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EGG PRODUCTION OF THE NORTHERN PIKE, ESOX LUCIUS L., AND THE PERCENTAGE SURVIVAL OF EGGS AND YOUNG ON THE SPAWNING GROUNDS*

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*Contribution from the Institute for Fisheries Research of the Michigan Department of Conservation.

W. F. Carbine

In 1937 I started an investigation of the life history of the northern pike. The aim was to devise procedures for the management of this important game fish. Particular attention was paid to egg production and to the survival of the young from the time of hatching until the time when they leave the spawning grounds since little information was available on these phases of pike life history.

The work was begun in southern Michigan, but most of the field observations were made from 1939 to 1942 at Houghton Lake, the largest and one of the most productive inland lakes in Michigan. Some of the results have already been published (Carbine, 1942).

EGG PRODUCTION

Materials and Methods

During 1939, 1940 and 1942, the writer and various staff members of the Institute for Fisheries Research secured at Houghton Lake 30 northern pike specimens (Table I) for egg counts. Some were caught during January

TABLE I

DATE OF COLLECTION, SIZE, CONDITION, AND NUMBER OF EGGS FOR 30 NORTHERN PIKE COLLECTED AT HOUGHTON LAKE (SEE FOOTNOTE NO. 2 FOR EXCEPTION)

Counts made by C. B. Obrecht, W. F. Carbine, George N. Washburn and John T. Greenbank.

Date collected	Standard length (millimeters)	Total length (inches)	Weight (ounces)	K	Number of eggs	Counted by
4-2-42	338	15.7	[3]11.0	0.808	7,691	Carbine
3-29-42	370	17.0	[3]16.0	0.896	13,309	"
4-15-39	443	20.3	34.0	1.109	[4]28,871	Obrecht
2-25-39	446	20.6	26.0	0.831	16,898	"
4-15-39	455	20.7	33.0	0.994	[4]22,966	"
2-25-39	450	20.7	34.0	1.058	24,030	"
4-22-39	452	20.7	33.5	1.029	25,982	"
4-18-39	458	20.9	31.5	0.930	25,760	"
4-18-39	460	21.0	33.0	0.962	21,086	Carbine
4-21-39	468	21.4	39.0	1.079	27,700	Obrecht
3-27-42	460	21.6	44.0	1.281	33,168	Carbine
4-21-39	475	21.7	33.5	0.886	19,418	Obrecht
4-21-39	490	22.3	39.0	0.940	12,599	"
4-21-39	485	22.3	39.5	0.982	27,550	Washburn
4-16-39	510	23.6	44.0	0.940	23,920	"
4-23-39	512	23.6	48.0	1.014	33,342	Obrecht
2-25-39	525	23.6	50.0	0.980	36,484	"
2-23-39	540	24.5	52.0	0.936	41,116	"
2-4-39	540	25.0	44.0	0.792	19,808	Carbine
2-26-39	559	25.4	52.0	0.844	47,289	Obrecht
4-17-39	570	25.9	56.0	0.857	38,756	"
2-25-39	566	26.0	54.0	0.844	29,945	"
4-13-39	571	26.0	60.0	0.914	37,332	Carbine
4-17-42[1]	584	26.1	[3]64.0	0.911	43,170	Greenbank and Carbine
2-25-39	578	26.2	60.0	0.881	38,989	Obrecht
4-18-39	578	26.2	70.0	1.027	44,902	"
1-28-43[2]	600	27.1	67.0	0.879	36,812	Carbine
1-28-39	600	27.2	68.0	0.893	54,085	Greenbank
2-23-39	638	28.4	88.0	0.961	55,754	Obrecht
4-23-39	775	35.0	170.5	1.038	97,273	"
AVERAGES	516.5	23.6	49.8	0.950	32,200	

[1]Collected by Dr. P. I. Tack from Houghton Lake.

[2]Collected by Dr. L. N. Allison from the Fletcher Pond of Thunder Bay River.

[3]Weights are averages obtained from other female northern pike from Houghton Lake.

[4]Eggs stripped from fish.

and February by ice fishermen, but the data were taken by the fishery investigators. A larger number was taken at random during the spawning run, from the weirs that were installed in ditches connected with the North Bay of Houghton Lake at Peterson's Resort (Carbine, 1942). With the exception of two fish that were stripped at the time of capture, only fish that were "green" (with egg sacs intact) were saved for samples.

Shortly after its capture each fish was weighed to the nearest gram or ounce, depending upon the size of the fish. Standard and total lengths were measured in millimeters, and ovaries were removed and preserved in 10 per cent formalin.

