fish fauna. Two specimens of the northern blackstripe topminnow, *Fundulus notatus*, were collected in 1935. Northern longnose gar, *Lepisosteus osseus oxyurus* (possibly also one other species of gar), and bowfin, *Amia calva*, are present, but in smaller numbers than in most lakes of the region. Gizzard shad, *Dorosoma cepedianum*, and carp, *Cyprinus carpio*, are thought to be absent. Their absence may well have a direct bearing on the abundance of the northern mimic shiner.[2]

ABUNDANCE

Notropis volucellus volucellus normally occurs in Shriner Lake in remarkable abundance. In June of 1936 the adult population of this lake, which has an area of 120 acres, was not less than 50,000 and this was but a small fraction of the number present in 1935 and previous years. The numbers dropped even lower in 1937, but later again increased, so that by June, 1940, on the authority of Mr. BODLEY, the population was nearing the 1935 level, which was considered normal by him and other residents of the region. On repeated occasions during the summer of 1935 we captured 25,000 or more individuals in single, short seine hauls with a 25-foot minnow seine, and invariably the main body of the school escaped. So great were the quantities of these minnows then occurring in Shriner Lake that they were not only the principal food for all the predatory birds and fishes, but also served as the food supply for fishes at the Tri-Lakes Hatchery, were used (and wasted) in huge quantities as bait, and were even caught for use as fertilizer by the people living along the lake shore.

In late July and August of 1935 these minnows sometimes congregated several layers deep and as closely packed as they could swim in the shallow water along the south shore of the lake—forming a solid school that extended well over 150 yards along shore and averaging not less than five yards in width. At the same time smaller schools, each of considerable size, could be found along the entire south shore. Tri-Lakes residents said that the concentrations became even greater in September and October, and that in normal years the schools in the fall are augumented by great quantities of young minnows. In 1935 I never observed more than 50 young at any one time, and these were never mixed in with the adult schools.

The decrease of the 1936 population in comparison with that of 1935 appears to have been caused by the almost complete failure of the fish to produce young in 1935. The population present in 1937 was decidedly less than in 1936, and there was an obvious and sharp decrease between May 22 and June 12, 1937. The number of these minnows present in Shiner Lake reached an alarmingly low stage in 1937, but since the population

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2 The common and scientific names used throughout this paper are the same as those employed by HUBBS and LAGLER (1941).

later returned to or approached its normal high level, it may be assumed that the 1937 breeding season was a successful one.

AGE AND GROWTH

Beginning early in the summer of 1935 measurements were taken in an effort to determine the growth rate and age of the breeding fish. When the first series, of nearly 600 specimens, had been measured the resultant length-frequency graph showed three definite peaks with marked depressions between. This was interpreted as meaning that three different age groups, of about equal numbers, were represented. Such an interpretation has been made under similar circumstances in other studies, involving even fewer specimens, and seemed to be a logical conclusion. When, however, the series was extended to include 1000 specimens the notches filled out, leaving a single peak, indicating that most of the fish were of the same age. It was, therefore, decided to measure 1000 minnows each Monday throughout the season, whenever possible. Total-length measurements have been made and recorded on 14,226 adults, most of them living fish. FIGURES 1 and 2 are taken from these records. The measurements of living specimens of such delicacy and size made the total-length measurement preferable to the standard measurement of length (without caudal fin).[3] For the purpose of comparison a series of fresh specimens were measured by both methods. The correlation table is herewith presented as TABLE 1.

TABLE 1

Correlation between total length (natural tip length) and standard length of *Notropis volucellus volucellus*, measured in millimeters. (There were 5 specimens in the 35 millimeter group, 10 in the 56 millimeter group, and 25 in each of the others.)

Total length	Standard length	Difference	Total length	Standard length	Difference
35	28.0	7.0	46	36.5	9.5
36	29.0	7.0	47	37.1	9.9
37	29.7	7.3	48	38.0	10.0
38	30.7	7.3	49	39.0	10.0
39	31.1	7.9	50	40.0	10.0
40	32.0	8.0	51	40.6	10.4
41	32.6	8.4	52	41.2	10.8
42	33.5	8.5	53	42.1	10.9
43	34.1	8.9	54	43.0	11.0
44	35.0	9.0	55	43.9	11.1
45	35.9	9.1	56	44.0	12.0

[3] The total length measurement used was the maximum length of the fish from the tip of the snout to the end of the tail with the lobes of the caudal fin in a normal position. The standard length measurement used in the preparation of TABLE 1 was the measurement from the tip of the snout to the structural base of the tail.

