THE ESTABLISHMENT OF THE ATLANTIC SMELT IN THE UPPER WATERS OF THE GREAT LAKES

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[Reprinted from PAPERS OF THE MICHIGAN ACADEMY OF SCIENCE, ARTS AND LETTERS, Vol. V, 1925]

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I. Introduction

SINCE 1906 several attempts have been made to introduce smelt (*Osmerus mordax*) into the upper waters of the Great Lakes. At least two of these attempts have been successful and the species is now spreading from one of these centers, if not from both. At each of these places the fish is now propagating itself and has become a true addition to the fauna. It is the purpose of the present paper to present the history of this introduction of the smelt, its origin, present distribution, and several items of its life-history pertinent to the understanding of all of these points.

The first attempt to introduce this fish into the upper waters of the Great Lakes appears to have been made in the St. Mary's River. In 1906 the Michigan State Fish Commission sought to make a success of the introduction of landlocked salmon by the propagation of smelt as its food. Their report [1] (1909) states that "a small consignment of smelt eggs from New England waters was received at the Soo hatchery last spring (1906) and deposited in the St. Mary's River." This was not a success apparently as the species has never been taken in that region. Since that time many attempts have been made to establish smelt in the upper waters of the Great Lakes or their contributing lakes and streams. The reports of the United States Bureau of Fisheries for 1909, 1912, 1914, 1915, 1916 and 1921 all record the Michigan State Fish Commission as the receiver of large

[1] *Biennial Report of the State Board of Fish Commissioners* (Michigan), for fiscal years 1905–1906 (1909).

numbers of eggs. Little is known of the fate of these eggs and only a few reports have been made regarding their deposition in the waters of the State of Michigan. Of the 1912 shipment the Michigan Fish Commission reports [2] that on April 4, 1912, 6,000,000 eggs were deposited in Torch Lake, Antrim County, and on April 6, 1912, 16,400,000 eggs were placed in Crystal Lake, Benzie County, Michigan. It is evident that smelt became established in Crystal Lake from this planting as will be further indicated later in this report. The fate of the Torch Lake planting will also be considered. In 1921 the State Fish Commission of Michigan received 2,000,000 eggs, which the report [3] (1922) intimates were deposited in Lake Michigan and Lake Huron, but about which they were unable to give further information. About 200,000 eggs also were sent to the Huron Mountain Club of Marquette County, the history of which will be indicated later.

All of the eggs used in the numerous plantings in the Great Lakes region were sent to this State by the Federal Bureau of Fisheries. This bureau has only one hatchery which collects smelt eggs. It is located at Green Lake, Maine. The smelt (Pl. XXIV) is a native of this lake, many of the eggs being obtained from natural spawning. The smelt of Green Lake is a native fresh-water race of the marine species common along the North Atlantic Coast. It is a native of many of the fresh waters of the New England states. Without doubt Green Lake, Maine, may be considered the home of all of the Great Lakes smelt.

II. Distribution of the Smelt

The first specimen of smelt taken from the upper waters of the Great Lakes was received from the Michigan Department of Conservation in May, 1922. No data were included with it except that it had been sent in to the Department by Mark Craw of Traverse City. A newspaper account (*Detroit Free Press*) of April 6, 1922, described an odd fish spawning at

[2] *Biennial Report of the State Board of Fish Commissioners* (Michigan), for fiscal years, 1911–1912 (1913).

[3] *Biennial Report of Department of Conservation* (Michigan), 1922.