Actual total counts of the eggs were made on all 30 specimens. In making 19 of the counts, Carl B. Obrecht used a counting board, patterned after boards used in the East. He made this board from a piece of black, hard-rubber radio panel, 3/8-inch thick and measuring 3 x 5 inches. In this he drilled 250 holes, 1/8-inch in diameter and 1/8-inch deep. Each hole was lightly counter-sunk. Another board with slightly smaller holes was used in counting the smaller eggs of winter-caught fish. To use this board, the well-separated eggs are merely spread over the surface so that they will lodge in the holes. After surplus eggs are removed, inspection reveals any empty holes and the count of 250, minus the empty holes is obtained.

To trace the growth of the eggs and the relationship between the various sizes present in an ovary, diameter measurements of ova were made by means of an ocular micrometer in a compound binocular microscope. The magnifications used gave a value of 0.04 mm. for each micrometer unit for the small eggs, and 0.2 mm. for the large eggs. The diameter was determined by placing the micrometer in a horizontal position with respect to the field

of the microscope and reading the vertical diameter of each egg, without regard to its shape or position in the field of the microscope. Due to distortion in the process of preservation, ova are seldom perfectly spherical in shape, and this method obviated any selection of the longest or shortest diameter. This gave measurements of the longest diameter of some eggs, the shortest of others, or measurements intermediate between the two. Clark (1925), who made a careful test of this method, found it to be reliable and the most satisfactory for constant use.

To show the growth history of the ova before the spawning season, a random sample of eggs was obtained after all eggs in the ovary had been teased apart. Measurements of the diameter of the large ova were made at the lower magnification until 500 eggs from each fish were recorded, and the process was then repeated at the higher magnification to obtain the measurements of 500 small ova. To show the relationship between the actual number of all eggs of each size present in the ovary, a section approximately 3/8-inch wide and about an inch long was carefully teased from the center of the ovary of one fish and measurements were made on all ova (totaling 3,688) in the sample.

To correlate the egg production with the condition of the fish, the coefficient of condition (K) was calculated by using the formula, $K = \frac{W \times 100}{L^3}$ in which W is the weight in grams and L the standard length in centimeters.

Because of the difficulty and uncertainty involved in determining the age of northern pike from examination of the scales, age determinations are not included in this paper.

Number of Eggs Per Female

The actual numbers of eggs contained in each of the 30 females (Table I) varied from 7,691 (for a fish having a total length of 15.7 inches and weighing

11 ounces) to 97,273 (for a 35-inch pike weighing 170.5 ounces). The following are average figures. The number of eggs produced was 32,200 for these fish, which had a total length of 23.6 inches and a weight of 49.8 ounces. The average total length of the fish in the sample agrees closely with that of all females which entered the spawning grounds (23.5 inches in 1939, 23.2 inches in 1940, and 22.4 inches in 1942).

The number of eggs increases rapidly with increase in length of fish and is roughly proportionate to the weight (Figs. 1 and 2). The number of eggs in a fish of any particular length or weight, however, varies greatly.

Despite a large fluctuation, there is some positive correlation between the condition of the female and its fecundity (Table I). The values for K fluctuate widely, and do not increase with size of fish: K averages 0.984 for the 14 fish 15.7 to 22.3 inches long, and 0.919 for the 16 that measure 23.6 to 35.0 inches. The specimen with the largest K value, however, did produce more eggs than other fish in the same general size range. Likewise, the fish having the lowest K value, produced fewer eggs than other specimens in the same general size group. The 6 fish having the highest number of eggs, taking into consideration the length of the fish, and the 6 having the lowest number (as determined from the plus or minus deviation from the average line in Fig. 1) had average K values of 1.007 and 0.893 respectively.

Growth History of the Developing Ova

Because northern pike spawn but once a year and because the spawning season is of short duration, the eggs of a female at spawning time are of two markedly distinct sizes: (1) large mature eggs, and (2) almost microscopic immature ones. To demonstrate the history of the maturing ova and to check the assumption that all ova that are to be spawned in one year become distinguishable during the seasonal development from the small immature eggs, diameter