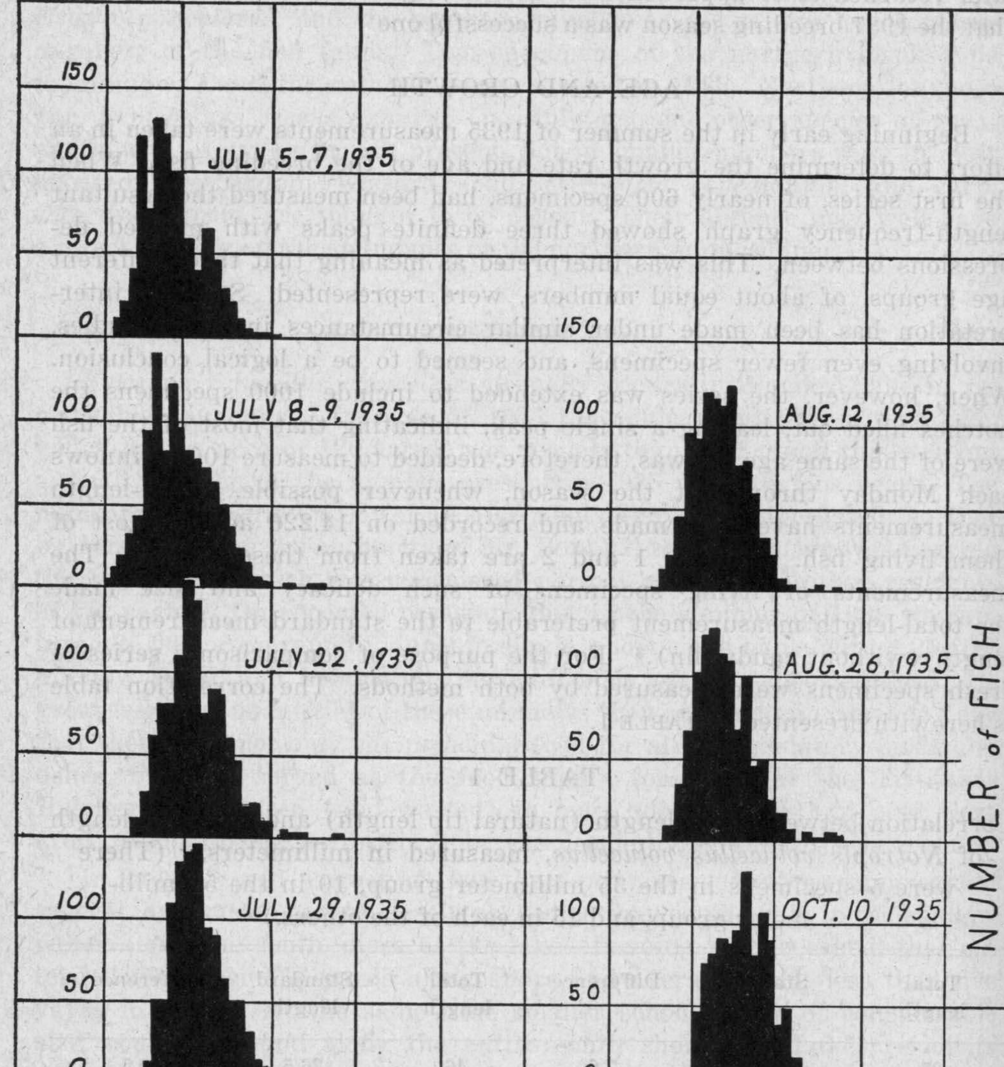

Figure 1. Total length measurements of the large collections made during the summer of 1935

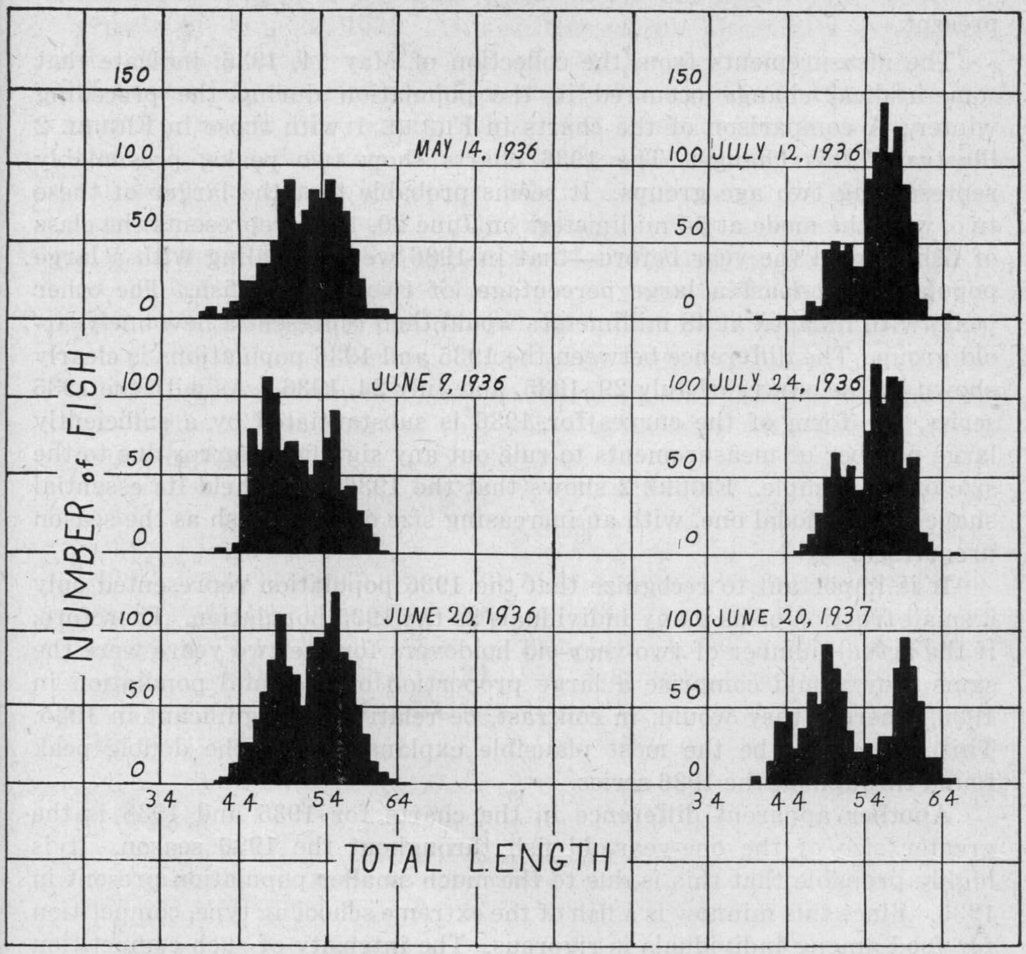

Figure 2. Total length measurements of the large collections made during the summers of 1936 and 1937.