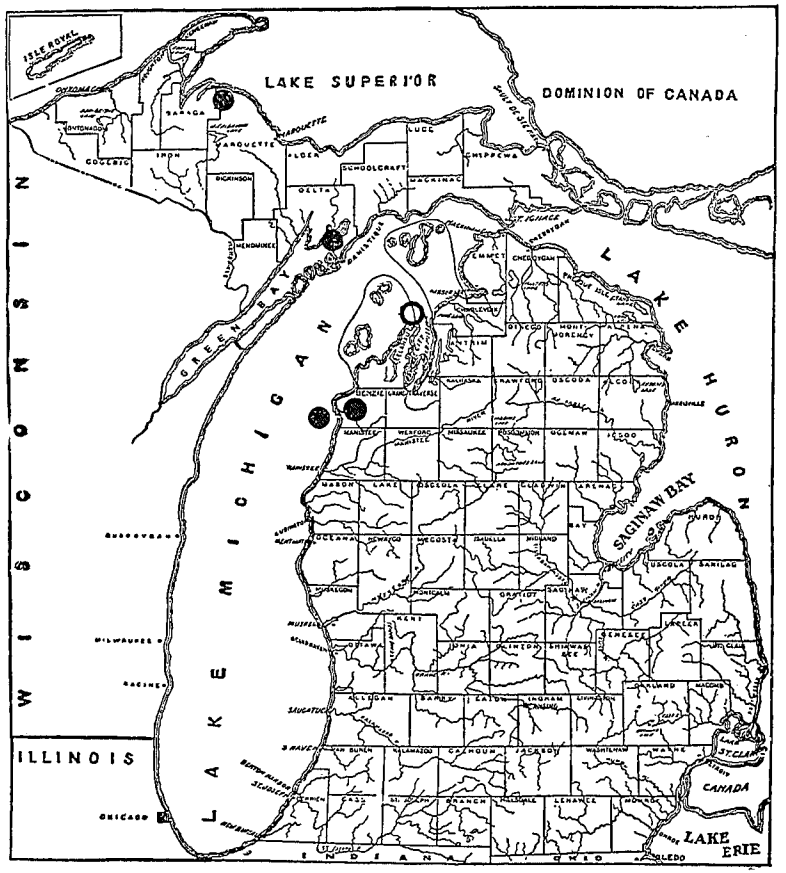

Fig. 25. Chart showing the Distribution of Smelt (*Osmerus mordax*) in the Upper Waters of the Great Lakes

Crystal Lake, Michigan, which seemed to be the smelt. These records formed the basis of a note in *Copeia*[4] by T. L. Hankinson and Carl L. Hubbs, which called attention to the fact that the smelt was present in the Great Lakes. Mark Craw has informed the writer that all the specimens that he collected came from Cold Creek at Beulah, Michigan; none were from Traverse Bay as indicated in the note referred to above.

Specimens have been taken or recorded from the following places in the upper Great Lakes basin, all of which are in the state of Michigan (see Fig. 25):

1. Crystal Lake, Benzie Co., Beulah, Michigan. Specimens have been taken in the lake proper in summer and winter and at a great range of depths; from a tributary, Cold Creek, at the village of Beulah; and from the outlet, East Betsie River, which runs into Lake Michigan.

2. Lake Michigan, five miles south of Frankfort, Michigan, and one and a half miles out in the lake. A specimen was taken in a gill-net by the commercial fishermen, L. Rodal and Sons, and sent to the writer by Mr. Roy Collins. These fishermen report that smelt is abundant in Lake Michigan off Frankfort.

3. Big Bay de Noc, Delta Co., Michigan. One specimen sent to the Museum of Zoölogy by commercial fishermen of that region.

4. Howe Lake and Trout Lake, Marquette Co., Michigan. Dr. Bryant Walker reported to the writer that the Huron Mountain Club planted these lakes with smelt eggs credited to them above. Dr. Walter Koelz made a trip into this region from August 23 to September 2 and caught smelt in both of these lakes. They were one to four years old, which indicates that they are established in these lakes. Howe Lake has no outlet, but Trout Lake drains through Pine Lake to Lake Superior. The presence of smelt is accounted for by the egg-plantings of 1912 and 1918.

5. Lake Michigan at Northport, Leelanau Co., Michigan. Dr. Koelz interpreted the description of a strange fish caught by fishermen of this region as that of a smelt.

[4] *Copeia*, No. 129, 1922.

This constitutes our knowledge of the distribution of smelt in the upper waters of the Great Lakes.

Fine mesh gill-nets, which caught smelt at Crystal Lake, failed to take smelt in Torch Lake, Antrim Co., which was planted at the same time that Crystal Lake received eggs.

The method of dispersal will be indicated under the discussion of the breeding habits. It would seem that it is actively extending its range in these waters, and may soon become a common fish in the Great Lakes.

III. The Establishment of the Smelt

The establishment of smelt in Crystal Lake has been complete, since the breeding fishes taken there eleven years later, that is on April 17, 1923, were the product of natural spawning in the spring of 1919, 1920 and 1921. This was ascertained by age-determinations made from their scales.[5] Fishes of two, three, four and five years were in the spawning run (see Pls. XXVI, XXVII). Young of the year and one-year-old fishes have not been taken.[5a] Large breeding runs in and about Beulah have occurred every spring since 1919. Many two-year-old fishes were taken April 6, 1925, which were hatched in the 1923 run here described.

It is quite certain that the smelt is well established in Howe and Trout lakes of Marquette County. The specimens collected there by Dr. Walter Koelz are from one to four years old. Successive plantings of smelt in any lake in the Great Lakes region are not indicated by the state or federal government reports. It is probable that they were the produce of natural spawning after the first planting.

Smelt are very abundant in Crystal Lake, Howe Lake and

[5] For a review of this method see Charles W. Creaser, "The Structure and Growth of the Scales of Fishes in relation to the Interpretation of Their Life-History, with Special Reference to the Sunfish (*Eupomotis gibbosus*)," Univ. of Mich., Museum of Zoölogy, Miscellaneous Publications (*forthcoming*).

[5a] Since this paper was presented the young of the year and the one-year-old smelt have been collected at Crystal Lake. This additional data will be considered in a later report.

Trout Lake. At Crystal Lake they are caught at all seasons of the year with hook and line, most frequently, however, in the winter through the ice by the perch fishermen. Last winter (1924) they reported that one half of their catch was smelt. In the spring at Crystal Lake large numbers come to the creeks to spawn.