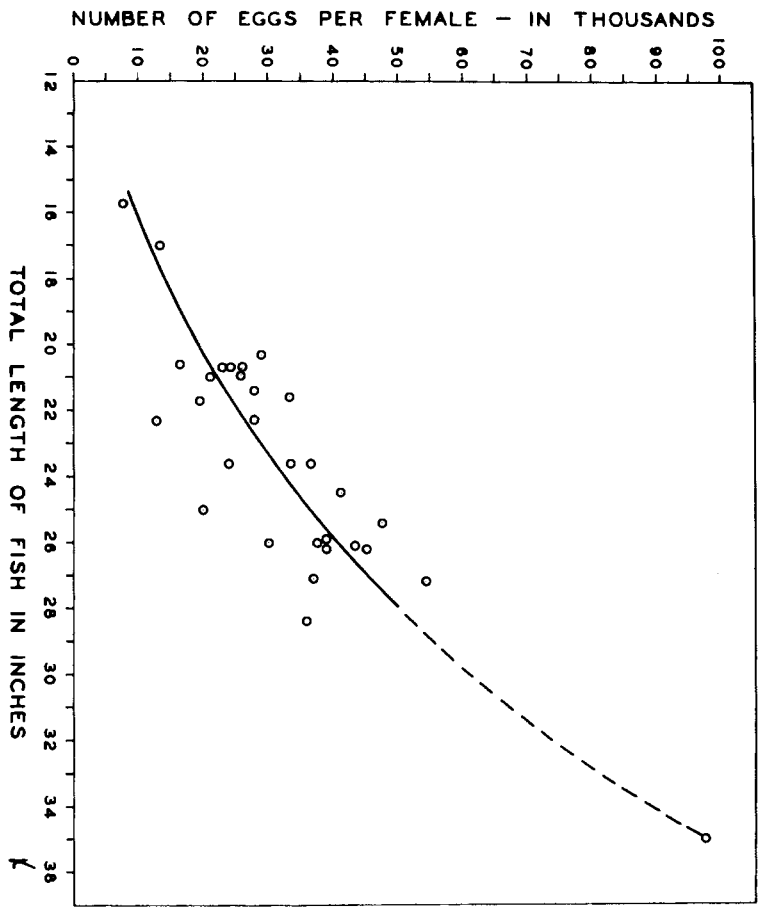

Fig. 1. Relation between the number of eggs and the total length of fish for 30 northern pike.

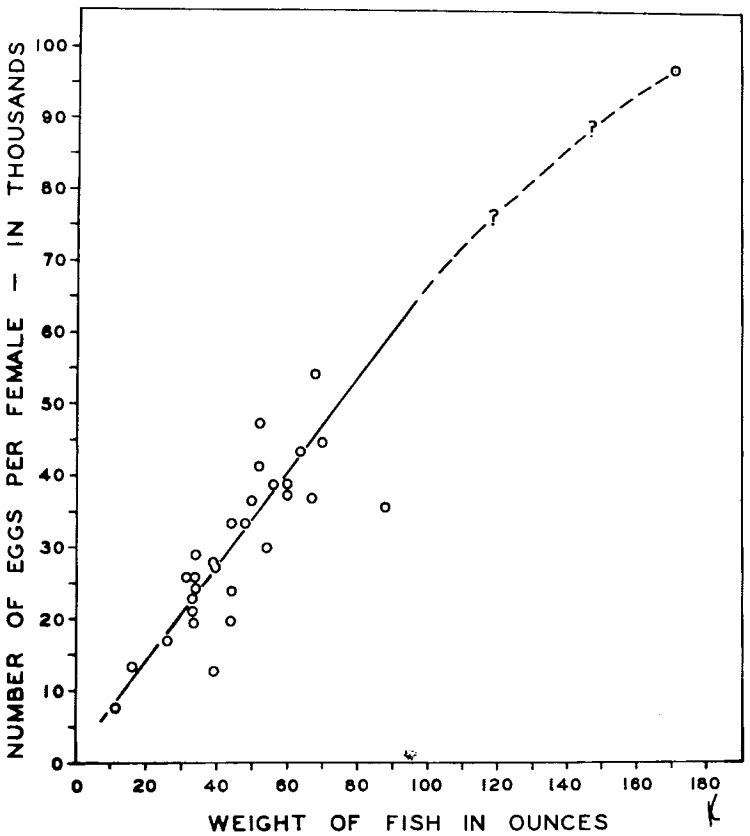

Fig. 2. Relation between the number of eggs and the weight of fish for 30 northern pike.

measurements of ova were made from seven fish collected at various dates before the spawning season (Fig. 3 A). The first specimen, a large fish from Drayton Plains hatchery stock known to be in its second year, was preserved on November 4. The fish of January 28, February 4 and 25 were taken through the ice at Houghton Lake by fishermen. Those of March 27 and April 15 and 26 came from Peterson's Ditches during the spawning run. The one collected on March 27, a "green" female, and the one taken April 15, a ripe female, were killed during the upstream migration to the spawning grounds.