It will be seen by referring to the July 8-9 histogram of FIGURE 1 that the mode falls at 40 millimeters. Three weeks later this peak had moved up to 44-45 millimeters; and it was at 46 millimeters on August 26. The intermediate stages may be followed on the charts. These figures indicate a period of extremely rapid growth during the month of July, for three or four weeks just after spawning, followed by a slowing down of the growth rate. This slowing down became more pronounced as the season progressed; the peak of the curve for October 28, 1935, falls between 47 and 48 millimeters. For each date the relationships are so nearly identical and the curves so regular that it is reasonable to conclude that the majority of the minnows were of the same age. From these data it was decided that most of the population had passed through only one winter. Only a relatively small proportion of the total population could be considered two years old, or older. The skewness of the growth curves, as well as scale studies, show, however, that a few two-year-old fish were present.

The measurements from the collection of May 14, 1936, indicate that some radical change occurred in the population during the preceding winter. A comparison of the charts in FIGURE 1 with those in FIGURE 2 illustrates this change. The 1936 charts show two peaks, presumably representing two age groups. It seems probable that the larger of these two, with the mode at 55 millimeters on June 20, 1936, represents the class of fish studied the year before—that in 1936 we are dealing with a large population, at least a large percentage, of two-year-old fish. The other peak, with its apex at 48 millimeters would then represent a new one-year-old group. The difference between the 1935 and 1936 populations is clearly shown by the curves of July 29, 1935, and July 24, 1936. As with the 1935 series, the form of the curves for 1936 is substantiated by a sufficiently large number of measurements to rule out any significant error due to the size of the sample. FIGURE 2 shows that the 1936 curve held its essential shape as a bimodal one, with an increasing size of all the fish as the season progressed.

It is important to recognize that the 1936 population represented only a small fraction of as many individuals as the 1935 population. Therefore, if the actual number of two-year-old holdovers for the two years were the same they would comprise a large proportion of the total population in 1936, whereas they would, in contrast, be relatively insignificant in 1935. This appears to be the most plausible explanation for the double peak found throughout the 1936 series.

Another apparent difference in the charts for 1935 and 1936 is the greater size of the one-year-old fish throughout the 1936 season. It is highly probable that this is due to the much smaller population present in 1936. Since this minnow is a fish of the extreme schooling type, competition for food among individuals is rigorous. The intensity of such competition no doubt becomes accentuated as the size of the school increases. This is especially true when the population reaches the staggering total that existed in Shriner Lake in 1935. It may be assumed that the intraspecific competition was decidedly less in 1936 and as a result the growth was more rapid. It is well known that crowded populations of game fishes do not attain the same growth as do uncrowded fishes, but I do not believe this has previously been demonstrated to be true of any of the minnows. This appears, however, to be the most satisfactory explanation for the average of 5 or 6 millimeters greater length attained by the 1936 first-year fish over that attained by the one-year-old group at corresponding dates in 1935. The modal group of the one-year-old class on July 29, 1935, measured 45 mm. in length; the same group of the comparable class on July 24, 1936, measured 50 mm. This is a difference of about 11 percent.

The possibility has been suggested that the first mode on the 1936 charts represents the same group of fish that made up the mode of the 1935 population. It is, however, highly improbable that a population with a modal length of 48 millimeters on October 28, 1935, would not show any growth by June 20, 1936. As a portion of this alternative explanation of the bimodal nature of the 1936 charts the second mode would have to represent fish three years old, or older. The number of these fish, in contrast to the few two-year-old fish in 1935, does not justify such an assumption. This alternative would admittedly be convenient in explaining my failure to find eggs, or young fish in any number, in 1935, because it assumes that the young of 1935 did not develop in sufficient numbers to make a mode on the 1936 charts, nor for that matter even skew the chart on the lower side, but the known rate of growth and the 1935 population distribution appears to exclude this alternative explanation.

The 1937 population was found to be similar in individual size to that of 1936, although the fish were so scarce in 1937 that but one good series was secured. The chart of this series is included with those of the 1936 season in FIGURE 2.

TABLE 2

Length-frequency distribution of male and female shiners caught on the same dates, arranged in classes 3 millimeters broad. Measurements were made on the following dates; 150 on July 21, 1935; 120 on August 12, 1935; 150 on June 20, 1936; and 74 on June 20, 1937

Mid-class length	37	40	43	46	49	52	55	58	61	64	Number measured
No. of females....	8	42	61	89	100	27	30	53	29	3	442
No. of males......	9	5	11	7	13	4	2	1[1]	..	...	52

[1] One male with a length of 59 millimeters, collected on June 20, 1937, was the only male found in three summer's work which was more than 54 millimeters in length.

The annuli on the scales bear out the conclusions reached by the measurement method. All scales from individuals at, or near, the mode in the 1935 series show only one winter check. Those individuals over 53 millimeters long (July 24, 1936, specimens) all prove to be two-year-old fish, whereas those under 50 millimeters fall without exception into the one-year-old class. The specimens from 50 to 53 millimeters represent both age groups, but the first annulus on those specimens with two winter checks, yet less than 53 millimeters in length, show that they hatched rather late in the summer of 1934.

Out of the 200 mounted sets of scales, no scale has been found with more than two annuli. It seems reasonable to assume that few, if any, of the fish live through a third winter. The great preponderance of one-year-old fish in normal (?) years indicates that most of the individuals in Shriner Lake survive only one winter.

The overlapping in size and age groups is caused in part by the smaller size of the male fish as contrasted with females. This difference in size of male and female fish is decided but there is sufficient overlap to prevent this size difference making a separate mode on charts or to make identifications of sexes possible on this basis. TABLE 2 shows the difference in size between male and female fish.