The Michigan State Department of Conservation, through Mr. Craw, tried to catch all of the smelt that came into Cold Creek at Beulah during the run of 1925. A gate was placed at the lower end of the stream (at the point from which a photograph, Figure 3 of Plate XXV, was taken). Another gate was placed about one-fourth of a mile up-stream. At night the fishes were allowed to pass the first gate and the fishermen removed them from the creek until midnight. As daylight came and the fishes started to return to the lake the lower gate was closed and all of them were retained in the stream, from which they were removed during the morning and early afternoon. Each person was allowed twenty pounds. The game warden kept an account of the number of men at work, as nearly as was possible under the circumstances. Some estimate of the number of fishes that came into Cold Creek can be made from the data thus gathered. On the average six smelt weigh one pound. The value of these may be figured on the basis of whitefish prices prevailing in that region at this time.

SMELT RUN AT COLD CREEK, BEULAH, MICHIGAN, APRIL, 1925

April	Time	Lbs. (Est.)	No. (Est.)	Value (at 35¢)
2	Evening	600	3,600	$ 210.00
3	6 A.M.–4:30 P.M.	4,500	27,000	1,575.00
3	9:30 P.M.–11:30 P.M.	2,500	15,000	875.00
4	4:30 P.M.–3:00 P.M.	5,400	32,400	1,890.00
4	9:30 P.M.–12:00 P.M.	1,300	7,800	455.00
5	9:30 A.M.–12:00 A.M.	1,300	7,800	455.00
6	All day	200	1,200	70.00
7	All day	100	600	35.00
8	All day	100	600	35.00
	Total 7 days	16,000	96,000	$ 5,600.00

These estimates are certainly under rather than over the actual numbers. They are probably quite close to the real figures.

In the other lakes the fishes were caught quite frequently in small mesh gill-nets. In Lake Michigan they seem to be quite abundant, since the fishermen report that one or two are entangled in almost every set of their large mesh gill-nets. Further collections are being made as part of the effort to determine the abundance of smelt in Lake Michigan.

IV. THE SPAWNING OF THE SMELT IN CRYSTAL LAKE

The smelt spawns very early in the spring before the ice breaks up in the lake as a whole. At Crystal Lake the spawning started on April 10, 1923, and by the sixteenth it was at its height. This was somewhat later than that of 1922, which was all over by the eighth of April. The run of 1925 was very heavy and was concentrated over the period of April 2 to April 8. All the fishes that entered the Creek were removed, none being allowed to return to the lake.

At Beulah the smelt ran up a small permanent stream known to the residents as Cold Creek. This stream is not over a mile long and has its headwaters in a cedar bog; in the portion used by the smelt, it flows through the village and enters the south end of the lake. During these last few hundred feet it is a clear stream running over a sand and gravel bed with a considerable current. The current was increased at the time of spawning by flood water from the melting ice and snow. Part of the lower portion of the stream was still covered by a snow-bridge. This was several inches above the water level and was firm enough to carry the weight of a man. Figure 1 of Plate XXV was taken from this bridge, which is in the immediate foreground. From this point to the mouth of the Creek was the main spawning ground of the smelt. Figure 3 of Plate XXV shows the rest of the spawning ground of the smelt. It was taken from a small foot-bridge located midway between the mouth of the stream and the snow-bridge. The creek here was not over two and one-half feet deep and was about ten feet wide.

It will be noticed that at its mouth the stream is much narrower because of the wave action of the lake. In the lake proper there was an open pool of water which received the flow of creek water over a delta of sand and gravel. The rest of the lake was covered with thick ice. Out from under this sheet of ice the fishes came in great numbers. They crossed the delta bar, pushed their way into the narrow mouth of the creek, and fought their way up the swift current of the ice-cold creek.

The main run of smelt is at night. Kendall [6] has reported runs on dark days in the streams of New England. A few smelt always remain in the stream during the day. They hang in the dark pools, under bridges, and the projecting banks and ice. But most of them returned to the lake in the morning as soon as it was light. At this time herring-gulls gathered in great numbers to feed upon them.

At night on April 17, 1923, just after the sun had set, the fishes began to emerge from the lake, a little cautiously at first and in no great numbers. They headed into the current as it became noticeable at the mouth of the creek and then worked their way towards the mouth. The smelt is not a strong stream fish and it was with considerable effort that it made its way against the current. An effort was made to avoid the swift current and refuge was often taken behind logs, rocks, vegetation and in the deeper pools. The fishes kept quite close to the bottom as long as any bottom was available to them. Their only object seemed to be that of going up the stream as far as they were able. They seemed to tire quickly and not many of them ascended more than four hundred feet. Up to this point they hung in great shifting masses, exerting themselves only enough to keep from being carried down-stream. During the run of 1925 over 700 pounds were taken from a branch of Cold Creek about a mile up the stream. The current was not as swift as in 1923.