The specimen secured on April 26 was one of several that entered the marshes on April 10, at which time they were marked. This particular fish was seen to be ripe on April 10, for some eggs were lost during the process of weighing, measuring and tagging. After spawning it returned from the marshes to the lake on April 25 with a serious head injury. On April 26 this pike was found dead, washed up on shore. The ovaries were then removed. This northern pike had therefore spawned sometime during the 17-day period between April 10 and 26. Because the fish was ripe when it entered the spawning grounds, it is probably safe to assume that spawning occurred at least two weeks before the ovaries were removed and preserved. The ovarian wall had shrunk little during this period. Close examination revealed the presence of 28 old, mature eggs, held over from spawning. The few large eggs that were well preserved were free from the follicles; those that were still enclosed in the follicles showed varying degrees of resorption. In addition to the 28 mature eggs a tremendous number of extremely small eggs were also present in the ovaries of this northern pike (Fig. 3 A, bottom graph). Some of these eggs were granular in appearance and were apparently

Fig. 3 A. Frequency polygons showing the growth history of northern pike eggs collected before, during and after the spawning season.

Because each polygon was based on measurements of 500 eggs and because more and different size classes were used in measuring the immature ova, the areas of the polygons are not proportional to the numbers of immature and of mature eggs present in the ovary.

The fish collected March 27 (a green female) and that of April 15 (a ripe female which was stripped) were killed on the upstream spawning run. See text for the data concerning the collection of the fish taken on April 26.

Fig. 3 B. Frequency polygons showing proportionate number and proportionate volume of the eggs of each size class in the ovary of a mature northern pike.

Based on measurements of the 3,688 ova comprising a random sample of the ovary of a fish collected January 28, 1943, from the Fletcher Pond of the Thunder Bay River. The immature eggs were measured in size classes of 0.04 mm., but these were combined by 5's to give size classes of 0.2 mm., to correspond with the measurements of the maturing eggs.

degenerating, because they were easily broken after preservation. The remainder of the small eggs still retained the nucleus and were the only ones measured.

In studying the growth of the ova (Fig. 3 A) chief attention should be paid to the eggs with diameter exceeding 0.4 mm., because these are the maturing eggs. Ova less than 0.4 mm. in diameter obviously remain immature through the late fall and winter; they constitute a distinct group of relatively uniform size in each adult female, during the fall and winter (Fig. 3 A) and no doubt throughout the year. Any increase in size beyond 0.4 mm. indicates the beginning of the growth of the ova toward maturity for the next spawning season. We were unable to obtain a fish with ovaries at this stage. The specimen in the earliest stage in the growth of the ova was taken on November 4, approximately five months before spawning. Differentiation between the two sizes of eggs was already well marked.

The only fish with eggs of intermediate size was collected on January 28. The few eggs of this size had either started to develop a short time before this fish was killed or else had been retarded in growth.

On each succeeding date from November 4, 1938 to April 15, 1939, the maturing ova were found to have attained a constantly greater average diameter. The March specimen had mature eggs of the largest size, either because of individual variation or because the sample was taken in another year (1942).

Mature eggs of the northern pike range in diameter from 2.2 to 3.4 mm.

The immature eggs greatly outnumber the maturing eggs in an ovary of a pike about to spawn, but the volume of the maturing eggs vastly exceeds that of the immature ones (Fig. 3 B). To illustrate these relations, measurements were made of the diameter of all the 3,688 eggs comprising a random sample from the ovary of a fish collected on January 28, 1943 (this fish measured 27.1 inches in total length and weighed 67 ounces). The volume of the eggs in each size class was computed mathematically from the average diameter of each class. The number and the volume of the eggs of each size class were computed and expressed as the percentage of the total number and of the total volume, respectively.