Whether the 1935 population or that of 1936 and 1937 represents the typical condition, or whether both represent normal stages in a cycle, are questions that can be answered only by further study. The residents at Shriner Lake insist that the 1935 population is the normal one and that the 1936 population was abnormally low. In any event it would seem that some calamity befell the eggs or young of the 1935 season so that only a very small percent of the expected young were produced, or at least survived to the 1936 breeding season. The preponderance of two-year-old individuals in the 1936 breeding population is additional proof that the decrease in numbers was caused by a virtual failure of the 1935 breeding season.

In commenting on the failure of the large 1935 population to produce a large year-class of young Dr. HUBBS (correspondence) has suggested that "cannibalism may be the explanation, for the superabundant adults of 1935 may have been pressed for food so much as to have consumed most of the fry." This point had escaped my attention but in view of the known habits of certain minnows and the demonstrated omnivorous feeding habits of the northern mimic shiner, coupled with its preference for the larger items in its regular diet and the obvious scarcity of food, is one which is worthy of full consideration as a distinct possibility.

The decrease in the 1937 population occurred in late May or early June of that year and was, therefore, a disturbance which killed breeding adults. This is discussed in the consideration of parasites discovered to be present in the Shriner Lake stock of the northern mimic shiner.

REPRODUCTION

In spite of the fact that our most intense efforts were directed toward a study of the breeding habits of *Notropis volucellus volucellus,* especially in 1935 when Mrs. BLACK and I spent practically every daylight hour on the lake when the water was quiet enough for observations, we never succeeded in locating a single egg of this shiner. Every conceivable habitat was examined, by a variety of methods, but to no avail. So far as I am aware this has been the experience of others, and to date the breeding place of this minnow remains unknown. The several reports of the New York Biological Survey (1928, 1929, 1930, and 1931) all agree that the species is a summer spawner, but like other sources fail to record the finding of eggs.

On the basis of negative evidence it is most probable that the species breeds at night in the relatively deep water (perhaps around the 15 to 20-foot level in Shriner Lake) in the dense weed beds which they frequent especially at night and in cloudy weather. This is no more than speculation, based on the observed habits of the fish and our failure to locate eggs in shallow water, or to see the minnows spawning during daylight hours, but it would be the focus of my attention should the opportunity again offer itself to study the breeding habits of this species. The fact that the minnow is virtually confined to weedy lakes and streams offers additional support of this premise.

Wherever *Notropis volucellus volucellus* breeds is it improbable that it is a nest-building species. This is indicated not only by its habits but also by its structure. Furthermore in nest-building cyprinids the males are usually larger and stronger than the females (HUBBS and COOPER, 1936: 12-13), not smaller on the average as they appear to be in *N. v. volucellus* (TABLE 2).

During the breeding season collections were almost entirely of females. Later in the summer the sexes proved to be approximately equal. A similar sexual segregation and disappearance of males was noted by HUBBS (MS) at Portage Lake during the summer of 1920. This sharp segregation of the sexes during the summer suggests the possibility that the males are holding territory or engaged in some other activity connected with the breeding cycle.

Notropis volucellus volucellus lends itself poorly to aquarium study and most work along this line was unsatisfactory due to its susceptibility to *Saprolegnia* and the inability of the fish to survive any treatment severe enough to deal with the fungus. Some successful aquarium introductions were made, although the mortality of the minnows during the establishment of aquaria was always extremely high. In one tank maintained at the Tri-Lakes Hatchery during the summer of 1935 fourteen adults were successfully kept throughout the breeding season. Although ripe when introduced into the tank they did not breed. Certain activities which included what appeared to be breeding play and the burrowing of a community shelter under a board, very similar to the nest of the bluntnose minnow, *Hyborhynchus notatus,* appeared to be phases of breeding behavior. However, eggs were never deposited. The examination of hundreds of similar situations around the lake margin during all three summers this species was studied never revealed a single mimic shiner egg in such a situation. Eggs of doubtful origin found in such places were always hatched out in aquaria and invariably proved to be those of the bluntnose minnow.

In the spring of 1937 various attempts were made to induce breeding in aquaria by the use of pituitary extract and theolin, separately and in sequence, but the extreme delicacy of the fish frustrated all experiments, since any treatment killed the subjects, even when the hormone substances were administered in the water.

During the summer of 1935 all the females were gravid by June 20 (the beginning date of the study). On July 9 only two large two-year-old fish out of 18 examined contained any eggs, and these were mostly spent, having only 85 and 125 eggs respectively.

In 1936 the first minnows secured were brought alive from Tri-Lakes to Bloomington on May 14. Every female was ripe at that time. The egg count for fish of the same size was quite variable and there is a slight possibility that even this early they had already started spawning. Further examination on June 20, however, showed every one still ripe, although the number of eggs was frequently much less than on the earlier date. On July 9 most of the females still contained eggs, but about half of them were nearly spent and the remaining half had deposited about 50 percent of their eggs. By July 24 only one ripe female, a two-year-old, 53 millimeter specimen, was found out of 45 examined. No egg count was made but the ovaries were very large and the eggs were apparently ready to be deposited. Results of the egg counts from 103 ovaries are given in TABLE 3.

TABLE 3

Yolked eggs found in ovaries of *Notropis volucellus volucellus* from Shriner Lake, by actual count, arranged according to the length of the fish and the date of collection

June 21, 1935: 36 mm., 130; 38 mm., 79; 40 mm., 105, 146, 157; 41 mm., 67, 77; 42 mm., 114, 115, 153, 169, 185; 46 mm., 248; 47 mm., 159; 48 mm., 277; 49 mm., 125; 50 mm., 260; 52 mm., 277; 53 mm., 298, 306. Average of 20, 217.