Later in the night (2 A.M.) great schools came into the ice-free pool in the lake. From this they tried to work their way

[6] "Fishes and Fishing in Sunapee Lake," *Rept. U. S. Comm. Fish.*, 1913, pp. 1–96.

into the current of the creek. The sand and gravel delta became one mass of fishes, so numerous that little or none of the bottom could be seen. The mouth of the creek became so filled that often the upper layer of fishes was forced clear out of the water by the pressure on all sides of them. Many were unable to get into the stream at all, and much spawn was deposited on the gravel-bottom pool of the lake. Misinterpretation of orders in 1925 caused the guard to try to hold the fishes in the stream until 7 A.M., some time after daylight, but they crowded about the screen so thickly that a dam was formed which flooded the creek and almost washed out the bridge.

Data on the light and current reaction, and on the spawning habit, were obtained at this time (1923) both at the inlet stream and at the outlet. These are presented under various heads as follows:

V. Light Reaction

It was noted at once that the fishes were quite sensitive to light. The run is at night and most of the fishes return to deep water during the day or hide under the banks and bridges. They are guided to the stream by a reaction to the current, which will be considered later.

With a strong light it was possible to watch the spawning fishes on the bottom of the creek. It was soon noted that they would avoid the lighted area of the creek bottom. When the light was flashed, those within the lighted area quickly left and very soon the area was vacant. In this way it was possible to drive the fishes in any direction by the change of the light. This observation of 1923 was used by the game warden in 1925 and the entrance of the smelt into the stream was controlled very readily by the use of a light. The escape from the lighted area was accomplished in two ways. Most frequently the fishes merely relaxed and allowed the current to carry them out of the lighted area down-stream to some dark water below, but they also would at times make a sudden dart ahead into the dark water. This last reaction was made only when the dark water was just a short distance ahead. When the light was held at

the mouth of the stream and directed towards the lake pool a large part of the run could be stopped, many of the fishes retreating under the ice. The run is stopped when the daylight causes this reaction and most of the fishes return to the lake by the dropping-back reaction followed by a retreat. In this dropping back they usually go tail first down the stream, a phenomenon very perplexing to the many fishermen who in 1925 were able to witness it, when the smelt were held by a screen in the stream long after daylight. They are thus left in the dark waters, under the bridges, overhanging banks of ice and snow, or they are carried back into the lake. As the run reached its height the fishes became less reactive to the light and more remained in the stream in the daytime.

Fish culturists have found that the light is harmful to the eggs of smelt and for the best results they use a room much darker than is usual for hatchery purposes. This reaction to the light has important relations to the regulation for their protection or control.

VI. The Reaction to Current

The ripe fishes at Crystal Lake seek out any pool of water free from ice along the shore of the lake. They remain at any opening where there is a current, regardless of the direction of this current. This reaction is clearly indicated by their presence in some numbers at the outlet of Crystal Lake. As well shown in the photograph (Plate XXV, Fig. 2), conditions here were almost identical with those of the inlet stream except for the direction of the current. Fishes found here were all headed up-stream. Some of them worked their way back into the lake. It is certain that these fishes came from Crystal Lake, since the dam is of such construction as to render it impassible to smelt. Smelt were found as far as one-half mile down-stream. All of these were probably from the lake, since there were several miles of swift flood water between them and Lake Michigan.

Only mature fishes were found in the pool or in the breeding run. The one-year-old fishes were missing. It would seem

that this reaction to the current is linked with the maturing of the germ cells. The older fishes do not have the reaction to current developed until the germ cells are mature. The young immature fish likely behave in the same manner as the unripe adults and hence do not appear in the spawning run.

This reaction to the current is important in relation to the increase in their range. The normal up-stream spawning reaction has little effect on the increase in range, except in rare cases to populate up-stream lakes. On the other hand the tendency to come to any pool with a current has a far reaching effect on their increase of range. Fishes coming to the outlet stream at night and staying in the current until daylight, when disturbed by the light or confused or fatigued by the current, have a way of relaxing themselves and later drifting with the current, usually tail first, until protection of the dark water is found. Thus the down-stream migration is more important from the standpoint of dispersal than the normal up-stream migration. The adults of this down-stream migration enter Lake Michigan, as also do the young hatched in the outlet stream. The normal up-stream migration only carries them back into Crystal Lake. The adults and fry of a normal up-stream spawning migration ordinarily return to the same lake unless there is an up-stream lake a very short distance away. Both of these types of migration will, no doubt, play a part in the further distribution of smelt. Since it seems to live a pelagic life in the lake, it must soon be distributed to all parts of any lake it reaches. As indicated under the discussion of its distribution, it is now quite abundant in the northern part of Lake Michigan, and the way is open for its introduction into Lake Superior through Trout Lake.

VII. The Spawning Habit of the Smelt

The smelt is the first species of fish to spawn at Crystal Lake. For this reason the eggs and early fry escape being destroyed by other fish which are largely inactive at this season.