Of the 3,688 ova that were measured, the maturing eggs constituted 11.7 per cent by number and 95.9 per cent by volume, whereas the immature eggs made up 88.3 per cent by number and 4.1 per cent by volume. Since the total number of maturing eggs in both ovaries of this fish was 36,812 (by count), it is computed that these ovaries contained 278,089 immature ova. Enough small eggs for several spawnings were therefore present in the ovaries of this fish. However, I do not believe that the 314,901 eggs estimated to be present in this fish would suffice for all spawnings of a pike that would reach a relatively large size and advanced age. A 35-inch pike was found to contain 97,273 mature eggs; in three years such a fish would produce more eggs than the total number of immature eggs estimated to occur in the 27-inch fish. Large pike show no apparent reduction in the relative number of immature ova. It is concluded that new eggs develop during the adult life of the pike. Some evidence was obtained to indicate that some of the immature ova as well as all unspawned mature eggs are resorbed after the spawning time. Such loss would provide a further need for new egg production in the adults.

The ovary of the fish used in determining the number of eggs in each size group (see Fig. 3 B) contained in its anterior, middle, and posterior parts, mature ova of the following diameters, as determined by measurements of 500 eggs from each part:

In the anterior part, 1.6 to 3.0 mm.; average 2.305±.0103 mm.,

In the middle part, 1.6 to 3.0 mm.; average 2.355±.0130 mm.,

In the posterior part, 1.6 to 3.0 mm.; average 2.304±.0103 mm.

The average size of the eggs is significantly larger in the middle part of this ovary than in the anterior and in the posterior parts (the difference is about three times the standard error of the difference). The difference, however, is only about 0.05 mm. It is therefore concluded that no considerable error was introduced by measuring the eggs (as for Fig. 3) from samples taken from the middle part only of each ovary.

The developmental cycle of the eggs in the northern pike is like that of the salmonoid fishes, lampreys and other fishes that spawn over a very brief period. Many fishes, for instance the halibut (Thompson, 1915), the grunion (Clark, 1925), and other species (Hickling and Rutenberg, 1936), deposit eggs more than once in a spawning season, and throughout most of the spawning period have eggs of more than two size groups in the ovary. In addition to the reserve stock of minute ova and the group of maturing ova, one can usually distinguish groups of ova of one or more intermediate sizes. These ova are obviously being prepared for future periods of egg laying.

In general this type of egg development appears to be characteristic of families or at least of genera. It comes as a surprise, then, to learn that both types of egg development occur in the pike genus, Esox. The mud pickerel, Esox vermiculatus, contains in its ovaries a group of eggs intermediate in

size between the immature eggs and the mature ones. In the one mature female studied, the immature eggs averaged about 0.1 mm. in diameter, and the seemingly mature (yellowish and rather free) eggs ranged in diameter from 1.2 to 2.0 mm. (Fig. 4). The mature eggs thus seem to average smaller than those of Esox lucius. This female of Esox vermiculatus that was studied measured 6.2 inches in total length, and was collected at Whitmore Lake, Washtenaw County, Michigan, on April 2, 1941. This was during the spawning period of this species, which coincides with or at least overlaps that of the northern pike. Newly hatched mud pickerel may be taken in early April in southern Michigan. The eggs of the intermediate size group ranged in diameter from 0.3 to 1.2 mm. It is estimated that the 6.2-inch mud pickerel contained a total of 15,732 eggs, of which 10,925 were immature, 4,004 of intermediate size, and 803 mature. Several spawnings during the spring are thus indicated. Occasionally mud pickerel also spawn in the fall, according to Lagler and Hubbs (1943).

Insert Fig. 4. See page 14.

PERCENTAGE SURVIVAL OF EGGS AND YOUNG ON THE SPAWNING GROUNDS

In the management of any species of fish, knowledge of the natural mortality and of the probable yield from any spawning is obviously important. It is desirable to know at what stage of development the mortality rate is highest. In the experiments described in this paper, a complete count was obtained of all adult northern pike migrating from Houghton Lake to the spawning grounds under observation, and in 1939 and 1940, complete counts