May 14, 1936: 49 mm., 295; 50 mm., 198, 426; 52 mm., 222, 275, 275, 353, 360, 367; 53 mm., 169, 320, 387, 400, 619; 54 mm., 210, 360, 538; 55 mm., 243, 276, 293, 415, 591, 654; 56 mm., 364, 382, 422, 463, 669, 773, 878; 57 mm., 150, 204, 311, 583; 58 mm., 258, 440, 453, 510, 654; 59 mm., 502; 60 mm., 430. Average of 41, 407.

June 19, 1936: *47 mm., 265; 49 mm., 190, 214; 52 mm., 226; 54 mm., 248, 283; 55 mm., 220; 56 mm., 362; 57 mm., 486, 658; 58 mm., 319, 365, 415, 505, 539; 60 mm., 156, 460, 499, 569; 61 mm., 500, 565, 617; 63 mm., 686. Average of 23, 406.

June 20, 1937: 39 mm., 208; 49 mm., 168, 182, 237; 50 mm., 210, 270; 51 mm., 192, 205; 55 mm., 264; 56 mm., 562; 57 mm., 432; 58 mm., 355; 59 mm., 314, 518; 60 mm., 521; 61 mm., 563, 604, 920; 63 mm., 683. Average of 19, 390.

Average for 103 ovaries, 367.

* Counts made by HOWARD D. MORGANBESSER from specimens collected, preserved and measured by the author.

The average number of eggs found was 367. More two-year-old females are included than one-year olds, but the fact that many of the individuals had already started spawning probably reduces the average to a figure close to the actual average of the breeding population. Any conclusive figure of this type would necessarily have to be based on a much larger number of ovaries than were counted for this general study.

FOOD

The food from 520 digestive tracts has been examined. The technique used was to kill and preserve the minnow in a solution of one part formalin to nine parts water, remove the digestive tract from the fish as soon as possible and preserve it in a similar formalin solution until it was possible to make the laboratory examination. At such time the tract was cleared in a mixture of 70 percent glycerin and 30 percent water for 24 to 48 hours. The food was then pressed out upon a slide and examined under various powers of a compound microscope. The most useful magnification was found to be a combination of a 10x eyepiece and a 35 millimeter objective, but with almost every specimen it was found necessary to use the higher magnifications. When at all possible the food was identified to the genus. Such identifications were based on WARD and WHIPPLE'S "Freshwater Biology" (1916).

In a vast majority of the specimens examined considerably more food was found in the mid-intestine or hind-intestine than in the stomach. Presumably food passes through the stomach rather quickly, but may remain in the posterior two-thirds of the digestive tract for sometime before passing out of the body. This observational assumption has been substantiated by feeding experiments on aquarium fish.

Plant material forms a surprisingly large part of the summer diet of this minnow, which by reason of its short intestine and pale peritoneum would be expected to be a carnivorous fish (TABLE 4). Calculated solely on the basis of times of occurrence plant material was found to be considerably more frequent than animals, but the total bulk of animal food was probably greater than that of the plants eaten. Because of the small size of the specimens and/or the minute quantities of food, a quantitative analysis of the food was regarded as impracticable.

All of the specimens were secured during the summer months (May to October) and there is no indication of a seasonal variation in the food. There is, on the other hand, good evidence that the diet varies diurnally. Such variation has apparently not been pointed out previously for any freshwater fish (other than feeding or not feeding). This daily cycle of food is well shown in TABLE 4. Additional night specimens would have been of considerable value in further clarifying this interesting problem, but for reasons discussed elsewhere these were impossible to secure.

Generally speaking one may say that Entomostraca and insects, both adult and immature forms, are readily taken whenever possible. Observations in aquaria show that the shiners have a decided preference for the larger items. Aquarium fish, when fed night plankton catches, snap up *Corethra* larvae and pupae first, and then take the larger types of Entomostraca. They eagerly swallow loose scales when the opportunity affords, whether from another member of the school or a different species. As many as seven scales have been found in a single stomach.

The principal feeding time is in the early morning. When the first fish appear in the schools they are nearly always well filled with food. Most of such food is Entomostraca, although even at this time some plant material is found. Later in the day when the zooplankton has descended into the deeper water and minnows are aggregated in shallow water in close-packed schools the percentage of empty stomachs and intestines increases, as does the percentage of occurrences of green and blue-green

TABLE 4

Food found in the complete digestive tract of *Notropis volucellus volucellus* in Shriner Lake, according to the number of specimens in which such foods were found

Hour	Date	No. of fish	Food Items[1] a	b	c	d	e	f	g	h	i	j
5 a.m.	Aug. 1, 1935	45	1	43	0	1	2	2	2	9	0	0
7 a.m.	Aug. 23, 1935	50	16	28	6	0	3	4	2	0	0	0
8:20 a.m.	July 30, 1935	41	18	10	13	8	2	1	12	0	2	2
9 a.m.	July 5, 1935	6	0	6	2	0	0	5	0	1	0	1
9 a.m.	July 31, 1935	20	8	5	7	1	1	3	1	0	0	0
10 a.m.	June 24, 1935	46	23	15	12	0	1	7	1	4	0	4
10 a.m.	July 26, 1935	29	10	0	6	2	4	2	3	0	1	1
11 a.m.	July 3, 1935	5	0	2	4	0	0	1	0	1	0	0
11 a.m.	Aug. 27, 1935	29	15	2	6	4	4	0	8	0	1	0
12 noon	Aug. 22, 1935	43	31	0	3	1	9	0	2	0	0	0
12:30 p.m.	Aug. 22, 1935	25	20	0	1	0	4	0	0	0	0	0
2 p.m.	July 31, 1935	13	7	2	1	1	2	3	3	0	0	0
2 p.m.	Aug. 20, 1935	117	29	6	72	19	51	1	64	2	1	9
5 p.m.	July 31, 1935	21	11	0	2	2	6	0	4	0	1	1
6:30 p.m.	Aug. 4, 1935	26	26	0	0	0	0	0	0	0	0	0
10 p.m. to 12 midnight	July 24, 1936	4	0	2	1	0	0	1	0	0	0	0
Total		520	214	121	135	39	89	31	102	17	6	18