Although the smelt has been reared in hatcheries, its spawn-

ing habit has not been well understood. Kendall [7] has reported a few inconclusive observations upon it. Various attempts have been made to effect artificial impregnation, but the best results have been obtained by the use of the natural spawn or from fishes induced to lay their eggs under more favorable conditions for hatching. At Crystal Lake in 1923 conditions were ideal for the observation of the spawning activity of the smelt, and what seems to be an explanation of it was obtained.

When the fishes enter the stream the eggs and sperm are ripe and the breeding fishes are in a running condition. The slightest pressure on the body forces the fishes to yield the eggs or sperm. In this running condition they enter the stream and come in contact with one another and force their way up the creek over the gravel bottom. Both sexes are present in these crowded schools of fishes. At times a few would become detached from the main group. These were watched for spawning activities. The males may be distinguished from the females in many cases. Most of the smaller ones are males while the majority of the very large ones are females. Wherever two fishes of this difference in size were discovered together, the activity was watched and afterwards an attempt to catch them in the hands was made to verify the sex determination. The males may be distinguished from the females at breeding time by the fact that they are covered with fine pearl tubercles which make their entire body feel like sandpaper. The females are smooth.

Apparently clean gravel was always covered with eggs after a pair had passed over it. Sometimes the bodies of the male and the female would vibrate together. Often this action was little more than the natural motion of the fishes in the stream. The caudal portions of smelt are always in motion when they are in the current and all of the schools are thus favorable places for this action to occur indeterminately with the mixed fishes. Certainly the stream was too dark for one fish to see another. What sex recognition there is must come through the difference in the reaction and the feeling. The

[7] *Ibid.*, p. 77.

fishes would be able to discriminate between the contact of two rough or two smooth bodies or the proper one of smooth and rough.

It is likely that the main spawning takes place as a result of the crowding together of the two sexes when they are in a running condition. The close contact, over the gravel bottom, of the fishes with the spawn running provides an excellent chance for the eggs to be fertilized. Eggs were found up and down the stream wherever the fishes had been running the night before. Many were found even in the lake, where the fishes were not able to make their way into the creek.

As has been indicated the main spawning ground of the smelt is in the streams, but they also spawn on the gravel delta in the lake or in any pool with a current. Kendall in his report states that they spawn on the wind-swept shores or even in lakes without sand shores.

VIII. Food Relations of the Smelt

At Crystal Lake a large number of smelt are taken through the ice with hook and line. The lake shiner, *Notropis atherinoides*, is used for bait. About twenty smelt caught in this way showed only this bait as stomach content. One specimen contained in its stomach only a single crustacean (Pontoporeia). This would indicate that the smelt does feed during the winter, but to what extent will have to be determined from specimens caught without the use of bait.

Fishes on the spawning ground eat but very little. Dr. Jan Metzelaar examined 110 smelt collected by the writer from Cold Creek, Beulah, Michigan. Most of these were empty but a few contained, in insignificant number, smelt eggs and the debris to which the eggs were attached.

Dr. Metzelaar examined the stomachs of 147 smelt taken at Crystal Lake by the writer about September 1. Of these, 20 were totally empty. Three contained young rock-bass; 78, the certainly identifiable remains of the lake-shiner, and 35 more, fish remains probably of this species; 25 contained insect larvae

or pupae, either midges (Chironomidae), or may-flies (Hexagenia). By volume-percentage the food was as follows:

Food	Percentage
Lake shiner, *Notropis atherinoides*	41.7
Fish remains, probably lake-shiner	55.6
Rock-bass, *Ambloplites rupestris*	1.0
Larvae and pupae of midges, Chironomids	0.6
Larvae of may-flies, Hexagenia	0.7
Pupal may-flies, Hexagenia	0.4
Total	100.0

From this it is evident that in summer the adult smelt of Crystal Lake feeds almost entirely (97.3 per cent) on the lake-shiner, a species of minnow which at this season of the year swims about in very large compact schools near the surface, over deep water. The adult fishes do not at this season prey to any degree on game fish. Furthermore they do not seriously compete at this time with other fishes for food, since, as is shown below, the other fishes do not feed on this shiner.

The food of the perch (*Perca flavescens*) in Crystal Lake as determined from forty-seven specimens taken at the same time and in the same net set as the smelt reported above, that is September 1, consisted of insects, 59 per cent, most of which were the larvae and pupae of midges; and crustaceans of various kinds, 41 per cent.

The food of the spot-tailed minnows (*Notropis hudsonius*), taken likewise in the same net, was found to be the same as that of the perch, while those from the shoals were feeding almost entirely on adult insects. No data are available as to the feeding habits of the adult fishes during the late spring and early summer. As yet nothing is known about the young fish of the one-year-old groups. Kendall [8] has found that the small smelt of the New England lakes feed upon crustaceans, and it is likely that the young fishes have similar feeding habits. If such is the case they would form rather important competitors of the perch of Crystal Lake.