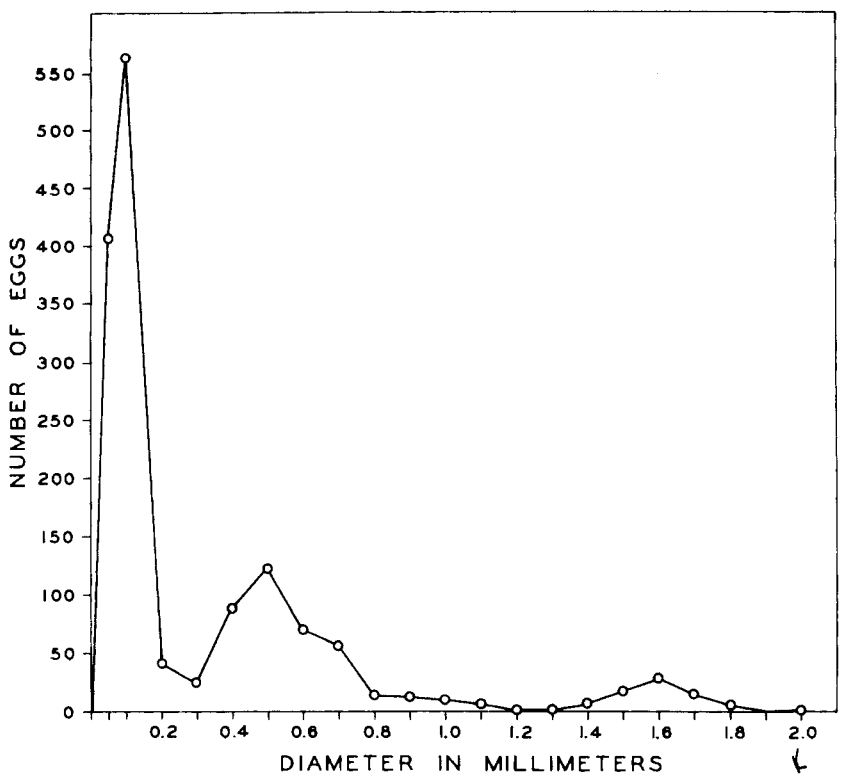

Fig. 4. Frequency polygon showing relationship of the number of eggs of various sizes present in a mud pickerel (Esox vermiculatus), taken April 2, 1941 from Whitmore Lake.

were made of all young migrating from the marshes to the lake (Carbine, 1942). It is therefore possible to present figures representing the survival of the young from the time of egg deposition until the last young pike had migrated from the marshes (a maximum period of 82 days from the time the first fry hatched in 1939 and of 85 days in 1940). Each year a portion of the young were fin-clipped before they were released in Houghton Lake in the hope that an estimate could be obtained of the percentage survival from the fingerling stage to that of legal size. Unfortunately so few captures of these fin-clipped fish were reported (voluntary returns only were available) that this experiment was abandoned.

In 1942, all of the migrating adults were trapped during the spawning run, but fry and fingerling weirs were not installed. On May 6, 1942, I stopped at Houghton Lake to check the success of the hatch of pike in the various marshes that had been under examination earlier in the year. It was surprising to find that Mr. John Peterson, who operates a resort near the marshes on which this investigation was being conducted, had installed and maintained weirs for trapping fry and fingerling pike, following the procedure previously used here (Carbine, 1942). During the past few years Mr. Peterson had become interested in our projects and desired to have as many pike as possible placed in Houghton Lake. He also wanted to compare the production obtained in 1942 with that of 1939 and 1940. He had been keeping accurate records of the number of young pike that were taken in the traps, from the time of the first migration until about June 1 (when the weirs were removed). According to the records kept by Mr. Peterson, up to May 6, slightly over 4,000 young northern pike had been taken in the traps and had been transferred to Houghton Lake. He estimated, from a two-hour tally, that approximately

half of the fish went through some small holes in the wings of the weir rather than into the traps. Since his record book was unfortunately lost, it is not possible to give the exact estimate on the total run of young pike for 1942. The figure of 8,000 given for 1942, in Table II, a rough calculation, is considered to be a minimal estimate.

The eggs and young of the northern pike suffered an enormous mortality on the Houghton Lake spawning grounds that were under observation in 1939, 1940 and 1942 (Table II). The approximately four million eggs estimated to have been spawned in 1939 contributed only 7,239 migrating young——about 1,800 young for each million eggs. The mortality was computed to be 99.82 per cent. For 1940, about 700 young resulted from the deposition of a million eggs, a mortality of 99.93 per cent. The corresponding figures for 1942 were 4,400 young per million eggs or 99.56 per cent mortality.

The stage at which the greatest loss occurred was not determined. Observations in the marshes and ditches proved that very large numbers survived through hatching and the period of yolk absorption. As many as 20 very young pike were caught in a single dip of a small scap-net. Gradually the numbers of young dwindled. Predation, including cannibalism, was observed, but the loss from each of many causes was not estimated.

The survival of eggs and young, 0.44 per cent, was relatively much higher in 1942 than in 1939 or 1940. The cause is thought not to lie in the smaller number of eggs laid, but rather in the higher water level. The marshes which provide the spawning and nursery waters for northern pike were more extensively covered in 1942 than in the other years, and remained covered for a longer period than in any of the last 8 to 10 years, according to local reports. The water level in 1942 did not become appreciably lower until all the fingerling pike had a chance to move out to the lake.