[1] The various classifications of food are as follows:

a. EMPTY.

b. ENTOMOSTRACA.—Identified genera include *Daphnia*, which made up the large majority, *Alona, Alonella, Bosmina*, and a single *Leptodora* taken from a night specimen. There were one of two Ostracoda, not identified further, and anauplius of a copepod.

c. GREEN ALGAE.—*Spirogyra* was decidedly in predominance, but much *Oedogonium* and *Zygnema* were present, in addition to varying amounts of *Cladophora*. *Tribonema* and *Mesocarpus* occurred more rarely. One filament of *Hyalotheca* was found, as well as an occasional member of the Volvocales and a few specimens which were unidentified as to limited group. Digestive action on the filamentous forms frequently made the identification difficult, and at times impossible.

d. BLUE-GREEN ALGAE.—*Oscillatoria* and *Lyngbya* were common, while *Anabaena* and *Nostoc* were comparatively rare. A few unidentified unicellular forms were found.

e. FISH SCALES.—The greater part of the scales were from individuals of the same species, but other cyprinid scales were found on a few occasions, as well as small sunfish scales and a few of the northern brook silversides, *Labidesthes sicculus sicculus*.

f. INSECTS—Almost all the insects were adult or immature Chironomidae. A few Thripidae were also found, as well as several unidentified insect fragments. Aquarium fish consumed mosquito larvae and pupae with great eagerness.

g. PLANT DEBRIS.—This general heading was made to include shreds and fragments from the larger rooted plants in the lakes. These were presumably eaten when found floating in the water.

h. DIATOMS.—These were limited to the genera *Navicula* and *Pinnularia*. They were always found in close association with daphnids and it is probable that they were originally eaten by the daphnids and thus reached the stomach of the shiner accidentally.

i. DESMIDS.—Identified genera included *Desmidium*, which was relatively common, and *Cosmarium*, which was rare. Like the diatoms they were of little significance as food.

j. MISCELLANEOUS.—Grouped under this heading are rotifers, protozoans, water mites, traces of mud, and plant spores(?), all rarely found.

algae, scales and plant debris. This food cycle seems to be merely a matter of expedience—the zooplankton is no longer available, but the other items of the diet are and consequently are eaten more frequently to satisfy the desire for food.

The one series collected in late afternoon (6:30 p.m.) was taken from a closely packed, non-feeding school (a school which had been severely harassed by bass for several hours) and all the digestive tracts were completely empty. On the single occasion we were fortunate enough to collect night specimens only four were secured. All these were found to have well-filled stomachs, indicating not only that they had fed earlier in the evening, but were still feeding. One fish caught near midnight had in its stomach an emerging insect (Diptera) which had just been swallowed. This limited data suggests that feeding may continue throughout the night. Aquarium experiments substantiate this observation. There is presumably a period of intensive feeding in the evening, after the school breaks up, comparable to the feeding of the early morning, undertaken while and before the school is forming. It was impossible, however, to secure specimens to test this assumption. On cloudy days, or days when the water is more or less murky, the minnows remain scattered through the weeds in depths ranging from 5 to 15 feet, or more, but on clear days they usually come inshore to school at daybreak, and the only times they have an opportunity to feed on the zooplankton are in the morning when the ascending minnow schools cross the path of the descending plankton, and in the evening when this movement is reversed.

PREDATORS

Foremost among the predators of *Notropis volucellus volucellus* in Shriner Lake are the bass. Both the largemouth, *Huro salmoides,* and the northern smallmouth, *Micropterus dolomieu dolomieu,* here gain a large proportion of their food by preying upon this minnow. Bass of all sizes, from four-inch young to the largest fish in the lake, follow the schools of minnows constantly.

The black crappie, *Pomoxis nigro-maculatus,* the warmouth, *Chaenobryttus coronarius,* the yellow perch, *Perca flavescens,* the mud pickerel, *Esox vermiculatus,* and the northern pike, *Esox lucius,* also hunt the minnows to the exclusion of almost all other food.

Next to the predatory fishes the principal natural enemy group is the birds. Belted kingfishers, *Ceryle alcyon,* and green herons, *Butorides virescens virescens,* which are both rather common around Shriner Lake, like the bass depend mainly upon these shiners for food. Great blue herons, *Ardea herodias herodias,* are frequent visitors and probably feed to some extent upon the shiners.

On one occasion a water snake, *Natrix* sp., was observed swallowing a northern mimic shiner while a large school of these fish swam calmly about it, apparently unaware of the presence of the snake. This is the only time I saw a *Natrix* at Shriner Lake.

Although the lake abounds with turtles, especially the musk turtle, *Sternotherus odoratus,* and the mid-western painted turtle, *Chrysemys picta marginata,* I saw no evidence that they preyed upon live minnows. The common snapper, *Chelydra serpentina,* is also common in Shriner Lake, but is far outnumbered by the other two species. At no time did we ever see a turtle catch, or attempt to catch, a live minnow, but all three species were frequently observed eating dead fish of various species, including the northern mimic shiner.

PARASITES

Among the more than 20,000 minnows that were handled during this study only four, all taken in the summer of 1935, were discovered to contain the larval form of the bird tapeworm, *Ligula.* This appears to be an exceptionally light infestation for a schooling species in the northern lakes.