[8] *Loc. cit.*

The feeding habits of the adults during the late summer show that the smelt at this time is not replacing the other food fishes, but that it is an actual addition to the native fauna. But since nothing is as yet known of the food habits of the young fishes, only additional study can determine the point.

The specimen of smelt obtained from Lake Michigan contained one fish which Mr. Hubbs identified as a young specimen of the lake-herring (or of some other species of the whitefish family) and a crustacean, *Mysis relicta*, which he has shown [9] forms the chief food of the deep-water species of whitefish, chubs, and the like.

In view of the known habit of smelt in feeding near the surface at Crystal Lake, and of the well-indicated possibility that the young of the whitefish have the same pelagic habit as that of the lake-shiner, *Notropis atherinoides*, the possible food-relation of smelt with these important food fish in the Great Lakes is apparent.

IX. The Growth of Smelt

Much can be told of the age and growth of smelt from a study of the specimens taken at Crystal Lake. The scales can be used for the determination of their age. Mastermann [10] has made a study of the European smelt from the scales. Only the general outline of the growth will be presented here, since a more detailed study of the material has not yet been completed.

The scales of smelt (Pls. XXVI, XXVII) show very clear year marks (annuli). They are very thin and have widely spaced ridges. Most of the scale is exposed and in this field the annulus shows very plainly. Since smelt are hatched in early spring and the specimens referred to were taken at this time of the year, each annulus represents just a year of growth. The annulus is formed when growth starts in the spring. The new scale-growth

[9] R. E. Coker, *Rept. U. S. Comm. Fish.*, Appendix 8, p. 13, 1921 (1922).

[10] "Report on Investigations upon the Smelt (*Osmerus eperlanus*) with Special Reference to Age Determination by Study of Scales and Its Bearing upon Sexual Maturity," *Board of Agriculture and Fisheries: Fisheries Investigation* (London), Series I, 1 (1913): 113–126.

is developed without reference to, and in discord with, the pattern of the older growth of scale. Well-defined length-groups, not yet fully worked out, are noticeable. These coincide with the groups established on the basis of scale determinations.

No one-year-old fish have as yet been taken; consequently only an estimate, based on scale proportion, can be made of the size of smelt at the end of their first year. Scale proportions indicate that the smelt is about three or four inches in length at this time. It continues to grow at a rapid rate throughout the second summer and by the time it matures (at the end of the second year) it has reached a size of from six to eight inches. The smallest of the two-year sizes so far examined was six and one-half inches in total length (see Pl. XXVI, Fig. 1) and the largest one seven and one-half inches. The three-year-old fishes reach a size up to nine and the four up to ten inches in total length (see Pl. XXVI, Fig. 2), and the five-year-old fishes (see Pl. XXVII) are from ten and three-quarters inches to twelve inches long. No six-year-old fishes have been examined, but the reports of fishes fourteen inches long indicate that smelt may live to be six years old.

It is also evident from the scales that the smelt does not start to grow until after it spawns and that it does not grow during the winter period.

As Kendall has shown, there are at least two 'types'[11] of smelt in the lakes of New England. One of these matures at a much smaller size than the other and it has corresponding differences in feeding habits. As has been shown above, the one introduced into Crystal Lake matures at a large size and reaches a size as large as that reported from the eastern lakes and from salt water. Some of the smaller races of smelt mature at a size of about three inches and never reach a size of over six inches. It is therefore apparent that it is the fast-growing type that has been introduced into the Great Lakes. This form

[11] Carl L. Hubbs has discussed the taxonomic status of these landlocked types of smelt and of the Atlantic species in his "Revision of the Osmerid Fishes of the North Pacific," *Proc. Biol. Soc. Wash.*, 38: 49–56. 1925.

is the one best fitted for commercial purposes, not the slow-growing type sometimes recommended as food for the land-locked salmon. The latter purpose of course was the one for which it was introduced.

Some data on the weight-increase has been obtained. At seven and three-quarters inches the fish weighs 1.5 ounces. This is about the average two-year-old size. The one-year-old fishes would probably weigh about 0.15 ounces. The three-year-old fishes weighed from 2.0 ounces when eight and one-fourth inches long to 3.0 ounces when nine and one-half inches long. Those of larger size, about eleven inches, weigh about 5.0 ounces. Much additional data are needed to establish the normal weight-increase of smelt.

X. The Age of the Smelt at Spawning

Smelt breeds in the early spring at the end of its second year. Evidence of this is found in the scales (see Pl. XXVI, Fig. 1), since the smallest breeding fishes always have two growing seasons indicated on the scales. The first winter is shown by a clear annulus, the other winter edge of the scale is present at the very margin in early spring. The annulus is not developed until the spring growth starts after spawning. Also when smelt eggs were planted in certain eastern lakes a breeding-run occurred two years later. Mastermann has found that the European smelt also breeds at the end of the second year.