TABLE II

ESTIMATES OF THE EGG PRODUCTION OF NORTHERN PIKE AND OF THE SURVIVAL OF EGGS AND OF YOUNG UP TO THE TIME OF DOWNSTREAM MIGRATION

Data obtained at Peterson's Ditches, Houghton Lake, Michigan

	1939	1940	1942
Number of spawning females	125	65	56
Number of spawning males	280	81	70
Ratio of males to females	224:100	125:100	125:100
Estimated number of eggs deposited[1]	4,025,000	2,093,000	1,803,000
Number of migrating young[2]	7,239	1,495	8,000
Percentage survival of eggs and young to time of migration	0.18	0.07	0.44

[1] Based on average of 32,200 eggs per female—see p. 5.

[2] See text in regard to estimate for 1942.

A very high mortality during the fry stage was also observed in the pike-propagation experiment conducted in 1937 at the Ortonville Rearing Pond of the Drayton Plains Fish Hatchery of the Michigan Department of Conservation. This 3-acre pond was stocked with approximately 150,000 northern pike fry on May 3, 1937, and when the pond was drained on October 14 (171 days from the date of hatching), a total of only 362 pike were recovered. The mortality from the fry stage was 99.76 per cent, identical with the average mortality of 99.77 per cent estimated to have occurred during the egg and early fingerling stages on the spawning grounds of Houghton Lake.

ACKNOWLEDGMENTS

I should like to express my appreciation to Albert S. Hazzard, director of the Institute for Fisheries Research, for assistance in planning the work, and for suggestions and help in the preparation of this report. Thanks are also due Carl B. Obrecht who counted most of the eggs; George N. Washburn and John T. Greenbank, who also assisted in some of the egg counts; Louis A. Krumholz, who drafted the figures; David S. Shetter, Walter R. Crowe and other members of the Institute, as well as various officers of the Department of Conservation, who assisted in the collection of material for the egg counts and in other phases of this investigation. I am indebted to Carl L. Hubbs for guidance and help in the analysis of the data, and in preparation of the report.

SUMMARY

1. Investigation of the life history of the northern pike, with special emphasis on egg production and survival of eggs and young on the spawning grounds were begun in 1939 and continued through the spawning season of 1942 at Houghton Lake, Michigan.

2. Most of the migrating young and adult northern pike were captured in weirs, although a few of the adults were caught by ice fishermen.

3. On the basis of actual counts of the eggs contained in each of 30 northern pike, the average number of eggs produced was estimated to be 32,200 (range 7,691 to 97,273).

4. The number of eggs increases rapidly with increase in length of the fish and is roughly proportionate to the weight.

5. Despite a great fluctuation, there is some positive correlation between the condition of the female and the number of eggs produced.

6. Diameter measurements of ova made on seven fish collected before, during and after the spawning season show that all eggs that are to be spawned in one season form a single size group, easily distinguishable throughout the seasonal development from the small immature eggs.

7. Mature eggs of the northern pike range in size from 2.2 to 3.4 mm.

8. The immature eggs present in the ovaries of a pike before the spawning season constitute 88.3 per cent of the number and 4.1 per cent of the total volume, whereas the maturing eggs made up 11.7 per cent by number and 95.9 per cent by volume.

9. The presence in the ovaries of the mud pickerel Esox vermiculatus of eggs of intermediate size indicates that this species spawns more than once during one season. This shows that one type of egg development is not characteristic of a genus.

10. A total of 125 females spawned in the marshes in 1939, 65 in 1940, and 56 in 1942.

11. The estimated egg production, based upon the average of 32,200 eggs per female, was 4,025,000 in 1939, and 2,093,000 in 1940, and 1,803,000 in 1942.

12. The approximately four million eggs assumed to have been spawned in 1939 contributed only 7,239 young; in 1940, only 1,495 young resulted from the laying of about two million eggs; and in 1942, an estimated 8,000 young resulted from the deposition of 1,800,000 eggs. The mortality of eggs and young, to the time when the young left the marshes, is therefore estimated to have been 99.82 per cent in 1939, 99.93 per cent in 1940, and 99.56 per cent in 1942. The increased yield in 1942 seems to have been correlated with a higher and more constant water level over the marshes.