Of much greater importance are two sporozoan parasites, one of an unidentified genus from the mucous lining of the mid-intestine, the other a species of *Myxobolus* which made rather large cysts in the muscle tissue. Both were fairly common in the specimens taken in October, 1936, and over 60 percent of those collected on May 22, 1937, were heavily infested with the *Myxobolus.* None of the specimens examined after June 12, 1937, showed either cysts or scars where they had been. The sudden decrease in the minnow population between May 22 and June 12, and the simultaneous disappearance of the parasitized individuals, can hardly be a simple coincidence. The parasitized minnows were either killed by the cysts, or were so weakened by the sporozoan that *Saprolegnia* or fin rot, both common in Shriner Lake in 1937, quickly killed the parasitized individuals. There remains the possibility that diseased fish were so weakened that they fell easy prey to the predators, and undoubtedly many of them did, but the decrease in the minnow population was so rapid and involved such large numbers of fish that it is virtually certain that most of them were killed outright by disease.

HABITS AND MOVEMENTS

Only broad generalizations can be made regarding the movements of this species, in spite of the various ideas advanced by the native fishermen regarding the whereabouts of the minnows depending upon the season, time of day, and weather. Even to these generalizations there are many exceptions.

At daybreak the minnows usually appear along shore from the deeper water in small ribbon-like schools, swimming rapidly. We recorded the first arrival at 4:45 a.m. on July 20, 1935, and at the same time on July 24, 1936. The small schools swim around and under the piers or go directly to the very shallow water, and are joined in rather quick succession by similiar schools for about thirty minutes, after which the main body of the school remains as a fixed unit for the rest of the day. On almost every incursion the minnows are followed inshore by the bass.

With the approach of darkness the shiners begin to go out into the open lake, following along the tops of the weeds and maintaining the same ribbon-like formations as that held when the fish cruise through weeds and come inshore in the morning.

These small schools have been seen to break up just before it becomes completely dark. It is apparent that they remain in the weeds at night and are probably scattered over the deeper weedy littoral. The four individuals we secured at night were evidently stragglers and were taken by trawling and seining over the sandy bottom in shallow water at the eastern end of the lake. By no method, however, were we ever able to secure night specimens from the weed beds, where trawling and seining could not be done with sufficient speed, and where traps were equally ineffective.

The avoidance of the shallow water at night by the northern mimic shiner in Shriner Lake is contrary to the habits exhibited by most fresh-water fishes. This statement on their behavior is, therefore, likely to be questioned. I should explain, perhaps, that many nights were spent in trying to secure night specimens for three distinct reasons: I felt that it was important to know their whereabouts at night; it was hoped that the finding of night specimens might solve the mystery of their breeding location and habits; and finally it was early recognized that stomach analyses of night-collected fishes would be valuable. All types of seines were used, and on every foot of the lake's shore which could be seined. We even resorted to swimming through the weeds with long seines and trying to get a few specimens by imitating purse-seining methods, and finally with the assistance of Dr. SCOTT built a heavy trawl especially for night collecting. This trawl was towed behind a boat powered with an outboard motor and caught many other fishes, as did our regular night seining, but only two mimic shiners. Two others were secured over sandy shoals with an ordinary minnow seine. Strong lights were rigged for the study of the lake bottom at night, but at no time, except when the four shiners were collected, did we ever see a specimen of *Notropis volucellus volucellus* in the shallow part of the lake at night. On many occasions we did see shiners moving about over the weeds at depths ranging from 10 to 15 feet with these spotlights, but always failed to secure specimens.

I have no way of knowing how far the peculiar habits of this fish in Shriner Lake may be determined by the unusual predator pressure centered on it because of its great numbers and dense schooling habits, nor am I familiar with the habits of this particular species in other lakes, but the fact that its night habits in Shriner Lake are in sharp contrast to the normal behavior of most minnows is clearly established.

The minnows vary greatly in their habitat choice during the daytime. Generally the greatest concentration is over sand and in very shallow water, but sometimes they remain out in the deeper littoral feeding over the weeds, and on such days they are to be found in small schools all around the lake. On other apparently similar days they are found in great schools in the west end of the lake, scattered through the water lilies and *Pontederia* of that region. Rarely they go into the water in which the rushes grow. One of their favorite daytime habitats is the boat landings which are so plentiful around the lake shore. Countless thousands have been observed congregated around a single pier, resting or hiding in the shade and swimming both over and through the weeds on the lakeward side and in the very shallow water on the shore side. When disturbed around these piers their action varies; sometimes all run toward open water, but usually they dash for the shelter of the pier and shallow water.

In attempting to find an answer for this puzzling change of daytime habitats wind and temperature were soon eliminated, since the actions of the minnows vary with complete disregard of these conditions. The gradual aggregation of the shiners into larger and larger schools is obviously part of a seasonal cycle, but their day-to-day movements cannot now be explained on any physical basis. Apparently the only plausible explanation for their daily actions is that of reactions of a self-preservation type. Changing physical conditions, if responsible for the activities of the bass and other predators, would thus apply indirectly to the minnows, but what these conditions may be are not apparent. The movements of the shiners during the day are plainly attempts to elude their natural enemies. It is certain that the very shallow water provides the best protection from the bass and other fish, but lays the minnows open to attack from the herons and kingfishers. The piers, on the other hand, offer excellent protection from the birds and fair protection from the fish. The side of the lake frequented seems to be primarily influenced by wind direction, since the shiners usually congregate (with some notable exceptions) on the quieter side of the lake. They will not cross the lake in the daytime as a result of a change in the direction of the wind, and one who has watched the devastation wrought by the ever present and almost always hungry bass on a school of the shiners which by some chance have been frightened out into the open water will readily understand the reason for this timidity on the part of the minnows. The preference for the still side of the lake may be related to the greater ease of detecting disturbances created by enemies in quiet water. The minnows are probably influenced in their choice of shelter by the feeding activities of the bass, for they remain under the piers or in the weeds if the bass are not too active, and over the sand in the shallow water when the bass are most actively feeding. It is not an uncommon sight in July and August to see these minnows rush shoreward before the onslaught of the attacking bass with such violence and abandon that dozens of them at a time become temporarily stranded on the dry lake shore. The massing of many thousands of these minnows in the extremely shallow water during such times must be observed to be fully comprehended.