The effort made at the time of the spawning-run leaves a mark on the scale of the smelt. The lateral edge of the scale is torn and broken at this time. This condition will be noticed on the outer edge of all the scales taken from breeding fishes of various ages. These breaks are rebuilt when the scale starts its spring growth and completes the annulus. This spawning annulus is very well shown in the second annulus of Figure 2, Plate XXVI. The first annulus of the spring when the fishes did not spawn is regular. A careful study of numerous scales of three- and four-year-old fishes shows that every annulus except the first

one has undergone some rebuilding at one point or another. From this evidence it is certain that the smelt breeds at the end of its second year and every year after until its death. The presence of different age-groups in the spawning-run also lends support to this conclusion. This spawning annulus is comparable to that established for the Atlantic salmon, a fish which makes a spawning-run.

Summary

The smelt has become completely established in Crystal Lake, Benzie County, Michigan, by planting from Green Lake, Maine. Large breeding-runs in and about Cold Creek at Beulah have occurred every spring since 1919. Smelt is also present in Lake Michigan and in Trout and Howe lakes of northern Michigan.

Spawning takes place at Crystal Lake before the ice breaks up in the lake as a whole. The fishes ascend small streams at night, returning to the lake during the day. Spawning fishes avoid the light by a 'dropping back' reaction. They seek out a current and orient themselves against it, regardless of the direction of the current. They are being distributed to Lake Michigan by this reaction, which directs them to the outlet stream down which they drift tail first at daylight. About 96,000 fishes entered Cold Creek during the spawning-run of 1925. An examination of the scales showed that the breeding runs are composed of two-, three-, four- and five-year-old fishes. Smelt breeds at the end of its second winter, and every year after that, as indicated by the spawning annuli. Growth is very rapid for the first two years, the period of immaturity, after which it falls off noticeably.

The two-, three- and four-year fishes at Crystal Lake in summer feed mostly (97.3 per cent) on the lake-shiner. One specimen from Lake Michigan was feeding on the young of the lake-herring and on the crustacean, *Mysis relicta*, known to be the food of the deep-water whitefish.

The spread of this introduced fish is of great scientific and economic interest, and further study of many of the points presented here will be undertaken.

This study of smelt in the Great Lakes is a part of the biological work supported by the State Department of Conservation of Michigan. The writer is delighted to acknowledge this assistance and also that of the Museum of Zoölogy of the University of Michigan.

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EXPLANATION OF PLATES

PLATE XXIV

A two-year-old, breeding, male smelt from Crystal Lake (life size).

PLATE XXV

FIG. 1. The upper spawning ground of smelt in Cold Creek, Beulah, Michigan.

FIG. 2. The outlet of Crystal Lake, East Betsie River, by which smelt are reaching Lake Michigan, and in which some spawn.

FIG. 3. The mouth of Cold Creek, Crystal Lake, reached by the smelt that come to the ice-free pool in the lake.

PLATE XXVI

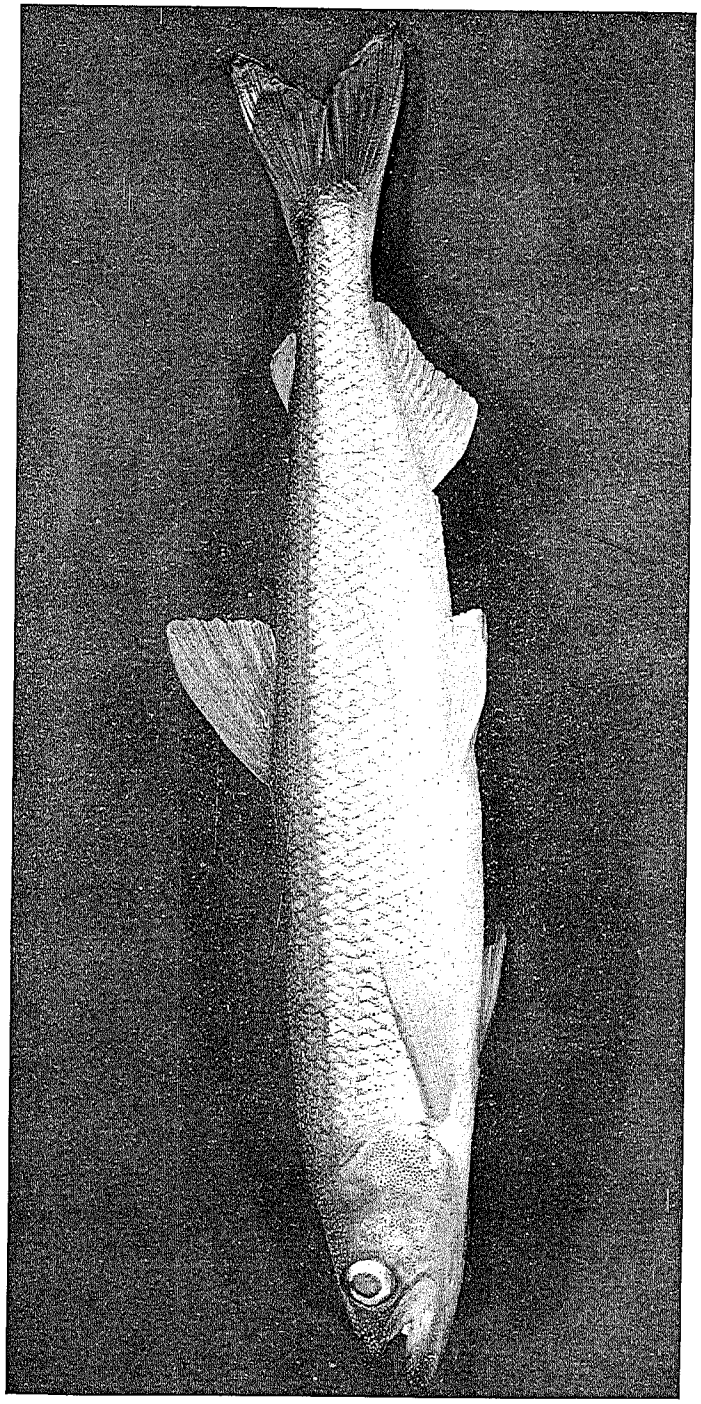
FIG. 1. The scale of the smallest breeding smelt. Two years of growth are indicated. The first winter is indicated by the well-formed annulus; the scale was taken at the end of the second winter.