INSTITUTE FOR FISHERIES RESEARCH

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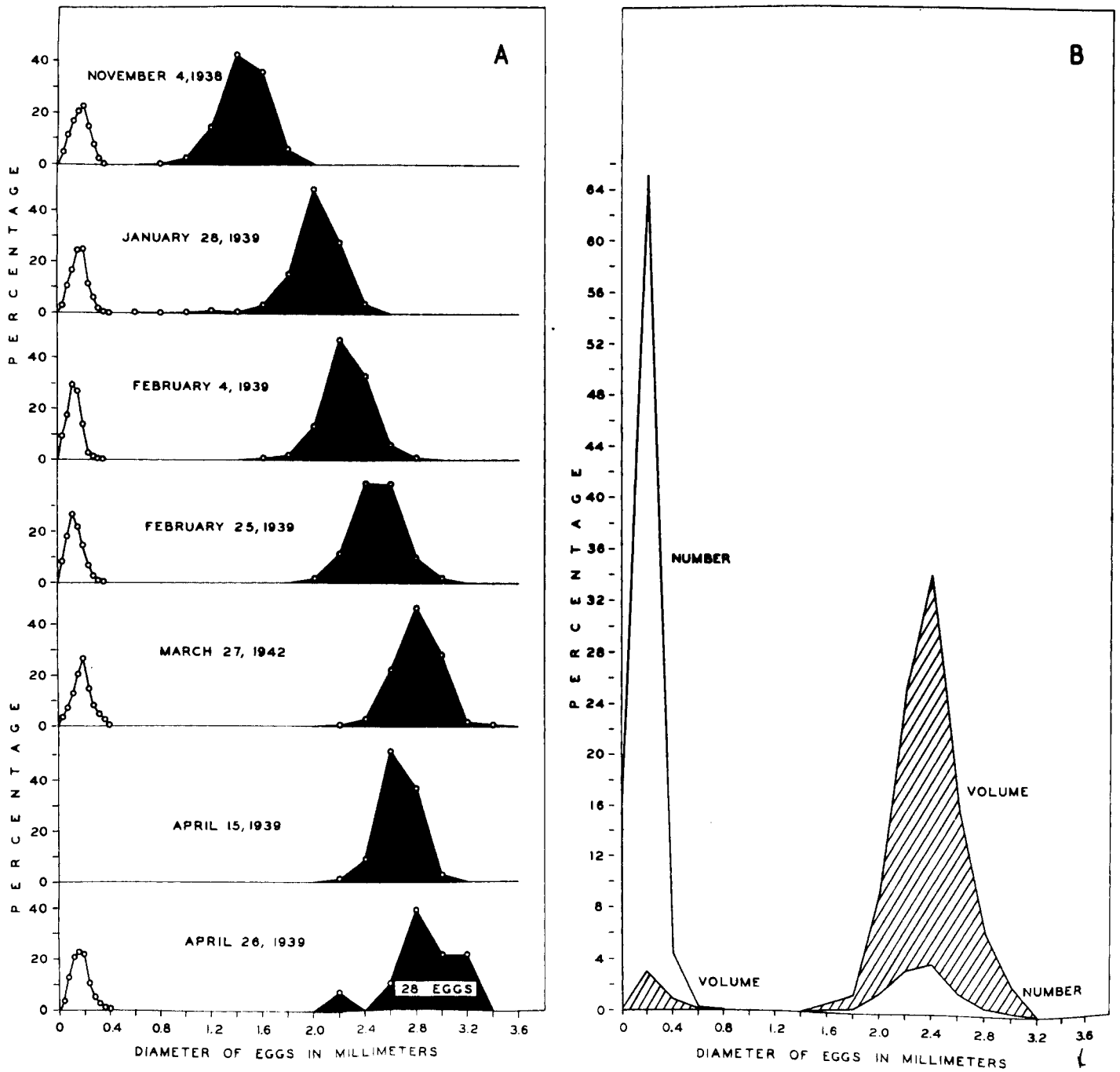
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NOVEMBER 4,1938
JANUARY 28, 1939
FEBRUARY 4, 1939
FEBRUARY 25, 1939
MARCH 27, 1942
APRIL 15, 1939
APRIL 26, 1939
28 EGGS
PERCENTAGE
0 0.4 0.8 1.2 1.6 2.0 2.4 2.8 3.2 3.6
DIAMETER OF EGGS IN MILLIMETERS
B
NUMBER
VOLUME
VOLUME
NUMBER
PERCENTAGE
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64
0 0.4 0.8 1.2 1.6 2.0 2.4 2.8 3.2 3.6
DIAMETER OF EGGS IN MILLIMETERS

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