The presence of the mixed types of shelter in close proximity to one another, allowing movements to be made from weeds to shallow sandy bottom to pier in a matter of seconds, is probably one of the factors which has helped this species reach its great abundance in Shriner Lake.

The few young fish discovered were on the shoals, either over sandy bottom or in *Chara* beds, and were 12 to 15 millimeters long when first observed. They maintained separate schools as late as September 6, 1935. Mr. BODLEY reports that the young join in the large fall aggregation before the first of October.

During the summer of 1920 Dr. HUBBS made some pertinent observations regarding the behavior of *Notropis volucellus volucellus* in Portage Lake, Washtenaw and Livingston counties, Michigan. His notes, which have not been published, have been placed at my disposal. Incidental mention of his observations has been made in previous parts of the present paper. Of particular interest is the close agreement in our observations. Dr. HUBBS noted, as I did, the tendency of the fish to form large gyrating schools in shallow water, the manner in which the bass preyed upon these schools, especially early in the morning, when the bass repeatedly rushed the minnow schools and chased them so close to shore that some would splash out of the water. He also observed that the schools were not to be found at night, at least on the shoals.

In Shriner Lake the schools attain their maximum density in the fall and may even congregate into one tremendous school sometime in September, according to information furnished by Mr. BODLEY. Something of this type of concentration was evident in the first week of September, 1935. Data are not available concerning their activity in the late fall and early winter, other than that these great shallow-water schools persist until the beginning of the ice cover. After the ice goes out in the spring, several days, usually weeks, elapse before the minnows appear in shallow water.

SUMMARY

The "shore minnow" of Shriner Lake is the northern mimic shiner, *Notropis volucellus volucellus* Cope. The species has usually been extraordinarily abundant in Shriner Lake, although its population reached a low ebb in 1936 and 1937, following a year of great abundance. The decided reduction in the size of the 1936 population as contrasted with the great quantity present in 1935 is attributable to an almost complete failure of the 1935 breeding season.

The only peculiarities of Shriner Lake which may account for the remarkable abundance of the northern mimic shiner there are its clarity and the wealth of rooted aquatic plants, together with the absence of the gizzard shad and carp.

Most of the 1935 breeding population (a normal one?) was made up of fish which had passed through one winter, but two-year-old fish were somewhat in the majority in the greatly reduced population of 1936. The two-

year-old fish were so few in 1935 as to make no noticeable peak on the ordinary size-frequency curve, but they did cause a positive skewness in the curves. Aging was accomplished by an analysis of size frequencies involving total-length measurements of 14,276 specimens. The estimates thus obtained were verified by a study of the scales of smaller series.

Fish of the same age attained a greater size in 1936 and 1937, when the population was small, than in 1935 when the species was abundant. This relation between size and population has frequently been shown for larger fresh-water fishes.

Ripe eggs were found in females from May 14 to July 24. The average number of eggs in 103 ovaries was 367.

Very little was learned of the breeding habits of the species. Exhaustive observations on the presumed breeding sites of the species produced no results. Partly on the basis of negative evidence it seems probable that the shiners in Shriner Lake breed in weeds of the deeper littoral region, and that they spawn at night. They probably broadcast their eggs instead of building nests.

There is a pronounced sexual segregation during the early sumer when the females are ripe. Collections made during this period produce few males, frequently none at all.

Food of this shiner consists of Entomostraca, insects, algae, scales, and other items of less significance. Green algae are almost as frequent an item in the summer diet as are daphnids and insects.

There is a definite diurnal variation in the food. Daphnids form the principal item in the early morning, and probably in the late evening, and green algae comprise the main item during the middle of the day.

The minnows are heavily preyed upon by all the predatory fishes and birds. The largemouth and smallmouth bass are the principal natural enemies. The northern mimic shiner is of great value as a forage fish in Shriner Lake.

These shiners are hosts to the larva of a species of *Ligula,* but the infestation is of insignificant proportions. Two sporozoan parasites, one unidentified, the other a member of the genus *Myxobolus,* are common. The sudden reduction of the adult population in the early summer of 1937 was probably due, either directly or indirectly, to an infestation of *Myxobolus.* There was a heavy infestation of the minnows with the sporozoan before, but not after, the decrease in the number of the minnows. *Saprolegnia* and fin rot were then common, probably as secondary infections. Whether the fish were killed outright by disease or so weakened as to fall easy victims to the predators is not known, but it is probable that most of them were killed by the parasites.

The habits and movements of the minnows during the daylight hours are apparently controlled by their predatory enemies. They congregate in tremendous schools in the fall. These schools gradualy increase in size throughout the summer and early fall.

The young fish are from 12 to 15 millimeters long when they first appear on the shoals. They at first maintain separate schools, although it is reported that they eventually join with the adults to form the large fall aggregation.

The fish come from deep water at daybreak and return to the deeper littoral when it becomes dark. The small schools disband just before complete darkness. When coming into the shallow water, when returning to the deep water and when cruising through the weeds these minnows travel in small ribbon-like schools, totally unlike the masses which occupy the shallow water during the larger part of the day throughout most of the summer.

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