FIG. 2. The scale of a breeding smelt, showing two annuli and three years of growth. Spawning marks are indicated for the second and third years.

PLATE XXVII

The scale of a breeding smelt showing four annuli and indicating five years of growth. Spawning marks are present in the second, third and fourth years. The numbers on the Plate indicate the growth by years.

PLATE XXIV



A TWO-YEAR-OLD, BREEDING, MALE SMELT FROM CRYSTAL LAKE (LIFE SIZE)

PLATE XXV

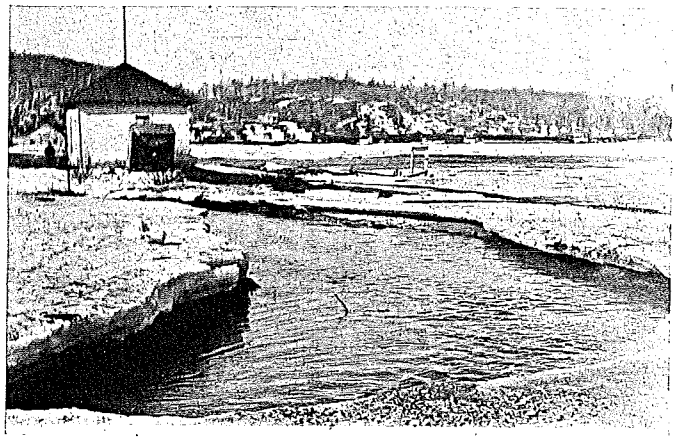


FIG. 1

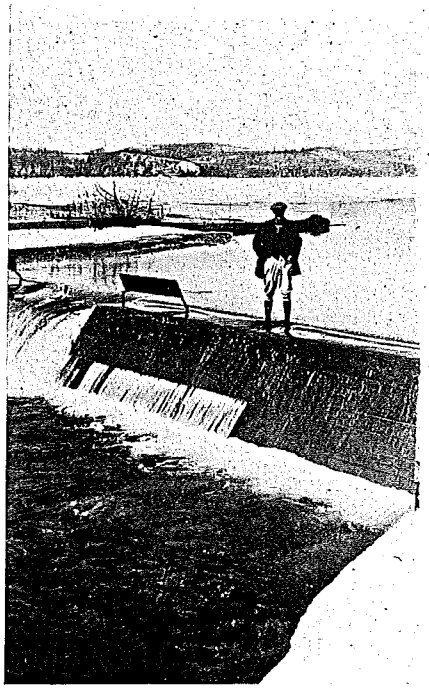


FIG. 2

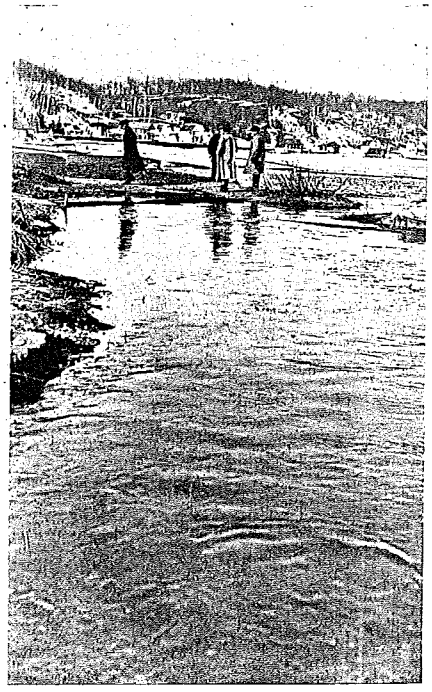


FIG. 3

PLATE XXVI

PLATE XXVII